REPORT

OF THE

FIFTY-SIXTH MEETING

OF THE

BRITISH ASSOCIATION

FOR THE

ADVANCEMENT OF SCIENCE;

HELD AT

BIRMINGHAM IN SEPTEMBER 1886.

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
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OBJECTS AND RULES
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OBJECTS.

THE ASSOCIATION contemplates no interference with the ground occupied by other institutions. Its objects are:—To give a stronger impulse and a more systematic direction to scientific inquiry,—to promote the intercourse of those who cultivate Science in different parts of the British Empire, with one another and with foreign philosophers,—to obtain a more general attention to the objects of Science, and a removal of any disadvantages of a public kind which impede its progress.

RULES.

Admission of Members and Associates.

All persons who have attended the first Meeting shall be entitled to become Members of the Association, upon subscribing an obligation to conform to its Rules.

The Fellows and Members of Chartered Literary and Philosophical Societies publishing Transactions, in the British Empire, shall be entitled, in like manner, to become Members of the Association.

The Officers and Members of the Councils, or Managing Committees, of Philosophical Institutions shall be entitled, in like manner, to become Members of the Association.

All Members of a Philosophical Institution recommended by its Council or Managing Committee shall be entitled, in like manner, to become Members of the Association.

Persons not belonging to such Institutions shall be elected by the General Committee or Council, to become Life Members of the Association, Annual Subscribers, or Associates for the year, subject to the approval of a General Meeting.

Compositions, Subscriptions, and Privileges.

LIFE MEMBERS shall pay, on admission, the sum of Ten Pounds. They shall receive *gratuitously* the Reports of the Association which may be published after the date of such payment. They are eligible to all the offices of the Association.

ANNUAL SUBSCRIBERS shall pay, on admission, the sum of Two Pounds, and in each following year the sum of One Pound. They shall receive *gratuitously* the Reports of the Association for the year of their admission and for the years in which they continue to pay *without intermission* their Annual Subscription. By omitting to pay this subscription in any particular year, Members of this class (Annual Subscribers) *lose for that and all future years* the privilege of receiving the volumes of the Association *gratis*: but they may resume their Membership and other privileges at any subsequent Meeting of the Association, paying on each such occasion the sum of One Pound. They are eligible to all the Offices of the Association.

ASSOCIATES for the year shall pay on admission the sum of One Pound. They shall not receive *gratuitously* the Reports of the Association, nor be eligible to serve on Committees, or to hold any office.

The Association consists of the following classes:—

1. Life Members admitted from 1831 to 1845 inclusive, who have paid on admission Five Pounds as a composition.

2. Life Members who in 1846, or in subsequent years, have paid on admission Ten Pounds as a composition.

3. Annual Members admitted from 1831 to 1839 inclusive, subject to the payment of One Pound annually. [May resume their Membership after intermission of Annual Payment.]

4. Annual Members admitted in any year since 1839, subject to the payment of Two Pounds for the first year, and One Pound in each following year. [May resume their Membership after intermission of Annual Payment.]

5. Associates for the year, subject to the payment of One Pound.

6. Corresponding Members nominated by the Council.

And the Members and Associates will be entitled to receive the annual volume of Reports, *gratis*, or to *purchase* it at reduced (or Members') price, according to the following specification, viz.:—

1. *Gratis.*—Old Life Members who have paid Five Pounds as a composition for Annual Payments, and previous to 1845 a further sum of Two Pounds as a Book Subscription, or, since 1845, a further sum of Five Pounds.

   New Life Members who have paid Ten Pounds as a composition.

   Annual Members *who have not intermitted* their Annual Subscription.

2. *At reduced or Members' Prices*, viz., two-thirds of the Publication Price. —Old Life Members who have paid Five Pounds as a composition for Annual Payments, but no further sum as a Book Subscription.

   Annual Members who have intermitted their Annual Subscription.

   Associates for the year. [Privilege confined to the volume for that year only.]

3. Members may purchase (for the purpose of completing their sets) any of the volumes of the Reports of the Association up to 1874, *of which more than* 15 *copies remain*, at 2*s.* 6*d.* per volume.[1]

Application to be made at the Office of the Association, 22 Albemarle Street, London, W.

Volumes not claimed within two years of the date of publication can only be issued by direction of the Council.

Subscriptions shall be received by the Treasurer or Secretaries.

Meetings.

The Association shall meet annually, for one week, or longer. The place of each Meeting shall be appointed by the General Committee two years in advance; and the arrangements for it shall be entrusted to the Officers of the Association.

General Committee.

The General Committee shall sit during the week of the Meeting, or longer, to transact the business of the Association. It shall consist of the following persons:—

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[1] A few complete sets, 1831 to 1874, are on sale, £10 the set.

CLASS A. PERMANENT MEMBERS.

1. Members of the Council, Presidents of the Association, and Presidents of Sections for the present and preceding years, with Authors of Reports in the Transactions of the Association.

2. Members who by the publication of Works or Papers have furthered the advancement of those subjects which are taken into consideration at the Sectional Meetings of the Association. *With a view of submitting new claims under this Rule to the decision of the Council, they must be sent to the Secretary at least one month before the Meeting of the Association. The decision of the Council on the claims of any Member of the Association to be placed on the list of the General Committee to be final.*

CLASS B. TEMPORARY MEMBERS.[1]

1. Delegates nominated by the Corresponding Societies under the conditions hereinafter explained. *Claims under this Rule to be sent to the Secretary before the opening of the Meeting.*

2. Office-bearers for the time being, or delegates, altogether not exceeding three, from Scientific Institutions established in the place of Meeting. *Claims under this Rule to be approved by the Local Secretaries before the opening of the Meeting.*

3. Foreigners and other individuals whose assistance is desired, and who are specially nominated in writing, for the Meeting of the year, by the President and General Secretaries.

4. Vice-Presidents and Secretaries of Sections.

Organizing Sectional Committees.[2]

The Presidents, Vice-Presidents, and Secretaries of the several Sections are nominated by the Council, and have power to act until their names are submitted to the General Committee for election.

From the time of their nomination they constitute Organizing Committees for the purpose of obtaining information upon the Memoirs and Reports likely to be submitted to the Sections,[3] and of preparing Reports thereon, and on the order in which it is desirable that they should be read, to be presented to the Committees of the Sections at their first meeting. The Sectional Presidents of former years are *ex officio* members of the Organizing Sectional Committees.[4]

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[1] Revised by the General Committee, 1884.

[2] Passed by the General Committee, Edinburgh, 1871.

[3] *Notice to Contributors of Memoirs.*—Authors are reminded that, under an arrangement dating from 1871, the acceptance of Memoirs, and the days on which they are to be read, are now as far as possible determined by Organizing Committees for the several Sections *before the beginning of the Meeting.* It has therefore become necessary, in order to give an opportunity to the Committees of doing justice to the several Communications, that each Author should prepare an Abstract of his Memoir, of a length suitable for insertion in the published Transactions of the Association, and that he should send it, together with the original Memoir, by book-post, on or before......................., addressed thus—'General Secretaries, British Association, 22 Albemarle Street, London, W. For Section ....' If it should be inconvenient to the Author that his paper should be read on any particular days, he is requested to send information thereof to the Secretaries in a separate note. Authors who send in their MSS. three complete weeks before the Meeting, and whose papers are accepted, will be furnished, before the Meeting, with printed copies of their Reports and Abstracts. No Report, Paper, or Abstract can be inserted in the Annual Volume unless it is handed either to the Recorder of the Section or to the Secretary, *before the conclusion of the Meeting.*

[4] Added by the General Committee, Sheffield, 1879.

An Organizing Committee may also hold such preliminary meetings as the President of the Committee thinks expedient, but shall, under any circumstances, meet on the first Wednesday of the Annual Meeting, at 11 A.M., to nominate the first members of the Sectional Committee, if they shall consider it expedient to do so, and to settle the terms of their report to the General Committee, after which their functions as an Organizing Committee shall cease.[1]

Constitution of the Sectional Committees.[2]

On the first day of the Annual Meeting, the President, Vice-Presidents, and Secretaries of each Section having been appointed by the General Committee, these Officers, and those previous Presidents and Vice-Presidents of the Section who may desire to attend, are to meet, at 2 P.M., in their Committee Rooms, and enlarge the Sectional Committees by selecting individuals from among the Members (not Associates) present at the Meeting whose assistance they may particularly desire. The Sectional Committees thus constituted shall have power to add to their number from day to day.

The List thus formed is to be entered daily in the Sectional Minute-Book, and a copy forwarded without delay to the Printer, who is charged with publishing the same before 8 A.M. on the next day in the Journal of the Sectional Proceedings.

Business of the Sectional Committees.

Committee Meetings are to be held on the Wednesday at 2 P.M., on the following Thursday, Friday, Saturday,[3] Monday, and Tuesday, from 10 to 11 A.M., punctually, for the objects stated in the Rules of the Association, and specified below.

The business is to be conducted in the following manner:—

1. The President shall call on the Secretary to read the minutes of the previous Meeting of the Committee.
2. No paper shall be read until it has been formally accepted by the Committee of the Section, and entered on the minutes accordingly.
3. Papers which have been reported on unfavourably by the Organizing Committees shall not be brought before the Sectional Committees.[4]

At the first meeting, one of the Secretaries will read the Minutes of last year's proceedings, as recorded in the Minute-Book, and the Synopsis of Recommendations adopted at the last Meeting of the Association and printed in the last volume of the Transactions. He will next proceed to read the Report of the Organizing Committee.[5] The list of Communications to be read on Thursday shall be then arranged, and the general distribution of business throughout the week shall be provisionally appointed. At the close of the Committee Meeting the Secretaries shall forward to the Printer a List of the Papers appointed to be read. The Printer is charged with publishing the same before 8 A.M. on Thursday in the Journal.

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[1] Revised by the General Committee, Swansea, 1880.

[2] Passed by the General Committee, Edinburgh, 1871.

[3] The meeting on Saturday was made optional by the General Committee at Southport, 1883.

[4] These rules were adopted by the General Committee, Plymouth, 1877.

[5] This and the following sentence were added by the General Committee, 1871.

On the second day of the Annual Meeting, and the following days, the Secretaries are to correct, on a copy of the Journal, the list of papers which have been read on that day, to add to it a list of those appointed to be read on the next day, and to send this copy of the Journal as early in the day as possible to the Printer, who is charged with printing the same before 8 A.M. next morning in the Journal. It is necessary that one of the Secretaries of each Section (generally the Recorder) should call at the Printing Office and revise the proof each evening.

Minutes of the proceedings of every Committee are to be entered daily in the Minute-Book, which should be confirmed at the next meeting of the Committee.

Lists of the Reports and Memoirs read in the Sections are to be entered in the Minute-Book daily, which, with *all Memoirs and Copies or Abstracts of Memoirs furnished by Authors, are to be forwarded, at the close of the Sectional Meetings*, to the Secretary.

The Vice-Presidents and Secretaries of Sections become *ex officio* temporary Members of the General Committee (*vide* p. xxix), and will receive, on application to the Treasurer in the Reception Room, Tickets entitling them to attend its Meetings.

The Committees will take into consideration any suggestions which may be offered by their Members for the advancement of Science. They are specially requested to review the recommendations adopted at preceding Meetings, as published in the volumes of the Association and the communications made to the Sections at this Meeting, for the purposes of selecting definite points of research to which individual or combined exertion may be usefully directed, and branches of knowledge on the state and progress of which Reports are wanted; to name individuals or Committees for the execution of such Reports or researches; and to state whether, and to what degree, these objects may be usefully advanced by the appropriation of the funds of the Association, by application to Government, Philosophical Institutions, or Local Authorities.

In case of appointment of Committees for special objects of Science, it is expedient that *all Members of the Committee should be named, and one of them appointed to act as Secretary, for insuring attention to business.*

Committees have power to add to their number persons whose assistance they may require.

The recommendations adopted by the Committees of Sections are to be registered in the Forms furnished to their Secretaries, and one Copy of each is to be forwarded, without delay, to the Secretary for presentation to the Committee of Recommendations. *Unless this be done, the Recommendations cannot receive the sanction of the Association.*

N.B.—Recommendations which may originate in any one of the Sections must *first be sanctioned by the Committee of that Section* before they can be referred to the Committee of Recommendations or confirmed by the General Committee.

The Committees of the Sections shall ascertain whether a Report has been made by every Committee appointed at the previous Meeting to whom a sum of money has been granted, and shall report to the Committee of Recommendations in every case where no such Report has been received.[1]

Notices regarding Grants of Money.

Committees and individuals, to whom grants of money have been

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[1] Passed by the General Committee at Sheffield, 1879.

entrusted by the Association for the prosecution of particular researches in science, are required to present to each following Meeting of the Association a Report of the progress which has been made; and the Individual or the Member first named of a Committee to whom a money grant has been made must (previously to the next Meeting of the Association) forward to the General Secretaries or Treasurer a statement of the sums which have been expended, and the balance which remains disposable on each grant.

Grants of money sanctioned at any one Meeting of the Association expire *a week before* the opening of the ensuing Meeting; nor is the Treasurer authorized, after that date, to allow any claims on account of such grants, unless they be renewed in the original or a modified form by the General Committee.

No Committee shall raise money in the name or under the auspices of the British Association without special permission from the General Committee to do so; and no money so raised shall be expended except in accordance with the rules of the Association.

In each Committee, the Member first named is the only person entitled to call on the Treasurer, Professor A. W. Williamson, University College, London, W.C., for such portion of the sums granted as may from time to time be required.

In grants of money to Committees, the Association does not contemplate the payment of personal expenses to the members.

In all cases where additional grants of money are made for the continuation of Researches at the cost of the Association, the sum named is deemed to include, as a part of the amount, whatever balance may remain unpaid on the former grant for the same object.

All Instruments, Papers, Drawings, and other property of the Association are to be deposited at the Office of the Association, 22 Albemarle Street, Piccadilly, London, W., when not employed in carrying on scientific inquiries for the Association.

Business of the Sections.

The Meeting Room of each Section is opened for conversation from 10 to 11 daily. *The Section Rooms and approaches thereto can be used for no notices, exhibitions, or other purposes than those of the Association.*

At 11 precisely the Chair will be taken,[1] and the reading of communications, in the order previously made public, commenced. At 3 P.M. the Sections will close.

Sections may, by the desire of the Committees, divide themselves into Departments, as often as the number and nature of the communications delivered in may render such divisions desirable.

A Report presented to the Association, and read to the Section which originally called for it, may be read in another Section, at the request of the Officers of that Section, with the consent of the Author.

Duties of the Doorkeepers.

1.—To remain constantly at the Doors of the Rooms to which they are appointed during the whole time for which they are engaged.

2.—To require of every person desirous of entering the Rooms the exhibition of a Member's, Associate's, or Lady's Ticket, or Reporter's

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[1] The meeting on Saturday may begin, if desired by the Committee, at any time not earlier than 10 or later than 11. Passed by the General Committee at Southport, 1883.

Ticket, signed by the Treasurer, or a Special Ticket signed by the Secretary.

3.—Persons unprovided with any of these Tickets can only be admitted to any particular Room by order of the Secretary in that Room.

No person is exempt from these Rules, except those Officers of the Association whose names are printed in the programme, p. 1.

Duties of the Messengers.

To remain constantly at the Rooms to which they are appointed during the whole time for which they are engaged, except when employed on messages by one of the Officers directing these Rooms.

Committee of Recommendations.

The General Committee shall appoint at each Meeting a Committee, which shall receive and consider the Recommendations of the Sectional Committees, and report to the General Committee the measures which they would advise to be adopted for the advancement of Science.

All Recommendations of Grants of Money, Requests for Special Researches, and Reports on Scientific Subjects shall be submitted to the Committee of Recommendations, and not taken into consideration by the General Committee unless previously recommended by the Committee of Recommendations.

Corresponding Societies.[1]

(1.) Any Society is eligible to be placed on the List of Corresponding Societies of the Association which undertakes local scientific investigations, and publishes notices of the results.

(2.) Applications may be made by any Society to be placed on the List of Corresponding Societies. Application must be addressed to the Secretary on or before the 1st of June preceding the Annual Meeting at which it is intended they should be considered, and must be accompanied by specimens of the publications of the results of the local scientific investigations recently undertaken by the Society.

(3.) A Corresponding Societies Committee shall be annually nominated by the Council and appointed by the General Committee for the purpose of considering these applications, as well as for that of keeping themselves generally informed of the annual work of the Corresponding Societies, and of superintending the preparation of a list of the papers published by them. This Committee shall make an annual report to the General Committee, and shall suggest such additions or changes in the List of Corresponding Societies as they may think desirable.

(4.) Every Corresponding Society shall return each year, on or before the 1st of June, to the Secretary of the Association, a schedule, properly filled up, which will be issued by the Secretary of the Association, and which will contain a request for such particulars with regard to the Society as may be required for the information of the Corresponding Societies Committee.

(5.) There shall be inserted in the Annual Report of the Association a list, in an abbreviated form, of the papers published by the Corresponding Societies during the past twelve months which contain the results of the local scientific work conducted by them; those papers only being included which refer to subjects coming under the cognisance of one or other of the various Sections of the Association.

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[1] Passed by the General Committee, 1884.

(6.) A Corresponding Society shall have the right to nominate any one of its members, who is also a Member of the Association, as its delegate to the Annual Meeting of the Association, who shall be for the time a Member of the General Committee.

Conference of Delegates of Corresponding Societies.

(7.) The Delegates of the various Corresponding Societies shall constitute a Conference, of which the Chairman, Vice-Chairmen, and Secretaries shall be annually nominated by the Council, and appointed by the General Committee, and of which the members of the Corresponding Societies Committee shall be *ex officio* members.

(8.) The Conference of Delegates shall be summoned by the Secretaries to hold one or more meetings during each Annual Meeting of the Association, and shall be empowered to invite any Member or Associate to take part in the meetings.

(9.) The Secretaries of each Section shall be instructed to transmit to the Secretaries of the Conference of Delegates copies of any recommendations forwarded by the Presidents of Sections to the Committee of Recommendations bearing upon matters in which the co-operation of Corresponding Societies is desired; and the Secretaries of the Conference of Delegates shall invite the authors of these recommendations to attend the meetings of the Conference and give verbal explanations of their objects and of the precise way in which they would desire to have them carried into effect.

(10.) It will be the duty of the Delegates to make themselves familiar with the purport of the several recommendations brought before the Conference, in order that they and others who take part in the meetings may be able to bring those recommendations clearly and favourably before their respective Societies. The Conference may also discuss propositions bearing on the promotion of more systematic observation and plans of operation, and of greater uniformity in the mode of publishing results.

Local Committees.

Local Committees shall be formed by the Officers of the Association to assist in making arrangements for the Meetings.

Local Committees shall have the power of adding to their numbers those Members of the Association whose assistance they may desire.

Officers.

A President, two or more Vice-Presidents, one or more Secretaries, and a Treasurer shall be annually appointed by the General Committee.

Council.

In the intervals of the Meetings, the affairs of the Association shall be managed by a Council appointed by the General Committee. The Council may also assemble for the despatch of business during the week of the Meeting.

Papers and Communications.

The Author of any paper or communication shall be at liberty to reserve his right of property therein.

Accounts.

The Accounts of the Association shall be audited annually, by Auditors appointed by the General Committee.

Table showing the Places and Times of Meeting of the British Association, with Presidents, Vice-Presidents, and Local Secretaries, from its Commencement.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
The EARL FITZWILLIAM, D.C.L., F.R.S., F.G.S., &c. York, September 27, 1831.	Rev. W. Vernon Harcourt, M.A., F.R.S., F.G.S.	William Gray, jun., Esq., F.G.S. Professor Phillips, M.A., F.R.S., F.G.S.
The REV. W. BUCKLAND, D.D., F.R.S., F.G.S., &c. Oxford, June 19, 1832.	Sir David Brewster, F.R.S. L. & E., &c. Rev. W. Whewell, F.R.S., Pres. Geol. Soc.	Professor Daubeny, M.D., F.R.S., &c. Rev. Professor Powell, M.A., F.R.S., &c.
The REV. ADAM SEDGWICK, M.A., V.P.R.S., V.P.G.S. Cambridge, June 25, 1833.	G. B. Airy, Esq., F.R.S., Astronomer Royal, &c. John Dalton, Esq., D.C.L., F.R.S.	Rev. Professor Henslow, M.A., F.L.S., F.G.S. Rev. W. Whewell, F.R.S.
SIR T. MACDOUGALL BRISBANE, K.C.B., D.C.L., F.R.S. L. & E. Edinburgh, September 8, 1834.	Sir David Brewster, F.R.S., &c. Rev. T. R. Robinson, D.D.	Professor Forbes, F.R.S. L. & E., &c. Sir John Robinson, Sec. R.S.E.
The REV. PROVOST LLOYD, LL.D. Dublin, August 10, 1835.	Viscount Oxmantown, F.R.S., F.R.A.S. Rev. W. Whewell, F.R.S., &c.	Sir W. R. Hamilton, Astron. Royal of Ireland, &c. Rev. Professor Lloyd, F.R.S.
The MARQUIS OF LANSDOWNE, D.C.L., F.R.S., &c. Bristol, August 22, 1836.	The Marquis of Northampton, F.R.S. Rev. W. D. Conybeare, F.R.S., F.G.S. J. C. Prichard, Esq., M.D., F.R.S.	Professor Daubeny, M.D., F.R.S., &c. V. F. Hovenden, Esq.
The EARL OF BURLINGTON, F.R.S., F.G.S., Chancellor of the University of London Liverpool, September 11, 1837.	The Bishop of Norwich, P.L.S., F.G.S. John Dalton, Esq., D.C.L., F.R.S. Sir Philip de Grey Egerton, Bart., F.R.S., F.G.S. Rev. W. Whewell, F.R.S.	Professor Traill, M.D. Wm. Wallace Currie, Esq. Joseph N. Walker, Esq., Pres. Royal Institution, Liverpool.
The DUKE OF NORTHUMBERLAND, F.R.S., F.G.S., &c. Newcastle-on-Tyne, August 20, 1838.	The Bishop of Durham, F.R.S., F.S.A. The Rev. W. Vernon Harcourt, F.R.S., &c. Prideaux John Selby, Esq., F.R.S.E.	John Adamson, Esq., F.L.S., &c. Wm. Hutton, Esq., F.G.S. Professor Johnston, M.A., F.R.S.
The REV. W. VERNON HARCOURT, M.A., F.R.S., &c. Birmingham, August 26, 1839.	The Marquis of Northampton. The Earl of Dartmouth The Rev. T. R. Robinson, D.D. John Corrie, Esq., F.R.S. The Very Rev. Principal Macfarlane	George Barker, Esq., F.R.S. Peyton Blakiston, Esq., M.D. Joseph Hodgson, Esq., F.R.S. Follett Osler, Esq.
The MARQUIS OF BREADALBANE, F.R.S. Glasgow, September 17, 1840.	Major-General Lord Greenock, F.R.S.E. Sir David Brewster, F.R.S. Sir T. M. Brisbane, Bart., F.R.S. The Earl of Mount-Edgcumbe	Andrew Liddell, Esq. Rev. J. P. Nicol, LL.D. John Strang, Esq.
The REV. PROFESSOR WHEWELL, F.R.S., &c. Plymouth, July 29, 1841.	The Earl of Morley. Lord Eliot, M.P. Sir C. Lemon, Bart. Sir T. D. Acland, Bart.	W. Snow Harris, Esq., F.R.S. Col. Hamilton Smith, F.L.S. Robert Were Fox, Esq. Richard Taylor, jun., Esq.
The LORD FRANCIS EGERTON, F.G.S. Manchester, June 23, 1842.	John Dalton, Esq., D.C.L., F.R.S. Hon. and Rev. W. Herbert, F.L.S., &c. Rev. A. Sedgwick, M.A., F.R.S. W. C. Henry, Esq., M.D., F.R.S. Sir Benjamin Heywood, Bart.	Peter Clare, Esq., F.R.A.S. W. Fleming, Esq., M.D. James Heywood, Esq., F.R.S.
The EARL OF ROSSE, F.R.S. Cork, August 17, 1843.	The Earl of Listowel. Viscount Adare Sir W. R. Hamilton, Pres. R.I.A. Rev. T. R. Robinson, D.D.	Professor John Stevelly, M.A. Rev. Jos. Carson, F.T.C. Dublin. William Keleher, Esq. Wm. Clear, Esq.
The REV. G. PEACOCK, D.D. (Dean of Ely), F.R.S. York, September 26, 1844.	Earl Fitzwilliam, F.R.S. Viscount Morpeth, F.G.S. The Hon. John Stuart Wortley, M.P. Sir David Brewster, K.H., F.R.S. Michael Faraday, Esq., D.C.L., F.R.S. Rev. W. V. Harcourt, F.R.S.	William Hatfeild, Esq., F.G.S. Thomas Meynell, Esq., F.L.S. Rev. W. Scoresby, LL.D., F.R.S. William West, Esq.
SIR JOHN F. W. HERSCHEL, Bart., F.R.S., &c. Cambridge, June 19, 1845.	The Earl of Hardwicke. The Bishop of Norwich Rev. J. Graham, D.D. Rev. G. Ainslie, D.D. G. B. Airy, Esq., M.A., D.C.L., F.R.S. The Rev. Professor Sedgwick, M.A., F.R.S.	William Hopkins, Esq., M.A., F.R.S. Professor Ansted, M.A., F.R.S.

PRSEIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
SIR RODERICK IMPEY MURCHISON, G.C.St.S., F.R.S. SOUTHAMPTON, September 10, 1846.	The Marquis of Winchester. The Earl of Yarborough, D.C.L. Lord Ashburton, D.C.L. Viscount Palmerston, M.P. Right Hon. Charles Shaw Lefevre, M.P. Sir George T. Staunton, Bart., M.P., D.C.L., F.R.S. The Lord Bishop of Oxford, F.R.S. Professor Owen, M.D., F.R.S. The Rev. Professor Powell, F.R.S.	Henry Clark, Esq., M.D. T. H. C. Moody, Esq.
SIR ROBERT HARRY INGLIS, Bart., D.C.L., F.R.S., M.P. for the University of Oxford OXFORD, June 23, 1847.	The Earl of Rosse, F.R.S. The Lord Bishop of Oxford, F.R.S. The Vice-Chancellor of the University Thomas G. Bucknall Estcourt, Esq., D.C.L., M.P. for the University of Oxford. The Very Rev. the Dean of Westminster, D.D., F.R.S. Professor Daubeny, M.D., F.R.S. The Rev. Prof. Powell, M.A., F.R.S.	Rev. Robert Walker, M.A., F.R.S. H. Wentworth Acland, Esq., B.M.
The MARQUIS OF NORTHAMPTON, President of the Royal Society, &c. SWANSEA, August 9, 1848.	The Marquis of Bute, K.T. Viscount Adare, F.R.S. Sir H. T. De la Beche, F.R.S., Pres. G.S. The Very Rev. the Dean of Llandaff, F.R.S. Lewis W. Dillwyn, Esq., F.R.S. W. R. Grove, Esq., F.R.S. J. H. Vivian, Esq., M.P., F.R.S. The Lord Bishop of St. David's	Matthew Moggridge, Esq. D. Nicol, Esq., M.D.
The REV. T. R. ROBINSON, D.D., M.R.I.A., F.R.A.S. BIRMINGHAM, September 12, 1849.	The Earl of Harrowby. The Lord Wrottesley, F.R.S. The Right Hon. Sir Robert Peel, Bart., M.P., D.C.L., F.R.S. Charles Darwin, Esq., M.A., F.R.S., Sec. G.S. Professor Faraday, D.C.L., F.R.S. Sir David Brewster, K.H., LL.D., F.R.S. Rev. Prof. Willis, M.A., F.R.S.	Captain Tindal, R.N. William Wills, Esq. Bell Fletcher, Esq., M.D. James Chance, Esq.
SIR DAVID BREWSTER, K.H., LL.D., F.R.S. L. & E., Principal of the United College of St. Salvator and St. Leonard, St. Andrews EDINBURGH, July 21, 1850.	The Right Hon. the Lord Provost of Edinburgh The Earl of Cathcart, K.C.B., F.R.S.E. The Earl of Rosebery, K.T., D.C.L., F.R.S. The Right Hon. David Boyle (Lord Justice-General), F.R.S.E. General Sir Thomas M. Brisbane, Bart., D.C.L., F.R.S., Pres. R.S.E. The Very Rev. John Lee, D.D., V.P.R.S.E., Principal of the University of Edinburgh. Professor W. P. Alison, M.D., V.P.R.S.E. Professor J. D. Forbes, F.R.S., Sec. R.S.E.	Rev. Professor Kelland, M.A., F.R.S. L. & E. Professor Balfour, M.D., F.R.S.E., F.L.S. James Tod, Esq., F.R.S.E.
GEORGE BIDDELL AIRY, Esq., D.C.L., F.R.S., Astronomer Royal IPSWICH, July 2, 1851.	The Lord Rendlesham, M.P. The Lord Bishop of Norwich Rev. Professor Sedgwick, M.A., F.R.S. Rev. Professor Henslow, M.A., F.L.S. Sir John P. Boileau, Bart., F.R.S. Sir William F. F. Middleton, Bart. J. C. Cobbold, Esq., M.P. T. B. Western, Esq.	Charles May, Esq., F.R.A.S. Dillwyn Sims, Esq. George Arthur Biddell, Esq. George Ransome, Esq., F.L.S.
COLONEL EDWARD SABINE, Royal Artillery, Treas. & V.P. of the Royal Society BELFAST, September 1, 1852.	The Earl of Enniskillen, D.C.L., F.R.S. The Earl of Rosse, Pres. R.S., M.R.I.A. Sir Henry T. De la Beche, F.R.S. Rev. Edward Hincks, D.D., M.R.I.A. Rev. P. S. Henry, D.D., Pres. Queen's College, Belfast Rev. T. R. Robinson, D.D., Pres. R.I.A., F.R.A.S. Professor G. G. Stokes, F.R.S. Professor Stevelly, LL.D.	W. J. C. Allen, Esq. William M'Gee, Esq., M.D. Professor W. P. Wilson.
WILLIAM HOPKINS, Esq., M.A., V.P.R.S., F.G.S., Pres. Camb. Phil. Society HULL, September 7, 1853.	The Earl of Carlisle, F.R.S. Lord Londesborough, F.R.S. Professor Faraday, D.C.L., F.R.S. Rev. Prof. Sedgwick, M.A., F.R.S. Charles Frost, Esq., F.S.A., Pres. of the Hull Lit. and Phil. Society William Spence, Esq., F.R.S. Lieut.-Col. Sykes, F.R.S. Professor Wheatstone, F.R.S.	Henry Cooper, Esq., M.D., V.P. Hull Lit. & Phil. Society. Bethel Jacobs, Esq., Pres. Hull Mechanics' Inst.

The EARL OF HARROWBY, F.R.S. LIVERPOOL, September 20, 1854.	The Lord Wrottesley, M.A., F.R.S., F.R.A.S. Sir Philip de Malpas Grey Egerton, Bart., M.P., F.R.S., F.G.S. Professor Owen, M.D., LL.D., F.R.S., F.L.S., F.G.S. Rev. Professor Whewell, D.D., F.R.S., Hon. M.R.I.A., F.G.S., Master of Trinity College, Cambridge William Lassell, Esq., F.R.S. L. & E., F.R.A.S. Joseph Brooks Yates, Esq., F.S.A., F.R.G.S.	Joseph Dickinson, Esq., M.D., F.R.S. Thomas Inman, Esq., M.D.
The DUKE OF ARGYLL, F.R.S., F.G.S. GLASGOW, September 12, 1855.	The Very Rev. Principal Macfarlane, D.D. Sir William Jardine, Bart., F.R.S.E. Sir Charles Lyell, M.A., LL.D., F.R.S. James Smith, Esq., F.R.S. L. & E. Walter Crum, Esq., F.R.S. Thomas Graham, Esq., M.A., F.R.S., Master of the Royal Mint Professor William Thomson, M.A., F.R.S.	John Strang, Esq., LL.D. Professor Thomas Anderson, M.D. William Gourlie, Esq.
CHARLES G. B. DAUBENY, Esq., M.D., LL.D., F.R.S., Professor of Botany in the University of Oxford CHELTENHAM, August 6, 1856.	The Earl of Ducie, F.R.S., F.G.S. The Lord Bishop of Gloucester and Bristol Sir Roderick I. Murchison, G.C.St.S., D.C.L., F.R.S. Thomas Barwick Lloyd Baker, Esq. The Rev. Francis Close, M.A.	Capt. Robinson, R.A. Richard Beamish, Esq., F.R.S. John West Hugell, Esq.
The REV. HUMPHREY LLOYD, D.D., D.C.L., F.R.S. L. & E., V.P.R.I.A. DUBLIN, August 26, 1857.	The Right Hon. the Lord Mayor of Dublin The Provost of Trinity College, Dublin The Marquis of Kildare. Lord Talbot de Malahide The Lord Chancellor of Ireland The Lord Chief Baron, Dublin Sir William R. Hamilton, LL.D., F.R.A.S., Astronomer Royal of Ireland Lieut.-Colonel Larcom, R.E., LL.D., F.R.S. Richard Griffith, Esq., LL.D., M.R.I.A., F.R.S.E., F.G.S.	Lundy E. Foote, Esq. Rev. Professor Jellett, F.T.C.D. W. Neilson Hancock, Esq., LL.D.
RICHARD OWEN, Esq., M.D., D.C.L., V.P.R.S., F.L.S., F.G.S., Superintendent of the Natural History Departments of the British Museum. LEEDS, September 22, 1858.	The Lord Monteagle, F.R.S. The Lord Viscount Goderich, M.P., F.R.G.S. The Right Hon. M. T. Baines, M.A., M.P. Sir Philip de Malpas Grey Egerton, Bart., M.P., F.R.S., F.G.S. The Rev. W. Whewell, D.D., F.R.S., Hon. M.R.I.A., F.G.S., F.R.A.S., Master of Trinity College, Cambridge James Garth Marshall, Esq., M.A., F.G.S. R. Monckton Milnes, Esq., D.C.L., M.P., F.R.G.S.	Rev. Thomas Hincks, B.A. W. Sykes Ward, Esq., F.C.S. Thomas Wilson, Esq., M.A.
HIS ROYAL HIGHNESS THE PRINCE CONSORT ABERDEEN, September 14, 1859.	The Duke of Richmond, K.G., F.R.S. The Earl of Aberdeen, LL.D., K.G., K.T., F.R.S. The Lord Provost of the City of Aberdeen Sir John F. W. Herschel, Bart., M.A., D.C.L., F.R.S. Sir David Brewster, K.H., D.C.L., F.R.S. Sir Roderick I. Murchison, G.C.St.S., D.C.L., F.R.S. The Rev. W. V. Harcourt, M.A., F.R.S. The Rev. T. R. Robinson, D.D., F.R.S. A. Thomson, Esq., LL.D., F.R.S., Convener of the County of Aberdeen	Professor J. Nicol, F.R.S.E., F.G.S. Professor Fuller, M.A. John F. White, Esq.
The LORD WROTTESLEY, M.A., V.P.R.S., F.R.A.S. OXFORD, June 27, 1860.	The Earl of Derby, K.G., P.C., D.C.L., Chancellor of the Univ. of Oxford The Rev. F. Jeune, D.C.L., Vice-Chancellor of the University of Oxford The Duke of Marlborough, D.C.L., F.G.S., Lord Lieutenant of Oxfordshire The Earl of Rosse, K.P., M.A., F.R.S., F.R.A.S. The Lord Bishop of Oxford, D.D., F.R.S. The Very Rev. H. G. Liddell, D.D., Dean of Christ Church, Oxford Professor Daubeny, M.D., LL.D., F.R.S., F.L.S., F.G.S. Professor Acland, M.D., F.R.S. Professor Donkin, M.A., F.R.S., F.R.A.S.	George Rolleston, Esq., M.D., F.L.S. H. J. S. Smith, Esq., M.A., F.C.S. George Griffith, Esq., M.A., F.C.S.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
WILLIAM FAIRBAIRN, Esq., LL.D., C.E., F.R.S. MANCHESTER, September 4, 1861.	The Earl of Ellesmere, F.R.G.S. The Lord Stanley, M.P., D.C.L., F.R.G.S. The Lord Bishop of Manchester, D.D., F.R.S., F.G.S. Sir Philip de Malpas Grey Egerton, Bart., M.P., F.R.S., F.G.S. Sir Benjamin Heywood, Bart., F.R.S. Thomas Bazley, Esq., M.P. James Aspinall Turner, Esq., M.P. James Prescott Joule, Esq., LL.D., F.R.S., Pres. Lit. & Phil. Soc. Manchester Professor E. Hodgkinson, F.R.S., M.R.I.A., M.I.C.E. Joseph Whitworth, Esq., F.R.S., M.Inst.C E.	R. D. Darbishire, Esq., B.A., F.G.S. Alfred Neild, Esq. Arthur Ransome, Esq., M.A. Professor H. E. Roscoe, B.A.
The REV. R. WILLIS, M.A., F.R.S., Jacksonian Professor of Natural and Experimental Philosophy in the University of Cambridge CAMBRIDGE, October 1, 1862.	The Rev. the Vice-Chancellor of the University of Cambridge The Very Rev. Harvey Goodwin, D.D., Dean of Ely The Rev. W. Whewell, D.D., F.R.S., Master of Trinity College, Cambridge The Rev. Professor Sedgwick, M.A., D.C.L., F.R.S. The Rev. J. Challis, M.A., F.R.S. G. B. Airy, Esq., M.A., D.C.L., F.R.S., Astronomer Royal Professor G. G. Stokes, M.A., D.C.L., Sec. R.S. Professor J. C. Adams, M.A., D.C.L., F.R.S., Pres. C.P.S.	Professor C. C. Babington, M.A., F.R.S., F.L.S. Professor G. D. Liveing, M.A. The Rev. N. M. Ferrers, M.A.
SIR W. ARMSTRONG, C.B., LL.D., F.R.S. NEWCASTLE-ON-TYNE, August 26, 1863.	Sir Walter C. Trevelyan, Bart., M.A. Sir Charles Lyell, LL.D., D.C.L., F.R.S., F.G.S. Hugh Taylor, Esq., Chairman of the Coal Trade Isaac Lowthian Bell, Esq., Mayor of Newcastle Nicholas Wood, Esq., President of the Northern Institute of Mining Engineers Rev. Temple Chevallier, B.D., F.R.A.S. William Fairbairn, Esq., LL.D., F.R.S.	A. Noble, Esq. Augustus H. Hunt, Esq. R. C. Clapham, Esq.
SIR CHARLES LYELL, Bart., M.A., D.C.L., F.R.S. BATH, September 14, 1864.	The Right Hon. the Earl of Cork and Orrery, Lord-Lieutenant of Somersetshire The Most Noble the Marquis of Bath The Right Hon. Earl Nelson The Right Hon. Lord Portman The Very Rev. the Dean of Hereford The Venerable the Archdeacon of Bath W. Tite, Esq., M.P., F.R.S., F.G.S., F.S.A. A. E. Way, Esq., M.P. Francis H. Dickinson, Esq. W. Sanders, Esq., F.R.S., F.G.S.	C. Moore, Esq., F.G.S. C. E. Davis, Esq. The Rev. H. H. Winwood, M.A.
JOHN PHILLIPS, Esq., M.A., LL.D., F.R.S., F.G.S., Professor of Geology in the University of Oxford BIRMINGHAM, September 6, 1865.	The Right Hon. the Earl of Lichfield, Lord-Lieutenant of Staffordshire The Right Hon. the Earl of Dudley The Right Hon. Lord Leigh, Lord-Lieutenant of Warwickshire The Right Hon. Lord Lyttelton, Lord-Lieutenant of Worcestershire The Right Hon. Lord Wrottesley, M.A., D.C.L., F.R.S., F.R.A.S. The Right Rev. the Lord Bishop of Worcester The Right Hon. C. B. Adderley, M.P. William Scholefield, Esq., M.P. F. Osler, Esq., F.R.S. J. T. Chance, Esq. The Rev. Charles Evans, M.A.	William Mathews, jun., Esq. M.A., F.G.S. John Henry Chamberlain, Esq. The Rev. G. D. Boyle, M.A.

WILLIAM R. GROVE, Esq., Q.C., M.A., F.R.S. NOTTINGHAM, August 22, 1866.	His Grace the Duke of Devonshire, Lord-Lieutenant of Derbyshire His Grace the Duke of Rutland, Lord-Lieutenant of Leicestershire The Right Hon. Lord Belper, Lord-Lieutenant of Nottinghamshire The Right Hon. J. E. Denison, M.P. J. C. Webb, Esq., High-Sheriff of Nottinghamshire Thomas Graham, Esq., F.R.S., Master of the Mint Joseph Hooker, Esq., M.D., F.R.S., F.L.S. John Russell Hinds, Esq., F.R.S., F.R.A.S. T. Close, Esq.	Dr. Robertson. Edward J. Lowe, Esq., F.R.A.S., F.L.S. The Rev. J. F. M'Callan, M.A.
HIS GRACE THE DUKE OF BUCCLEUCH, K.G., D.C.L., F.R.S. DUNDEE, September 4, 1867.	The Right Hon. the Earl of Airlie, K.T. The Right Hon. the Lord Kinnaird, K.T. Sir John Ogilvy, Bart., M.P. Sir Roderick I. Murchison, Bart., K.C.B., LL.D., F.R.S., F.G.S., &c. Sir David Baxter, Bart. Sir David Brewster, D.C.L., F.R.S., Principal of the University of Edinburgh James D. Forbes, Esq., LL.D., F.R.S., Principal of the United College of St. Salvator and St. Leonard, University of St. Andrews	J. Henderson, jun., Esq. John Austin Lake Gloag, Esq. Patrick Anderson, Esq.
JOSEPH DALTON HOOKER, Esq., M.D., D.C.L., F.R.S., F.L.S. NORWICH, August 19, 1868.	The Right Hon. the Earl of Leicester, Lord-Lieutenant of Norfolk Sir John Peter Boileau, Bart., F.R.S. The Rev. Adam Sedgwick, M.A., LL.D., F.R.S., F.G.S., &c., Woodwardian Professor of Geology in the University of Cambridge Sir John Lubbock, Bart., F.R.S., F.L.S., F.G.S. John Couch Adams, Esq., M.A., D.C.L., F.R.S., F.R.A.S., Lowndean Professor of Astronomy and Geometry in the University of Cambridge Thomas Brightwell, Esq.	Dr. Donald Dalrymple. Rev. Joseph Crompton, M.A. Rev. Canon Hinds Howell.
PROFESSOR GEORGE G. STOKES, D.C.L., F.R.S. EXETER, August 18, 1869.	The Right Hon. the Earl of Devon The Right Hon. Sir Stafford H. Northcote, Bart., C.B., M.P., &c. Sir John Bowring, LL.D., F.R.S. William B. Carpenter, Esq., M.D., F.R.S., F.L.S. Robert Were Fox, Esq., F.R.S. W. H. Fox Talbot, Esq., M.A., LL.D., F.R.S., F.L.S.	Henry S. Ellis, Esq., F.R.A.S. John C. Bowring, Esq. The Rev. R. Kirwan.
PROFESSOR T. H. HUXLEY, LL.D., F.R.S. F.G.S. LIVERPOOL, September 14, 1870.	The Right Hon. the Earl of Derby, LL.D., F.R.S. Sir Philip de Malpas Grey Egerton, Bart., M.P. The Right Hon. W. E. Gladstone, D.C.L., M.P. S. R. Graves, Esq., M.P. Sir Joseph Whitworth, Bart., LL.D., D.C.L., F.R.S. James P. Joule, Esq., LL.D., D.C.L., F.R.S. Joseph Mayer, Esq., F.S.A., F.R.G.S.	Rev. W. Banister. Reginald Harrison, Esq. Rev. Henry H. Higgins, M.A. Rev. Dr. A. Hume, F.S.A.
PROFESSOR SIR WILLIAM THOMSON, M.A., LL.D., F.R.S. L. & E. EDINBURGH, August 2, 1871.	His Grace the Duke of Buccleuch, K.G., D.C.L., F.R.S. The Right Hon. the Lord Provost of Edinburgh The Right Hon. John Inglis, LL.D., Lord Justice-General of Scotland Sir Alexander Grant, Bart., M.A., Principal of the University of Edinburgh Sir Roderick I. Murchison, Bart., K.C.B., G.C.St.S., D.C.L., F.R.S. Sir Charles Lyell, Bart., D.C.L., F.R.S., F.G.S. Dr. Lyon Playfair, C.B., M.P., F.R.S. Professor Christison, M.D., D.C.L., Pres. R.S.E. Professor Balfour, F.R.S. L. & E.	Professor A. Crum Brown, M.D., F.R.S.E. J. D. Marwick, Esq., F.R.S.E.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
W. B. CARPENTER, Esq., M.D., LL.D., F.R.S., F.L.S. BRIGHTON, August 14, 1872.	The Right Hon. the Earl of Chichester, Lord-Lieutenant of the County of Sussex. His Grace the Duke of Norfolk His Grace the Duke of Richmond, K.G., P.C., D.C.L. His Grace the Duke of Devonshire, K.G., D.C.L., F.G.S. Sir John Lubbock, Bart., M.P., F.R.S., F.L.S., F.G.S. Dr. Sharpey, LL.D., Sec. R.S., F.L.S. Joseph Prestwich, Esq., F.R.S., Pres. G.S.	Charles Carpenter, Esq. The Rev. Dr. Griffith. Henry Willett, Esq.
PROFESSOR ALEXANDER W. WILLIAMSON, Ph.D., F.R.S., F.C.S. BRADFORD, September 17, 1873.	The Right Hon. the Earl of Rosse, F.R.S., F.R.A.S. The Right Hon. Lord Houghton, D.C.L., F.R.S. The Right Hon. W. E. Forster, M.P. The Mayor of Bradford. Sir John Hawkshaw, F.R.S., F.G.S. J. P. Gassiot, Esq., D.C.L., F.R.S. Professor Phillips, D.C.L., F.R.S.	The Rev. J. R. Campbell, D.D. Richard Goddard, Esq. Peile Thompson, Esq.
PROFESSOR J. TYNDALL, D.C.L., LL.D., F.R.S. BELFAST, August 19, 1874.	The Right Hon. the Earl of Enniskillen, D.C.L., F.R.S. The Right Hon. the Earl of Rosse, F.R.S. Sir Richard Wallace, Bart., M.P. The Rev. Dr. Henry. Dr. Andrews, F.R.S. The Rev. Dr. Robinson, F.R.S. Professor Stokes, D.C.L., F.R.S.	W. Quartus Ewart, Esq. Professor G. Fuller, C.E. T. Sinclair, Esq.
SIR JOHN HAWKSHAW, C.E., F.R.S., F.G.S. BRISTOL, August 25, 1875.	The Right Hon. the Earl of Ducie, F.R.S., F.G.S. The Right Hon. Sir Stafford H. Northcote, Bart., C.B., M.P., F.R.S. The Mayor of Bristol Major-General Sir Henry C. Rawlinson, K.C.B., LL.D., F.R.S., F.R.G.S. Dr. W. B. Carpenter, LL.D., F.R.S., F.L.S., F.G.S. W. Sanders, Esq., F.R.S., F.G.S.	W. Lant Carpenter, Esq., B.A., B.Sc., F.C.S. John H. Clarke, Esq.
PROFESSOR THOMAS ANDREWS, M.D., LL.D., F.R.S., Hon. F.R.S.E. GLASGOW, September 6, 1876.	His Grace the Duke of Argyll, K.T., LL.D., F.R.S. L. & E., F.G.S. The Hon. the Lord Provost of Glasgow Sir William Stirling Maxwell, Bart., M.A., M.P. Professor Sir William Thomson, M.A., LL.D., D.C.L., F.R.S. L. & E. Professor Allen Thomson, M.D., LL.D., F.R.S. L. & E. Professor A. C. Ramsay, LL.D., F.R.S., F.G.S. James Young, Esq., F.R.S., F.C.S.	Dr. W. G. Blackie, F.R.G.S. James Grahame, Esq. J. D. Marwick, Esq.
PROFESSOR ALLEN THOMSON, M.D., LL.D., F.R.S. L. & E. PLYMOUTH, August 15, 1877.	The Right Hon. the Earl of Mount-Edgcumbe The Right Hon. Lord Blachford, K.C.M.G. William Spottiswoode, Esq., M.A., LL.D., F.R.S., F.R.A.S., F.R.G.S. William Froude, Esq., M.A., C.E., F.R.S. Charles Spence Bate, Esq., F.R.S., F.L.S.	William Adams, Esq. William Square, Esq. Hamilton Whiteford, Esq.
WILLIAM SPOTTISWOODE, Esq., M.A., D.C.L., LL.D., F.R.S., F.R.A.S., F.R.G.S. DUBLIN, August 14, 1878.	The Right Hon. the Lord Mayor of Dublin The Provost of Trinity College, Dublin His Grace the Duke of Abercorn, K.G. The Right Hon. the Earl of Enniskillen, D.C.L., F.R.S., F.G.S. The Right Hon. the Earl of Rosse, B.A., D.C.L., F.R.S., F.R.A.S., M.R.I.A. The Right Hon. Lord O'Hagan, M.R.I.A. Professor G. G. Stokes, M.A., D.C.L., LL.D., Sec. R.S.	Professor R. S. Ball, M.A., F.R.S. James Goff, Esq. John Norwood, Esq., LL.D. Professor G. Sigerson, M.D.
PROFESSOR G. J. ALLMAN, M.D., LL.D., F.R.S. L. & E., M.R.I.A., Pres. L.S. SHEFFIELD, August 20, 1879.	His Grace the Duke of Devonshire, K.G., M.A., LL.D., F.R.S., F.R.G.S. The Right Hon. the Earl Fitzwilliam, K.G., F.R.G.S. The Right Hon. the Earl of Wharncliffe, F.R.G.S. W. H. Brittain, Esq. (Master Cutler) Professor T. H. Huxley, Ph.D., LL.D., Sec. R.S., F.L.S., F.G.S. Professor W. Odling, M.B., F.R.S., F.C.S.	H. Clifton Sorby, Esq., LL.D., F.R.S., F.G.S. J. F. Moss, Esq.

ANDREW CROMBIE RAMSAY, Esq., LL.D., F.R.S., V.P.G.S., Director-General of the Geological Survey of the United Kingdom, and of the Museum of Practical Geology SWANSEA, August 25, 1880.	The Right Hon. the Earl of Jersey The Mayor of Swansea The Hon. Sir W. R. Grove, M.A., D.C.L., F.R.S. H. Hussey Vivian, Esq., M.P., F.G.S. L. Ll. Dillwyn, Esq., M.P., F.L.S., F.G.S. J. Gwyn Jeffreys, Esq., LL.D., F.R.S., F.L.S., Treas. G.S., F.R.G.S.	W. Morgan Esq., Ph.D., F.C.S. James Strick, Esq.
SIR JOHN LUBBOCK, Bart., M.P., D.C.L., LL.D., F.R.S., Pres. L.S., F.G.S. YORK, August 31, 1881.	His Grace the Archbishop of York, D.D., F.R.S. The Right Hon. the Lord Mayor of York The Right Hon. Lord Houghton, D.C.L., F.R.S., F.R.G.S. The Venerable Archdeacon Creyke, M.A. The Hon. Sir W. R. Grove, M.A., D.C.L., F.R.S. Professor G. G. Stokes, M.A., D.C.L., LL.D., Sec. R.S. Sir John Hawkshaw, C.E., F.R.S., F.G.S., F.R.G.S. Allen Thomson, Esq., M.D., LL.D., F.R.S. L. & E. Professor Allman, M.D., LL.D., F.R.S. L. & E., F.L.S.	Rev. Thomas Adams, M.A. Tempest Anderson, Esq., M.D., B.Sc.
C. W. SIEMENS, Esq., D.C.L., LL.D., F.R.S., F.C.S., M.Inst.C.E. SOUTHAMPTON, August 23, 1882.	The Right Hon. the Lord Mount-Temple Captain Sir F. J. Evans, K.C.B., F.R.S., F.R.A.S., F.R.G.S., Hydrographer to the Admiralty F. A. Abel, Esq., C.B., F.R.S., V.P.C.S., Director of the Chemical Establishment of the War Department Professor De Chaumont, M.D., F.R.S. Major-General A. C. Cooke, R.E., C.B., F.R.G.S., Director-General of the Ordnance Survey. Wyndham S. Portal, Esq. Professor Prestwich, M.A., F.R.S., F.G.S., F.C.S. Philip Lutley Sclater, Esq., M.A., Ph.D., F.R.S., F.L.S., F.G.S.	C. W. A. Jellicoe, Esq. John E. Le Feuvre, Esq. Morris Miles, Esq.
ARTHUR CAYLEY, Esq., M.A., D.C.L., LL.D., F.R.S., V.P.R.A.S., Sadlerian Professor of Pure Mathematics in the University of Cambridge SOUTHPORT, September 19, 1883.	The Right Hon. the Earl of Derby, M.A., LL.D., F.R.S., F.R.G.S. The Right Hon. the Earl of Crawford and Balcarres, LL.D., F.R.S., F.R.A.S. The Right Hon. the Earl of Lathom Principal J. W. Dawson, C.M.G., M.A., LL.D., F.R.S., F.G.S. J. G. Greenwood, Esq., LL.D., Vice-Chancellor of the Victoria University Professor H. E. Roscoe, Ph.D., LL.D., F.R.S., F.C.S.	J. H. Ellis, Esq. Dr. Vernon. T. W. Willis, Esq.
The RIGHT HON. LORD RAYLEIGH, M.A., D.C.L., LL.D., F.R.S., F.R.A.S., F.R.G.S., Professor of Experimental Physics in the University of Cambridge. MONTREAL, August 27, 1884.	His Excellency the Governor-General of Canada, G.C.M.G., LL.D. The Right Hon. Sir John Alexander Macdonald, K.C.B., D.C.L., LL.D. The Right Hon. Sir Lyon Playfair, K.C.B., M.P., Ph.D., LL.D., F.R.S.L. & E., F.C.S. The Hon. Sir Alexander Tilloch Galt, G.C.M.G. The Hon. Sir Charles Tupper, K.C.M.G. Chief Justice Sir A. A. Dorion, C.M.G. Principal Sir William Dawson, C.M.G., M.A., LL.D., F.R.S., F.G.S. The Hon. Dr. Chauveau Professor Edward Frankland, M.D., D.C.L., Ph.D., LL.D., F.R.S., F.C.S. W. H. Hingston, Esq., M.D., D.C.L., L.R.C.S.E. Thomas Sterry Hunt, Esq., M.A., D.Sc., LL.D., F.R.S.	S. E. Dawson, Esq. R. A. Ramsay, Esq. S. Rivard, Esq. S. C. Stevenson, Esq. Thos. White, Esq., M.P.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
The RIGHT HON. SIR LYON PLAYFAIR, K.C.B., M.P., Ph.D., LL.D., F.R.S. L. & E., F.C.S. ABERDEEN, September 9, 1885.	His Grace the Duke of Richmond and Gordon, K.G., D.C.L., Chancellor of the University of Aberdeen The Right Hon. the Earl of Aberdeen, LL.D., Lord-Lieutenant of Aberdeenshire The Right Hon. the Earl of Crawford and Balcarres, M.A., LL.D., F.R.S., F.R.A.S. James Matthews, Esq., Lord Provost of the City of Aberdeen Professor Sir William Thomson, M.A., LL.D., F.R.S. L. & E., F.R.A.S. Alexander Bain, Esq., M.A., LL.D., Rector of the University of Aberdeen The Very Rev. Principal Pirie, D.D., Vice-Chancellor of the University of Aberdeen Professor W. H. Flower, LL.D., F.R.S., F.L.S., Pres. Z.S., F.G.S., Director of the Natural History Museum, London Professor John Struthers, M.D., LL.D.	J. W. Crombie, Esq., M.A. Angus Fraser, Esq., M.A., M.D., F.C.S. Professor G. Pirie, M.A.
SIR J. WILLIAM DAWSON, C.M.G., M.A., LL.D., F.R.S., F.G.S., Principal and Vice-Chancellor of McGill University, Montreal, Canada BIRMINGHAM, September 1, 1886.	The Right Hon. the Earl of Bradford, Lord-Lieutenant of Shropshire. The Right Hon. Lord Leigh, D.C.L., Lord-Lieutenant of Warwickshire. The Right Hon. Lord Norton, K.C.M.G. The Right Hon. Lord Wrottesley, Lord-Lieutenant of Staffordshire The Right Rev. the Lord Bishop of Worcester, D.D. Thomas Martineau, Esq., Mayor of Birmingham Professor G. G. Stokes, M.A., D.C.L., LL.D., Pres. R.S. Professor W. A. Tilden, D.Sc., F.R.S., F.C.S. Rev. A. R. Vardy, M.A. Rev. H. W. Watson, D.Sc., F.R.S.	J. Barham Carslake, Esq. Rev. H. W. Crosskey, LL.D., F.G.S. Charles J. Hart, Esq.

MATHEMATICAL AND PHYSICAL SCIENCES.

COMMITTEE OF SCIENCES, I.—MATHEMATICS AND GENERAL PHYSICS.

Presidents and Secretaries of the Sections of the Association.

Date and Place	Presidents	Secretaries
1832. Oxford	Davies Gilbert, D.C.L., F.R.S.	Rev. H. Coddington.
1833. Cambridge	Sir D. Brewster, F.R.S.	Prof. Forbes.
1834. Edinburgh	Rev. W. Whewell, F.R.S.	Prof. Forbes, Prof. Lloyd.
	SECTION A.—MATHEMATICS AND PHYSICS.	
1835. Dublin	Rev. Dr. Robinson	Prof. Sir W. R. Hamilton, Prof. Wheatstone.
1836. Bristol	Rev. William Whewell, F.R.S.	Prof. Forbes, W. S. Harris, F. W. Jerrard.
1837. Liverpool	Sir D. Brewster, F.R.S.	W. S. Harris, Rev. Prof. Powell, Prof. Stevelly.
1838. Newcastle	Sir J. F. W. Herschel, Bart., F.R.S.	Rev. Prof. Chevallier, Major Sabine, Prof. Stevelly.
1839. Birmingham	Rev. Prof. Whewell, F.R.S.	J. D. Chance, W. Snow Harris, Prof. Stevelly.
1840. Glasgow	Prof. Forbes, F.R.S.	Rev. Dr. Forbes, Prof. Stevelly, Arch. Smith.
1841. Plymouth	Rev. Prof. Lloyd, F.R.S.	Prof. Stevelly.
1842. Manchester	Very Rev. G. Peacock, D.D., F.R.S.	Prof. M'Culloch, Prof. Stevelly, Rev. W. Scoresby.
1843. Cork	Prof. M'Culloch, M.R.I.A.	J. Nott, Prof. Stevelly.
1844. York	The Earl of Rosse, F.R.S.	Rev. Wm. Hey, Prof. Stevelly.
1845. Cambridge	The Very Rev. the Dean of Ely.	Rev. H. Goodwin, Prof. Stevelly, G. G. Stokes.
1846. Southampton.	Sir John F. W. Herschel, Bart., F.R.S.	John Drew, Dr. Stevelly, G. G. Stokes.
1847. Oxford	Rev. Prof. Powell, M.A., F.R.S.	Rev. H. Price, Prof. Stevelly, G. G. Stokes.
1848. Swansea	Lord Wrottesley, F.R.S.	Dr. Stevelly, G. G. Stokes.
1849. Birmingham	William Hopkins, F.R.S.	Prof. Stevelly, G. G. Stokes, W. Ridout Wills.
1850. Edinburgh	Prof. J. D. Forbes, F.R.S., Sec. R.S.E.	W. J. Macquorn Rankine, Prof. Smyth, Prof. Stevelly, Prof. G. G. Stokes.
1851. Ipswich	Rev. W. Whewell, D.D., F.R.S.	S. Jackson, W. J. Macquorn Rankine, Prof. Stevelly, Prof. G. G. Stokes.
1852. Belfast	Prof. W. Thomson, M.A., F.R.S. L. & E.	Prof. Dixon, W. J. Macquorn Rankine, Prof. Stevelly, J. Tyndall.
1853. Hull	The Very Rev. the Dean of Ely, F.R.S.	B. Blaydes Haworth, J. D. Sollitt, Prof. Stevelly, J. Welsh.
1854. Liverpool	Prof. G. G. Stokes, M.A., Sec. R.S.	J. Hartnup, H. G. Puckle, Prof. Stevelly, J. Tyndall, J. Welsh.
1855. Glasgow	Rev. Prof. Kelland, M.A., F.R.S. L. & E.	Rev. Dr. Forbes, Prof. D. Gray, Prof. Tyndall.
1856. Cheltenham	Rev. R. Walker, M.A., F.R.S.	C. Brooke, Rev. T. A. Southwood, Prof. Stevelly, Rev. J. C. Turnbull.
1857. Dublin	Rev. T. R. Robinson, D.D., F.R.S., M.R.I.A.	Prof. Curtis, Prof. Hennessy, P. A. Ninnis, W. J. Macquorn Rankine, Prof. Stevelly.
1858. Leeds	Rev. W. Whewell, D.D., V.P.R.S.	Rev. S. Earnshaw, J. P. Hennessy, Prof. Stevelly, H. J. S. Smith, Prof. Tyndall.
1859. Aberdeen	The Earl of Rosse, M.A., K.P., F.R.S.	J. P. Hennessy, Prof. Maxwell, H. J. S. Smith, Prof. Stevelly.

Date and Place	Presidents	Secretaries
1860. Oxford	Rev. B. Price, M.A., F.R.S.	Rev. G. C. Bell, Rev. T. Rennison, Prof. Stevelly.
1861. Manchester	G. B. Airy, M.A., D.C.L., F.R.S.	Prof. R. B. Clifton, Prof. H. J. S. Smith, Prof. Stevelly.
1862. Cambridge	Prof. G. G. Stokes, M.A., F.R.S.	Prof. R. B. Clifton, Prof. H. J. S. Smith, Prof. Stevelly.
1863. Newcastle	Prof. W. J. Macquorn Rankine, C.E., F.R.S.	Rev. N. Ferrers, Prof. Fuller, F. Jenkin, Prof. Stevelly, Rev. C. T. Whitley.
1864. Bath	Prof. Cayley, M.A., F.R.S., F.R.A.S.	Prof. Fuller, F. Jenkin, Rev. G. Buckle, Prof. Stevelly.
1865. Birmingham	W. Spottiswoode, M.A., F.R.S., F.R.A.S.	Rev. T. N. Hutchinson, F. Jenkin, G. S. Mathews, Prof. H. J. S. Smith, J. M. Wilson.
1866. Nottingham	Prof. Wheatstone, D.C.L., F.R.S.	Fleeming Jenkin, Prof. H. J. S. Smith, Rev. S. N. Swann.
1867. Dundee	Prof. Sir W. Thomson, D.C.L., F.R.S.	Rev. G. Buckle, Prof. G. C. Foster, Prof. Fuller, Prof. Swan.
1868. Norwich	Prof. J. Tyndall, LL.D., F.R.S.	Prof. G. C. Foster, Rev. R. Harley, R. B. Hayward.
1869. Exeter	Prof. J. J. Sylvester, LL.D., F.R.S.	Prof. G. C. Foster, R. B. Hayward, W. K. Clifford.
1870. Liverpool	J. Clerk Maxwell, M.A., LL.D., F.R.S.	Prof. W. G. Adams, W. K. Clifford, Prof. G. C. Foster, Rev. W. Allen Whitworth.
1871. Edinburgh	Prof. P. G. Tait, F.R.S.E.	Prof. W. G. Adams, J. T. Bottomley, Prof. W. K. Clifford, Prof. J. D. Everett, Rev. R. Harley.
1872. Brighton	W. De La Rue, D.C.L., F.R.S.	Prof. W. K. Clifford, J. W. L. Glaisher, Prof. A. S. Herschel, G. F. Rodwell.
1873. Bradford	Prof. H. J. S. Smith, F.R.S.	Prof. W. K. Clifford, Prof. Forbes, J. W. L. Glaisher, Prof. A. S. Herschel.
1874. Belfast	Rev. Prof. J. H. Jellett, M.A., M.R.I.A.	J. W. L. Glaisher, Prof. Herschel, Randal Nixon, J. Perry, G. F. Rodwell.
1875. Bristol	Prof. Balfour Stewart, M.A., LL.D., F.R.S.	Prof. W. F. Barrett, J. W. L. Glaisher, C. T. Hudson, G. F. Rodwell.
1876. Glasgow	Prof. Sir W. Thomson, M.A., D.C.L., F.R.S.	Prof. W. F. Barrett, J. T. Bottomley, Prof. G. Forbes, J. W. L. Glaisher, T. Muir.
1877. Plymouth	Prof. G. C. Foster, B.A., F.R.S., Pres. Physical Soc.	Prof. W. F. Barrett, J. T. Bottomley, J. W. L. Glaisher, F. G. Landon.
1878. Dublin	Rev. Prof. Salmon, D.D., D.C.L., F.R.S.	Prof. J. Casey, G. F. Fitzgerald, J. W. L. Glaisher, Dr. O. J. Lodge.
1879. Sheffield	George Johnstone Stoney, M.A., F.R.S.	A. H. Allen, J. W. L. Glaisher, Dr. O. J. Lodge, D. MacAlister.
1880. Swansea	Prof. W. Grylls Adams, M.A., F.R.S.	W. E. Ayrton, J. W. L. Glaisher, Dr. O. J. Lodge, D. MacAlister.
1881. York	Prof. Sir W. Thomson, M.A., LL.D., D.C.L., F.R.S.	Prof. W. E. Ayrton, Prof. O. J. Lodge, D. MacAlister, Rev. W. Routh.
1882. Southampton.	Rt. Hon. Prof. Lord Rayleigh, M.A., F.R.S.	W. M. Hicks, Prof. O. J. Lodge, D. MacAlister, Rev. G. Richardson.
1883. Southport	Prof. O. Henrici, Ph.D., F.R.S.,	W. M. Hicks, Prof. O. J. Lodge, D. MacAlister, Prof. R. C. Rowe.
1884. Montreal	Prof. Sir W. Thomson, M.A., LL.D., D.C.L., F.R.S	C. Carpmael, W. M. Hicks, Prof. A. Johnson, Prof. O. J. Lodge, Dr. D. MacAlister.
1885. Aberdeen	Prof. G. Chrystal, M.A., F.R.S.E.	R. E. Baynes, R. T. Glazebrook, Prof. W. M. Hicks, Prof. W. Ingram.
1886. Birmingham	Prof. G. H. Darwin, M.A., LL.D., F.R.S.	R. E. Baynes, R. T. Glazebrook, Prof. J. H. Poynting, W. N. Shaw.

CHEMICAL SCIENCE.

COMMITTEE OF SCIENCES, II.—CHEMISTRY, MINERALOGY.

Date and Place	Presidents	Secretaries
1832. Oxford	John Dalton, D.C.L., F.R.S.	James F. W. Johnston.
1833. Cambridge	John Dalton, D.C.L., F.R.S.	Prof. Miller.
1834. Edinburgh	Dr. Hope	Mr. Johnston, Dr Christison.
	SECTION B.—CHEMISTRY AND MINERALOGY.	
1835. Dublin	Dr. T. Thomson, F.R.S.	Dr. Apjohn, Prof. Johnston.
1836. Bristol	Rev. Prof. Cumming	Dr. Apjohn, Dr. C. Henry, W. Herapath.
1837. Liverpool	Michael Faraday, F.R.S.	Prof. Johnston, Prof. Miller, Dr. Reynolds.
1838. Newcastle	Rev. William Whewell, F.R.S.	Prof. Miller, H. L. Pattinson, Thomas Richardson.
1839. Birmingham	Prof. T. Graham, F.R.S.	Dr. Golding Bird, Dr. J. B. Melson.
1840. Glasgow	Dr. Thomas Thomson, F.R.S.	Dr. R. D. Thomson, Dr. T. Clark, Dr. L. Playfair.
1841. Plymouth	Dr. Daubeny, F.R.S.	J. Prideaux, Robert Hunt, W. M. Tweedy.
1842. Manchester	John Dalton, D.C.L., F.R.S.	Dr. L. Playfair, R. Hunt, J. Graham.
1843. Cork	Prof. Apjohn, M.R.I.A.	R. Hunt, Dr. Sweeny.
1844. York	Prof. T. Graham, F.R.S.	Dr. L. Playfair, E. Solly, T. H. Barker.
1845. Cambridge	Rev. Prof. Cumming	R. Hunt, J. P. Joule, Prof. Miller, E. Solly.
1846. Southampton	Michael Faraday, D.C.L., F.R.S.	Dr. Miller, R. Hunt, W. Randall.
1847. Oxford	Rev. W. V. Harcourt, M.A., F.R.S.	B. C. Brodie, R. Hunt, Prof. Solly.
1848. Swansea	Richard Phillips, F.R.S.	T. H. Henry, R. Hunt, T. Williams.
1849. Birmingham	John Percy, M.D., F.R.S.	R. Hunt, G. Shaw.
1850. Edinburgh	Dr. Christison, V.P.R.S.E.	Dr. Anderson, R. Hunt, Dr. Wilson.
1851. Ipswich	Prof. Thomas Graham, F.R.S.	T. J. Pearsall, W. S. Ward.
1852. Belfast	Thomas Andrews, M.D., F.R.S.	Dr. Gladstone, Prof. Hodges, Prof. Ronalds.
1853. Hull	Prof. J. F. W. Johnston, M.A., F.R.S.	H. S. Blundell, Prof. R. Hunt, T. J. Pearsall.
1854. Liverpool	Prof. W. A. Miller, M.D., F.R.S.	Dr. Edwards, Dr. Gladstone, Dr. Price.
1855. Glasgow	Dr. Lyon Playfair, C.B., F.R.S.	Prof. Frankland, Dr. H. E. Roscoe.
1856. Cheltenham	Prof. B. C. Brodie, F.R.S.	J. Horsley, P. J. Worsley, Prof. Voelcker.
1857. Dublin	Prof. Apjohn, M.D., F.R.S., M.R.I.A.	Dr. Davy, Dr. Gladstone, Prof. Sullivan.
1858. Leeds	Sir J. F. W. Herschel, Bart., D.C.L.	Dr. Gladstone, W. Odling, R. Reynolds.
1859. Aberdeen	Dr. Lyon Playfair, C.B., F.R.S.	J. S. Brazier, Dr. Gladstone, G. D. Liveing, Dr. Odling.
1860. Oxford	Prof. B. C. Brodie, F.R.S.	A. Vernon Harcourt, G. D. Liveing, A. B. Northcote.
1861. Manchester	Prof. W. A. Miller, M.D., F.R.S.	A. Vernon Harcourt, G. D. Liveing.
1862. Cambridge	Prof. W. A. Miller, M.D., F.R.S.	H. W. Elphinstone, W. Odling, Prof. Roscoe.
1863. Newcastle	Dr. Alex. W. Williamson, F.R.S.	Prof. Liveing, H. L. Pattinson, J. C. Stevenson.
1864. Bath	W. Odling, M.B., F.R.S., F.C.S.	A. V. Harcourt, Prof. Liveing, R. Biggs.
1865. Birmingham	Prof. W. A. Miller, M.D., V.P.R.S.	A. V. Harcourt, H. Adkins, Prof. Wanklyn, A. Winkler Wills.
1866. Nottingham	H. Bence Jones, M.D., F.R.S.	J. H. Atherton, Prof. Liveing, W. J. Russell, J. White.

Date and Place	Presidents	Secretaries
1867. Dundee	Prof. T. Anderson, M.D., F.R.S.E.	A. Crum Brown, Prof. G. D. Liveing, W. J. Russell.
1868. Norwich	Prof. E. Frankland, F.R.S., F.C.S.	Dr. A. Crum Brown, Dr. W. J. Russell, F. Sutton.
1869. Exeter	Dr. H. Debus, F.R.S., F.C.S.	Prof. A. Crum Brown, Dr. W. J. Russell, Dr. Atkinson.
1870. Liverpool	Prof. H. E. Roscoe, B.A., F.R.S., F.C.S.	Prof. A. Crum Brown, A. E. Fletcher, Dr. W. J. Russell.
1871. Edinburgh	Prof. T. Andrews, M.D., F.R.S.	J. T. Buchanan, W. N. Hartley, T. E. Thorpe.
1872. Brighton	Dr. J. H. Gladstone, F.R.S.	Dr. Mills, W. Chandler Roberts, Dr. W. J. Russell, Dr. T. Wood.
1873. Bradford	Prof. W. J. Russell, F.R.S.	Dr. Armstrong, Dr. Mills, W. Chandler Roberts, Dr. Thorpe.
1874. Belfast	Prof. A. Crum Brown, M.D., F.R.S.E., F.C.S.	Dr. T. Cranstoun Charles, W. Chandler Roberts, Prof. Thorpe.
1875. Bristol	A. G. Vernon Harcourt, M.A., F.R.S., F.C.S.	Dr. H. E. Armstrong, W. Chandler Roberts, W. A. Tilden.
1876. Glasgow	W. H. Perkin, F.R.S.	W. Dittmar, W. Chandler Roberts, J. M. Thomson, W. A. Tilden.
1877. Plymouth	F. A. Abel, F.R.S., F.C.S.	Dr. Oxland, W. Chandler Roberts, J. M. Thomson.
1878. Dublin	Prof. Maxwell Simpson, M.D., F.R.S., F.C.S.	W. Chandler Roberts, J. M. Thomson, Dr. C. R. Tichborne, T. Wills.
1879. Sheffield	Prof. Dewar, M.A., F.R.S.	H. S. Bell, W. Chandler Roberts, J. M. Thomson.
1880. Swansea	Joseph Henry Gilbert, Ph.D., F.R.S.	H. B. Dixon, Dr. W. R. Eaton Hodgkinson, P. Phillips Bedson, J. M. Thomson.
1881. York	Prof. A. W. Williamson, Ph.D., F.R.S.	P. Phillips Bedson, H. B. Dixon, T. Gough.
1882. Southampton.	Prof. G. D. Liveing, M.A., F.R.S.	P. Phillips Bedson, H. B. Dixon, J. L. Notter.
1883. Southport	Dr. J. H. Gladstone, F.R.S.	Prof. P. Phillips Bedson, H. B Dixon, H. For edson, H. .
1884. Montreal	Prof. Sir H. E. Roscoe, Ph.D., LL.D., F.R.S.	Prof. P. Phillips B of. W. B. Dixon, T. McFarlane, Pr H. Pike.
1885. Aberdeen	Prof. H. E. Armstrong, Ph.D., F.R.S., Sec. C.S.	Prof. P. Phillips Bedson, H. B. Dixon, H. Forster Morley, Dr. W. J. Simpson.
1886. Birmingham	W. Crookes, F.R.S., V.P.C.S.	Prof. P. Phillips Bedson, H. B. Dixon, H. Forster Morley, W. W. J. Nicol, C. J. Woodward.

GEOLOGICAL (AND, UNTIL 1851, GEOGRAPHICAL) SCIENCE.

COMMITTEE OF SCIENCES, III.—GEOLOGY AND GEOGRAPHY.

1832. Oxford	R. I. Murchison, F.R.S.	John Taylor.
1833. Cambridge.	G. B. Greenough, F.R.S.	W. Lonsdale, John Phillips.
1834. Edinburgh.	Prof. Jameson	Prof. Phillips, T. Jameson Torrie, Rev. J. Yates.

SECTION C.—GEOLOGY AND GEOGRAPHY.

1835. Dublin	R. J. Griffith	Captain Portlock, T. J. Torrie.
1836. Bristol	Rev. Dr. Buckland, F.R.S.—*Geography*, R. I. Murchison, F.R.S.	William Sanders, S. Stutchbury, T. J. Torrie.
1837. Liverpool	Rev. Prof. Sedgwick, F.R.S.—*Geography*, G. B. Greenough, F.R.S.	Captain Portlock, R. Hunter.—*Geography*, Captain H. M. Denham, R.N.

Date and Place	Presidents	Secretaries
1838. Newcastle...	C. Lyell, F.R.S., V.P.G.S.—*Geography*, Lord Prudhope.	W. C. Trevelyan, Capt. Portlock.—*Geography*, Capt. Washington.
1839. Birmingham	Rev. Dr. Buckland, F.R.S.—*Geography*, G.B. Greenough, F.R.S.	George Lloyd, M.D., H. E. Strickland, Charles Darwin.
1840. Glasgow ...	Charles Lyell, F.R.S.—*Geography*, G. B. Greenough, F.R.S.	W. J. Hamilton, D. Milne, Hugh Murray, H. E. Strickland, John Scoular, M.D.
1841. Plymouth...	H. T. De la Beche, F.R.S. ...	W. J. Hamilton, Edward Moore, M.D., R. Hutton.
1842. Manchester	R. I. Murchison, F.R.S.	E. W. Binney, R. Hutton, Dr. R. Lloyd, H. E. Strickland.
1843. Cork.........	Richard E. Griffith, F.R.S., M.R.I.A.	Francis M. Jennings, H. E. Strickland.
1844. York.........	Henry Warburton, M.P., Pres. Geol. Soc.	Prof. Ansted, E. H. Bunbury.
1845. Cambridge.	Rev. Prof. Sedgwick, M.A., F.R.S.	Rev. J. C. Cumming, A. C. Ramsay, Rev. W. Thorp.
1846. Southampton.	Leonard Horner, F.R.S.—*Geography*, G. B. Greenough, F.R.S.	Robert A. Austen, Dr. J. H. Norton, Prof. Oldham.—*Geography*, Dr. C. T. Beke.
1847. Oxford......	Very Rev. Dr. Buckland, F.R.S.	Prof. Ansted, Prof. Oldham, A. C. Ramsay, J. Ruskin.
1848. Swansea ...	Sir H. T. De la Beche, C.B., F.R.S.	Starling Benson, Prof. Oldham, Prof. Ramsay.
1849. Birmingham	Sir Charles Lyell, F.R.S., F.G.S.	J. Beete Jukes, Prof. Oldham, Prof. A. C. Ramsay.
1850. Edinburgh[1]	Sir Roderick I. Murchison, F.R.S.	A. Keith Johnston, Hugh Miller, Prof. Nicol.

SECTION C (*continued*).—GEOLOGY.

Date and Place	Presidents	Secretaries
1851. Ipswich ...	William Hopkins, M.A., F.R.S.	C. J. F. Bunbury, G. W. Ormerod, Searles Wood.
1852. Belfast......	Lieut.-Col. Portlock, R.E., F.R.S.	James Bryce, James MacAdam, Prof. M'Coy, Prof. Nicol.
1853. Hull.........	Prof. Sedgwick, F.R.S.........	Prof. Harkness, William Lawton.
1854. Liverpool..	Prof. Edward Forbes, F.R.S.	John Cunningham, Prof. Harkness, G. W. Ormerod, J. W. Woodall.
1855. Glasgow ...	Sir R. I. Murchison, F.R.S....	James Bryce, Prof. Harkness, Prof. Nicol.
1856. Cheltenham	Prof. A. C. Ramsay, F.R.S....	Rev. P. B. Brodie, Rev. R. Hepworth, Edward Hull, J. Scougall, T. Wright.
1857. Dublin	The Lord Talbot de Malahide	Prof. Harkness, Gilbert Sanders, Robert H. Scott.
1858. Leeds	William Hopkins, M.A., LL.D., F.R.S.	Prof. Nicol, H. C. Sorby, E. W. Shaw.
1859. Aberdeen...	Sir Charles Lyell, LL.D., D.C.L., F.R.S.	Prof. Harkness, Rev. J. Longmuir, H. C. Sorby.
1860. Oxford	Rev. Prof. Sedgwick, LL.D., F.R.S., F.G.S.	Prof. Harkness, Edward Hull, Capt. D. C. L. Woodall.
1861. Manchester	Sir R. I. Murchison, D.C.L., LL.D., F.R.S.	Prof. Harkness, Edward Hull, T. Rupert Jones, G. W. Ormerod.
1862. Cambridge	J. Beete Jukes, M.A., F.R.S.	Lucas Barrett, Prof. T. Rupert Jones, H. C. Sorby.

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[1] At a meeting of the General Committee held in 1850, it was resolved 'That the subject of Geography be separated from Geology and combined with Ethnology, to constitute a separate Section, under the title of the "Geographical and Ethnological Section,"' for Presidents and Secretaries of which see page lii.

Date and Place	Presidents	Secretaries
1863. Newcastle	Prof. Warington W. Smyth, F.R.S., F.G.S.	E. F. Boyd, John Daglish, H. C. Sorby, Thomas Sopwith.
1864. Bath.........	Prof. J. Phillips, LL.D., F.R.S., F.G.S.	W. B. Dawkins, J. Johnston, H. C. Sorby, W. Pengelly.
1865. Birmingham	Sir R. I. Murchison, Bart., K.C.B.	Rev. P. B. Brodie, J. Jones, Rev. E. Myers, H. C. Sorby, W. Pengelly.
1866. Nottingham	Prof. A. C. Ramsay, LL.D., F.R.S.	R. Etheridge, W. Pengelly, T. Wilson, G. H. Wright.
1867. Dundee ...	Archibald Geikie, F.R.S., F.G.S.	Edward Hull, W. Pengelly, Henry Woodward.
1868. Norwich ...	R. A. C. Godwin-Austen, F.R.S., F.G.S.	Rev. O. Fisher, Rev. J. Gunn, W. Pengelly, Rev. H. H. Winwood.
1869. Exeter	Prof. R. Harkness, F.R.S., F.G.S.	W. Pengelly, W. Boyd Dawkins, Rev. H. H. Winwood.
1870. Liverpool...	Sir Philip de M.Grey Egerton, Bart., M.P., F.R.S.	W. Pengelly, Rev. H. H. Winwood, W. Boyd Dawkins, G. H. Morton.
1871. Edinburgh	Prof. A. Geikie, F.R.S., F.G.S.	R. Etheridge, J. Geikie, T. McKenny Hughes, L. C. Miall.
1872. Brighton...	R. A. C. Godwin-Austen, F.R.S., F.G.S.	L. C. Miall, George Scott, William Topley, Henry Woodward.
1873. Bradford...	Prof. J. Phillips, D.C.L., F.R.S., F.G.S.	L. C. Miall, R. H. Tiddeman, W. Topley.
1874. Belfast......	Prof. Hull, M.A., F.R.S., F.G.S.	F. Drew, L. C. Miall, R. G. Symes, R. H. Tiddeman.
1875. Bristol......	Dr. Thomas Wright, F.R.S.E., F.G.S.	L. C. Miall, E. B. Tawney, W. Topley.
1876. Glasgow ...	Prof. John Young, M.D.	J. Armstrong, F. W. Rudler, W. Topley.
1877. Plymouth...	W. Pengelly, F.R.S............	Dr. Le Neve Foster, R. H. Tiddeman, W. Topley.
1878. Dublin......	John Evans, D.C.L., F.R.S., F.S.A., F.G.S.	E. T. Hardman, Prof. J. O'Reilly, R. H. Tiddeman.
1879. Sheffield ...	Prof. P. Martin Duncan, M.B., F.R.S., F.G.S.	W. Topley, G. Blake Walker.
1880. Swansea ...	H. C. Sorby, LL.D., F.R.S., F.G.S.	W. Topley, W. Whitaker.
1881. York.........	A. C. Ramsay, LL.D., F.R.S., F.G.S.	J. E. Clark, W. Keeping, W. Topley, W. Whitaker.
1882. Southampton.	R. Etheridge, F.R.S., F.G.S.	T. W. Shore, W. Topley, E. Westlake, W. Whitaker.
1883. Southport	Prof. W. C. Williamson, LL.D., F.R.S.	R. Betley, C. E. De Rance, W. Topley, W. Whitaker.
1884. Montreal ...	W. T. Blanford, F.R.S., Sec. G.S.	F. Adams, Prof. E. W. Claypole, W. Topley, W. Whitaker.
1885. Aberdeen...	Prof. J. W. Judd, F.R.S., Sec. G.S.	C. E. De Rance, J. Horne, J. J. H Teall, W. Topley.
1886. Birmingham	Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S.	W. J. Harrison, J. J. H. Teall, W. Topley, W. W. Watts.

BIOLOGICAL SCIENCES.

COMMITTEE OF SCIENCES, IV.—ZOOLOGY, BOTANY, PHYSIOLOGY, ANATOMY.

1832. Oxford......	Rev. P. B. Duncan, F.G.S. ...	Rev. Prof. J. S. Henslow.
1833. Cambridge[1]	Rev. W. L. P. Garnons, F.L.S.	C. C. Babington, D. Don.
1834. Edinburgh.	Prof. Graham....................	W. Yarrell, Prof. Burnett.

[1] At this Meeting Physiology and Anatomy were made a separate Committee, for Presidents and Secretaries of which see p. li.

SECTION D.—ZOOLOGY AND BOTANY.

Date and Place	Presidents	Secretaries
1835. Dublin	Dr. Allman	J. Curtis, Dr. Litton.
1836. Bristol	Rev. Prof. Henslow	J. Curtis, Prof. Don, Dr. Riley, S. Rootsey.
1837. Liverpool	W. S. MacLeay	C. C. Babington, Rev. L. Jenyns, W. Swainson.
1838. Newcastle	Sir W. Jardine, Bart.	J. E. Gray, Prof. Jones, R. Owen, Dr. Richardson.
1839. Birmingham	Prof. Owen, F.R.S.	E. Forbes, W. Ick, R. Patterson.
1840. Glasgow	Sir W. J. Hooker, LL.D.	Prof. W. Couper, E. Forbes, R. Patterson.
1841. Plymouth	John Richardson, M.D., F.R.S.	J. Couch, Dr. Lankester, R. Patterson.
1842. Manchester	Hon. and Very Rev. W. Herbert, LL.D., F.L.S.	Dr. Lankester, R. Patterson, J. A. Turner.
1843. Cork	William Thompson, F.L.S.	G. J. Allman, Dr. Lankester, R. Patterson.
1844. York	Very Rev. the Dean of Manchester.	Prof. Allman, H. Goodsir, Dr. King, Dr. Lankester.
1845. Cambridge	Rev. Prof. Henslow, F.L.S.	Dr. Lankester, T. V. Wollaston.
1846. Southampton.	Sir J. Richardson, M.D., F.R.S.	Dr. Lankester, T. V. Wollaston, H. Wooldridge.
1847. Oxford	H. E. Strickland, M.A., F.R.S.	Dr. Lankester, Dr. Melville, T. V. Wollaston.

SECTION D (*continued*).—ZOOLOGY AND BOTANY, INCLUDING PHYSIOLOGY.

[For the Presidents and Secretaries of the Anatomical and Physiological Subsections and the temporary Section E of Anatomy and Medicine, see p. li.]

1848. Swansea	L. W. Dillwyn, F.R.S.	Dr. R. Wilbraham Falconer, A. Henfrey, Dr. Lankester.
1849. Birmingham	William Spence, F.R.S.	Dr. Lankester, Dr. Russell.
1850. Edinburgh	Prof. Goodsir, F.R.S. L. & E.	Prof. J. H. Bennett, M.D., Dr. Lankester, Dr. Douglas Maclagan.
1851. Ipswich	Rev. Prof. Henslow, M.A., F.R.S.	Prof. Allman, F. W. Johnston, Dr. E. Lankester.
1852. Belfast	W. Ogilby	Dr. Dickie, George C. Hyndman, Dr. Edwin Lankester.
1853. Hull	C. C. Babington, M.A., F.R.S.	Robert Harrison, Dr. E. Lankester.
1854. Liverpool	Prof. Balfour, M.D., F.R.S.	Isaac Byerley, Dr. E. Lankester.
1855. Glasgow	Rev. Dr. Fleeming, F.R.S.E.	William Keddie, Dr. Lankester.
1856. Cheltenham	Thomas Bell, F.R.S., Pres.L.S.	Dr. J. Abercrombie, Prof. Buckman, Dr. Lankester.
1857. Dublin	Prof. W. H. Harvey, M.D., F.R.S.	Prof. J. R. Kinahan, Dr. E. Lankester, Robert Patterson, Dr. W. E. Steele.
1858. Leeds	C. C. Babington, M.A., F.R.S.	Henry Denny, Dr. Heaton, Dr. E. Lankester, Dr. E. Perceval Wright.
1859. Aberdeen	Sir W. Jardine, Bart., F.R.S.E.	Prof. Dickie, M.D., Dr. E. Lankester, Dr. Ogilvy.
1860. Oxford	Rev. Prof. Henslow, F.L.S.	W. S. Church, Dr. E. Lankester, P. L. Sclater, Dr. E. Perceval Wright.
1861. Manchester	Prof. C. C. Babington, F.R.S.	Dr. T. Alcock, Dr. E. Lankester, Dr. P. L. Sclater, Dr. E. P. Wright.
1862. Cambridge	Prof. Huxley, F.R.S.	Alfred Newton, Dr. E. P. Wright.
1863. Newcastle	Prof. Balfour, M.D., F.R.S.	Dr. E. Charlton, A. Newton, Rev. H. B. Tristram, Dr. E. P. Wright.
1864. Bath	Dr. John E. Gray, F.R.S.	H. B. Brady, C. E. Broom, H. T. Stainton, Dr. E. P. Wright.
1865. Birmingham	T. Thomson, M.D., F.R.S.	Dr. J. Anthony, Rev. C. Clarke, Rev. H. B. Tristram, Dr. E. P. Wright.

SECTION D (*continued*).—BIOLOGY.[1]

Date and Place	Presidents	Secretaries
1866. Nottingham	Prof. Huxley, LL.D., F.R.S. —*Physiological Dep.*, Prof. Humphry, M.D., F.R.S.—*Anthropological Dep.*, Alf. R. Wallace, F.R.G.S.	Dr. J. Beddard, W. Felkin, Rev. H. B. Tristram, W. Turner, E. B. Tylor, Dr. E. P. Wright.
1867. Dundee ...	Prof. Sharpey, M.D., Sec. R.S. —*Dep. of Zool. and Bot.*, George Busk, M.D., F.R.S.	C. Spence Bate, Dr. S. Cobbold, Dr. M. Foster, H. T. Stainton, Rev. H. B. Tristram, Prof. W. Turner.
1868. Norwich ...	Rev. M. J. Berkeley, F.L.S. —*Dep. of Physiology*, W. H. Flower, F.R.S.	Dr. T. S. Cobbold, G. W. Firth, Dr. M. Foster, Prof. Lawson, H. T. Stainton, Rev. Dr. H. B. Tristram, Dr. E. P. Wright.
1869. Exeter	George Busk, F.R.S., F.L.S. —*Dep. of Bot. and Zool.*, C. Spence Bate, F.R.S.—*Dep. of Ethno.*, E. B. Tylor.	Dr. T. S. Cobbold, Prof. M. Foster, E. Ray Lankester, Prof. Lawson, H. T Stainton, Rev. H. B. Tristram.
1870. Liverpool...	Prof. G. Rolleston, M.A., M.D., F.R.S., F.L.S.—*Dep. of Anat. and Physiol.*, Prof. M. Foster, M.D., F.L.S.—*Dep. of Ethno.*, J. Evans, F.R.S.	Dr. T. S. Cobbold, Sebastian Evans, Prof. Lawson, Thos. J. Moore, H. T. Stainton, Rev. H. B. Tristram, C. Staniland Wake, E. Ray Lankester.
1871. Edinburgh	Prof. Allen Thomson, M.D., F.R.S.—*Dep. of Bot. and Zool.*, Prof. Wyville Thomson, F.R.S.—*Dep. of Anthropol.*, Prof. W. Turner, M.D.	Dr. T. R. Fraser, Dr. Arthur Gamgee, E. Ray Lankester, Prof. Lawson, H. T. Stainton, C. Staniland Wake, Dr. W. Rutherford, Dr. Kelburne King.
1872. Brighton ...	Sir J. Lubbock, Bart., F.R.S.—*Dep. of Anat. and Physiol.*, Dr. Burdon Sanderson, F.R.S.—*Dep. of Anthropol.*, Col. A. Lane Fox, F.G.S.	Prof. Thiselton-Dyer, H. T. Stainton, Prof. Lawson, F. W. Rudler, J. H. Lamprey, Dr. Gamgee, E. Ray Lankester, Dr. Pye-Smith.
1873. Bradford ...	Prof. Allman, F.R.S.—*Dep. of Anat. and Physiol.*, Prof. Rutherford, M.D.—*Dep. of Anthropol.*, Dr. Beddoe, F.R.S.	Prof. Thiselton-Dyer, Prof. Lawson, R. M'Lachlan, Dr. Pye-Smith, E. Ray Lankester, F. W. Rudler, J. H. Lamprey.
1874. Belfast	Prof. Redfern, M.D.—*Dep. of Zool. and Bot.*, Dr. Hooker, C.B., Pres. R.S.—*Dep. of Anthrop.*, Sir W. R. Wilde, M.D.	W. T. Thiselton-Dyer, R. O. Cunningham, Dr. J. J. Charles, Dr. P. H. Pye-Smith, J. J. Murphy, F. W. Rudler.
1875. Bristol	P. L. Sclater, F.R.S.—*Dep. of Anat. and Physiol.*, Prof. Cleland, M.D., F.R.S.—*Dep. of Anthropol.*, Prof. Rolleston, M.D., F.R.S.	E. R. Alston, Dr. McKendrick, Prof. W. R. M'Nab, Dr. Martyn, F. W. Rudler, Dr. P. H. Pye-Smith, Dr. W. Spencer.
1876. Glasgow ...	A. Russel Wallace, F.R.G.S., F.L.S.—*Dep. of Zool. and Bot.*, Prof. A. Newton, M.A., F.R.S.—*Dep. of Anat. and Physiol.*, Dr. J. G. McKendrick, F.R.S.E.	E. R. Alston, Hyde Clarke, Dr. Knox, Prof. W. R. M'Nab, Dr. Muirhead, Prof. Morrison Watson.
1877. Plymouth...	J. Gwyn Jeffreys, LL.D., F.R.S., F.L.S.—*Dep. of Anat. and Physiol.*, Prof. Macalister, M.D.—*Dep. of Anthropol.*, Francis Galton, M.A., F.R.S.	E. R. Alston, F. Brent, Dr. D. J. Cunningham, Dr. C. A. Hingston, Prof. W. R. M'Nab, J. B. Rowe, F. W. Rudler.

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[1] At a meeting of the General Committee in 1865, it was resolved:—'That the title of Section D be changed to Biology;' and 'That for the word "Subsection," in the rules for conducting the business of the Sections, the word "Department" be substituted.'

Date and Place	Presidents	Secretaries
1878. Dublin	Prof. W. H. Flower, F.R.S.—*Dep. of Anthropol.*, Prof. Huxley, Sec. R.S.—*Dep. of Anat. and Physiol.*, R. McDonnell, M.D., F.R.S.	Dr. R. J. Harvey, Dr. T. Hayden, Prof. W. R. M'Nab, Prof. J. M. Purser, J. B. Rowe, F. W. Rudler.
1879. Sheffield ...	Prof. St. George Mivart, F.R.S.—*Dep. of Anthropol.*, E. B. Tylor, D.C.L., F.R.S. —*Dep. of Anat. and Physiol.*, Dr. Pye-Smith.	Arthur Jackson, Prof. W. R. M'Nab, J. B. Rowe, F. W. Rudler, Prof. Schäfer.
1880. Swansea ...	A. C. L. Günther, M.D., F.R.S. —*Dep. of Anat. and Physiol.*, F. M. Balfour, M.A., F.R.S.—*Dep. of Anthropol.*, F. W. Rudler, F.G.S.	G. W. Bloxam, John Priestley, Howard Saunders, Adam Sedgwick.
1881. York.........	Richard Owen, C.B., M.D., F.R.S.—*Dep. of Anthropol.*, Prof. W. H. Flower, LL.D., F.R.S.—*Dep. of Anat. and Physiol.*, Prof. J. S. Burdon Sanderson, M.D., F.R.S.	G. W. Bloxam, W. A. Forbes, Rev. W. C. Hey, Prof. W. R. M'Nab, W. North, John Priestley, Howard Saunders, H. E. Spencer.
1882. Southampton.	Prof. A. Gamgee, M.D., F.R.S. —*Dep. of Zool. and Bot.*, Prof. M. A. Lawson, M.A., F.L.S.—*Dep. of Anthropol.*, Prof. W. Boyd Dawkins, M.A., F.R.S.	G. W. Bloxam, W. Heape, J. B. Nias, Howard Saunders, A. Sedgwick, T. W. Shore, jun.
1883. Southport[1]	Prof. E. Ray Lankester, M.A., F.R.S.—*Dep. of Anthropol.*, W. Pengelly, F.R.S.	G. W. Bloxam, Dr. G. J. Haslam, W. Heape, W. Hurst, Prof. A. M. Marshall, Howard Saunders, Dr. G. A. Woods.
1884. Montreal[2]...	Prof. H. N. Moseley, M.A., F.R.S.	Prof. W. Osler, Howard Saunders, A. Sedgwick, Prof. R. R. Wright.
1885. Aberdeen ...	Prof. W. C. McIntosh, M.D., LL.D., F.R.S. L. & E.	W. Heape, J. McGregor-Robertson, J. Duncan Matthews, Howard Saunders, H. Marshall Ward.
1886. Birmingham	W. Carruthers, Pres. L.S., F.R.S., F.G.S.	Prof. T. W. Bridge, W. Heape, Prof. W. Hillhouse, W. L. Sclater, Prof. H. Marshall Ward.

ANATOMICAL AND PHYSIOLOGICAL SCIENCES.

COMMITTEE OF SCIENCES, V.—ANATOMY AND PHYSIOLOGY.

1833. Cambridge	Dr. Haviland	Dr. Bond, Mr. Paget.
1834. Edinburgh	Dr. Abercrombie	Dr. Roget, Dr. William Thomson.

SECTION E (UNTIL 1847).—ANATOMY AND MEDICINE.

1835. Dublin	Dr. Pritchard.....................	Dr. Harrison, Dr. Hart.
1836. Bristol	Dr. Roget, F.R.S.	Dr. Symonds.
1837. Liverpool...	Prof. W. Clark, M.D.	Dr. J. Carson, jun., James Long, Dr. J. R. W. Vose.
1838. Newcastle	T. E. Headlam, M.D.	T. M. Greenhow, Dr. J. R. W. Vose.
1839. Birmingham	John Yelloly, M.D., F.R.S....	Dr. G. O. Rees, F. Ryland.
1840. Glasgow ...	James Watson, M.D.	Dr. J. Brown, Prof. Couper, Prof. Reid.

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[1] By direction of the General Committee at Southampton (1882) the Departments of Zoology and Botany and of Anatomy and Physiology were amalgamated.

[2] By authority of the General Committee, Anthropology was made a separate Section, for Presidents and Secretaries of which see p. lvii.

SECTION E.—PHYSIOLOGY.

Date and Place	Presidents	Secretaries
1841. Plymouth ...	P. M. Roget, M.D., Sec. R.S.	Dr. J. Butter, J. Fuge, Dr. R. S. Sargent.
1842. Manchester	Edward Holme, M.D., F.L.S.	Dr. Chaytor, Dr. R. S. Sargent.
1843. Cork	Sir James Pitcairn, M.D. ...	Dr. John Popham, Dr. R. S. Sargent.
1844 York	J. C. Pritchard, M.D.	I. Erichsen, Dr. R. S. Sargent.
1845. Cambridge	Prof. J. Haviland, M.D.	Dr. R. S. Sargent, Dr. Webster.
1846. Southampton.	Prof. Owen, M.D., F.R.S. ...	C. P. Keele, Dr. Laycock, Dr. Sargent.
1847. Oxford[1] ...	Prof. Ogle, M.D., F.R.S.	Dr. Thomas K. Chambers, W. P. Ormerod.

PHYSIOLOGICAL SUBSECTIONS OF SECTION D.

1850. Edinburgh	Prof. Bennett, M.D., F.R.S.E.	
1855. Glasgow ...	Prof. Allen Thomson, F.R.S.	Prof. J. H. Corbett, Dr. J. Struthers.
1857. Dublin......	Prof. R. Harrison, M.D.	Dr. R. D. Lyons, Prof. Redfern.
1858. Leeds	Sir Benjamin Brodie, Bart., F.R.S.	C. G. Wheelhouse.
1859. Aberdeen...	Prof. Sharpey, M.D., Sec. R.S.	Prof. Bennett, Prof. Redfern.
1860. Oxford......	Prof. G. Rolleston, M.D., F.L.S.	Dr. R. M'Donnell, Dr. Edward Smith.
1861. Manchester	Dr. John Davy, F.R.S.L. & E.	Dr. W. Roberts, Dr. Edward Smith.
1862. Cambridge	G. E. Paget, M.D...............	G. F. Helm, Dr. Edward Smith.
1863. Newcastle	Prof. Rolleston, M.D., F.R.S.	Dr. D. Embleton, Dr. W. Turner.
1864. Bath.........	Dr. Edward Smith, LL.D., F.R.S.	J. S. Bartrum, Dr. W. Turner.
1865. Birmingham.[2]	Prof. Acland, M.D., LL.D., F.R.S.	Dr. A. Fleming, Dr. P. Heslop, Oliver Pembleton, Dr. W. Turner.

GEOGRAPHICAL AND ETHNOLOGICAL SCIENCES.

[For Presidents and Secretaries for Geography previous to 1851, see Section C, p. xlvi.]

ETHNOLOGICAL SUBSECTIONS OF SECTION D.

1846. Southampton	Dr. Pritchard.....................	Dr. King.
1847. Oxford......	Prof. H. H. Wilson, M.A. ...	Prof. Buckley.
1848. Swansea ...	....	G. Grant Francis.
1849. Birmingham	....	Dr. R. G. Latham.
1850. Edinburgh	Vice-Admiral Sir A. Malcolm	Daniel Wilson.

SECTION E.—GEOGRAPHY AND ETHNOLOGY.

1851. Ipswich ...	Sir R. I. Murchison, F.R.S., Pres. R.G.S.	R. Cull, Rev. J. W. Donaldson, Dr. Norton Shaw.
1852. Belfast......	Col. Chesney, R.A., D.C.L., F.R.S.	R. Cull, R. MacAdam, Dr. Norton Shaw.
1853. Hull.........	R. G. Latham, M.D., F.R.S.	R. Cull, Rev. H. W. Kemp, Dr. Norton Shaw.
1854. Liverpool...	Sir R. I. Murchison, D.C.L., F.R.S.	Richard Cull, Rev. H. Higgins, Dr. Ihne, Dr. Norton Shaw.
1855. Glasgow ...	Sir J. Richardson, M.D., F.R.S.	Dr. W. G. Blackie, R. Cull, Dr. Norton Shaw.
1856. Cheltenham	Col. Sir H. C. Rawlinson, K.C.B.	R. Cull, F. D. Hartland, W. H. Rumsey, Dr. Norton Shaw.
1857. Dublin......	Rev. Dr. J. Henthorn Todd, Pres. R.I.A.	R. Cull, S. Ferguson, Dr. R. R. Madden, Dr. Norton Shaw.

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[1] By direction of the General Committee at Oxford, Sections D and E were incorporated under the name of 'Section D—Zoology and Botany, including Physiology' (see p. xlix). The Section being then vacant was assigned in 1851 to Geography.

[2] *Vide* note on page l.

Date and Place	Presidents	Secretaries
1858. Leeds	Sir R. I. Murchison, G.C.St.S., F.R.S.	R. Cull, Francis Galton, P. O'Callaghan, Dr. Norton Shaw, Thomas Wright.
1859. Aberdeen...	Rear - Admiral Sir James Clerk Ross, D.C.L., F.R.S.	Richard Cull, Prof. Geddes, Dr. Norton Shaw.
1860. Oxford......	Sir R. I. Murchison, D.C.L., F.R.S.	Capt. Burrows, Dr. J. Hunt, Dr. C. Lemprière, Dr. Norton Shaw.
1861. Manchester	John Crawfurd, F.R.S.........	Dr. J. Hunt, J. Kingsley, Dr. Norton Shaw, W. Spottiswoode.
1862. Cambridge	Francis Galton, F.R.S.........	J.W.Clarke, Rev. J. Glover, Dr. Hunt, Dr. Norton Shaw, T. Wright.
1863. Newcastle	Sir R. I. Murchison, K.C.B., F.R.S.	C. Carter Blake, Hume Greenfield, C. R. Markham, R. S. Watson.
1864. Bath.........	Sir R. I. Murchison, K.C.B., F.R.S.	H. W. Bates, C. R. Markham, Capt. R. M. Murchison, T. Wright.
1865. Birmingham	Major-General Sir H. Rawlinson, M.P., K.C.B., F.R.S.	H. W. Bates, S. Evans, G. Jabet, C. R. Markham, Thomas Wright.
1866. Nottingham	Sir Charles Nicholson, Bart., LL.D.	H. W. Bates, Rev. E. T. Cusins, R. H. Major, Clements R. Markham, D. W. Nash, T. Wright.
1867. Dundee ...	Sir Samuel Baker, F.R.G.S.	H. W. Bates, Cyril Graham, Clements R. Markham, S. J. Mackie, R. Sturrock.
1868. Norwich ...	Capt. G. H. Richards, R.N., F.R.S.	T. Baines, H. W. Bates, Clements R Markham, T. Wright.

SECTION E (*continued*).—GEOGRAPHY.

Date and Place	Presidents	Secretaries
1869. Exeter......	Sir Bartle Frere, K.C.B., LL.D., F.R.G.S.	H. W. Bates, Clements R. Markham, J. H. Thomas.
1870. Liverpool...	Sir R. I. Murchison, Bt., K.C.B., LL.D., D.C.L., F.R.S., F.G.S.	H.W.Bates, David Buxton, Albert J. Mott, Clements R. Markham.
1871. Edinburgh	Colonel Yule, C.B., F.R.G.S.	A. Buchan, A. Keith Johnston, Clements R. Markham, J. H. Thomas.
1872. Brighton ...	Francis Galton, F.R.S.........	H. W. Bates, A. Keith Johnston, Rev. J. Newton, J. H. Thomas.
1873. Bradford ...	Sir Rutherford Alcock, K.C.B.	H. W. Bates, A. Keith Johnston, Clements R. Markham.
1874. Belfast......	Major Wilson, R.E., F.R.S., F.R.G.S.	E. G. Ravenstein, E. C. Rye, J. H. Thomas.
1875. Bristol......	Lieut. - General Strachey, R.E., C.S.I., F.R.S., F.R.G.S., F.L.S., F.G.S.	H. W. Bates, E. C. Rye, F. F. Tuckett.
1876. Glasgow ...	Capt. Evans, C.B., F.R.S.......	H. W. Bates, E. C. Rye, R. Oliphant Wood.
1877. Plymouth...	Adm. Sir E. Ommanney, C.B., F.R.S., F.R.G.S., F.R.A.S.	H. W. Bates, F. E. Fox, E. C. Rye.
1878. Dublin......	Prof. Sir C. Wyville Thomson, LL.D., F.R.S.L.&E.	John Coles, E. C. Rye.
1879. Sheffield ...	Clements R. Markham, C.B., F.R.S., Sec. R.G.S.	H. W. Bates, C. E. D. Black, E. C. Rye.
1880. Swansea ...	Lieut.-Gen. Sir J. H. Lefroy, C.B., K.C.M.G., R.A., F.R.S., F.R.G.S.	H. W. Bates, E. C. Rye.
1881. York.........	Sir J. D. Hooker, K.C.S.I., C.B., F.R.S.	J. W. Barry, H. W. Bates.
1882. Southampton.	Sir R. Temple, Bart., G.C.S.I., F.R.G.S.	E. G. Ravenstein, E. C. Rye.
1883. Southport	Lieut.-Col. H. H. Godwin-Austen, F.R.S.	John Coles, E. G. Ravenstein, E. C. Rye.

Date and Place	Presidents	Secretaries
1884. Montreal ...	Gen. Sir J. H. Lefroy, C.B., K.C.M.G., F.R.S., V.P.R.G.S.	Rev. Abbé Laflamme, J. S. O'Halloran, E. G. Ravenstein, J. F. Torrance
1885. Aberdeen...	Gen. J. T. Walker, C.B., R.E., LL.D., F.R.S.	J. S. Keltie, J. S. O'Halloran, E. G. Ravenstein, Rev. G. A. Smith.
1886. Birmingham	Maj.-Gen. Sir. F. J. Goldsmid, K.C.S.I., C.B., F.R.G.S.	F. T. S. Houghton, J. S. Keltie, E. G. Ravenstein.

STATISTICAL SCIENCE.

COMMITTEE OF SCIENCES, VI.—STATISTICS.

1833. Cambridge	Prof. Babbage, F.R.S.	J. E. Drinkwater.
1834. Edinburgh	Sir Charles Lemon, Bart.......	Dr. Cleland, C. Hope Maclean.

SECTION F.—STATISTICS.

1835. Dublin	Charles Babbage, F.R.S.	W. Greg, Prof. Longfield.
1836. Bristol	Sir Chas. Lemon, Bart., F.R.S.	Rev. J. E. Bromby, C. B. Fripp, James Heywood.
1837. Liverpool...	Rt. Hon. Lord Sandon	W. R. Greg, W. Langton, Dr. W. C. Tayler.
1838. Newcastle	Colonel Sykes, F.R.S.	W. Cargill, J. Heywood, W. R. Wood.
1839. Birmingham	Henry Hallam, F.R.S.	F. Clarke, R. W. Rawson, Dr. W. C. Tayler.
1840. Glasgow ...	Rt. Hon. Lord Sandon, M.P., F.R.S.	C. R. Baird, Prof. Ramsay, R. W. Rawson.
1841. Plymouth...	Lieut.-Col. Sykes, F.R.S.......	Rev. Dr. Byrth, Rev. R. Luney, R. W. Rawson.
1842. Manchester	G. W. Wood, M.P., F.L.S. ...	Rev. R. Luney, G. W. Ormerod, Dr. W. C. Tayler.
1843. Cork	Sir C. Lemon, Bart., M.P. ...	Dr. D. Bullen, Dr. W. Cooke Tayler.
1844. York	Lieut.-Col. Sykes, F.R.S., F.L.S.	J. Fletcher, J. Heywood, Dr. Laycock.
1845. Cambridge	Rt. Hon. the Earl Fitzwilliam	J. Fletcher, Dr. W. Cooke Tayler.
1846. Southampton.	G. R. Porter, F.R.S.	J. Fletcher, F. G. P. Neison, Dr. W. C. Tayler, Rev. T. L. Shapcott.
1847. Oxford	Travers Twiss, D.C.L., F.R.S.	Rev. W. H. Cox, J. J. Danson, F. G. P. Neison.
1848. Swansea ...	J. H. Vivian, M.P., F.R.S. ...	J. Fletcher, Capt. R. Shortrede.
1849. Birmingham	Rt. Hon. Lord Lyttelton......	Dr. Finch, Prof. Hancock, F. G. P. Neison.
1850. Edinburgh	Very Rev. Dr. John Lee, V.P.R.S.E.	Prof. Hancock, J. Fletcher, Dr. J. Stark.
1851. Ipswich ...	Sir John P. Boileau, Bart. ...	J. Fletcher, Prof. Hancock.
1852. Belfast......	His Grace the Archbishop of Dublin.	Prof. Hancock, Prof. Ingram, James MacAdam, jun.
1853. Hull	James Heywood, M.P., F.R.S.	Edward Cheshire, W. Newmarch.
1854. Liverpool...	Thomas Tooke, F.R.S.	E. Cheshire, J. T. Danson, Dr. W. H. Duncan, W. Newmarch.
1855. Glasgow ...	R. Monckton Milnes, M.P. ...	J. A. Campbell, E. Cheshire, W. Newmarch, Prof. R. H. Walsh.

SECTION F (*continued*).—ECONOMIC SCIENCE AND STATISTICS.

1856. Cheltenham	Rt. Hon. Lord Stanley, M.P.	Rev. C. H. Bromby, E. Cheshire, Dr. W. N. Hancock, W. Newmarch, W. M. Tartt.
1857. Dublin	His Grace the Archbishop of Dublin, M.R.I.A.	Prof. Cairns, Dr. H. D. Hutton, W. Newmarch.
1858. Leeds	Edward Baines	T. B. Baines, Prof. Cairns, S. Brown, Capt. Fishbourne, Dr. J. Strang.

Date and Place	Presidents	Secretaries
1859. Aberdeen...	Col. Sykes, M.P., F.R.S.	Prof. Cairns, Edmund Macrory, A. M. Smith, Dr. John Strang.
1860. Oxford	Nassau W. Senior, M.A.	Edmund Macrory, W. Newmarch, Rev. Prof. J. E. T. Rogers.
1861. Manchester	William Newmarch, F.R.S....	David Chadwick, Prof. R. C. Christie, E. Macrory, Rev. Prof. J. E. T. Rogers.
1862. Cambridge	Edwin Chadwick, C.B.	H. D. Macleod, Edmund Macrory.
1863. Newcastle .	William Tite, M.P., F.R.S. ...	T. Doubleday, Edmund Macrory Frederick Purdy, James Potts.
1864. Bath	William Farr, M.D., D.C.L., F.R.S.	E. Macrory, E. T. Payne. F. Purdy.
1865. Birmingham	Rt. Hon. Lord Stanley, LL.D., M.P.	G. J. D. Goodman, G. J. Johnston, E. Macrory.
1866. Nottingham	Prof. J. E. T. Rogers...........	R. Birkin, jun., Prof. Leone Levi, E. Macrory.
1867. Dundee	M. E. Grant Duff, M.P.	Prof. Leone Levi, E. Macrory, A. J. Warden.
1868. Norwich	Samuel Brown, Pres. Instit. Actuaries.	Rev. W. C. Davie, Prof. Leone Levi.
1869. Exeter	Rt. Hon. Sir Stafford H. Northcote, Bart., C.B., M.P.	Edmund Macrory, Frederick Purdy, Charles T. D. Acland.
1870. Liverpool...	Prof. W. Stanley Jevons, M.A.	Chas. R. Dudley Baxter, E. Macrory, J. Miles Moss.
1871. Edinburgh	Rt. Hon. Lord Neaves	J. G. Fitch, James Meikle.
1872. Brighton ...	Prof. Henry Fawcett, M.P. ...	J. G. Fitch, Barclay Phillips.
1873. Bradford ...	Rt. Hon. W. E. Forster, M.P.	J. G. Fitch, Swire Smith.
1874. Belfast......	Lord O'Hagan	Prof. Donnell, Frank P. Fellows, Hans MacMordie.
1875. Bristol	James Heywood, M.A., F.R.S., Pres.S.S.	F. P. Fellows, T. G. P. Hallett, E. Macrory.
1876. Glasgow ...	Sir George Campbell, K.C.S.I., M.P.	A. M'Neel Caird, T. G. P. Hallett, Dr. W. Neilson Hancock, Dr. W. Jack.
1877. Plymouth...	Rt. Hon. the Earl Fortescue	W. F. Collier, P. Hallett, J. T. Pim.
1878. Dublin	Prof. J. K. Ingram, LL.D., M.R.I.A.	W. J. Hancock, C. Molloy, J. T. Pim.
1879. Sheffield ...	G. Shaw Lefevre, M.P., Pres. S.S.	Prof. Adamson, R. E. Leader, C. Molloy.
1880. Swansea ...	G. W. Hastings, M.P.	N. A. Humphreys, C. Molloy.
1881. York.........	Rt. Hon. M. E. Grant-Duff, M.A., F.R.S.	C. Molloy, W. W. Morrell, J. F. Moss.
1882. Southampton.	Rt. Hon. G. Sclater-Booth, M.P., F.R.S.	G. Baden-Powell, Prof. H. S. Foxwell, A. Milnes, C. Molloy.
1883. Southport	R. H. Inglis Palgrave, F.R.S.	Rev. W. Cunningham, Prof. H. S. Foxwell, J. N. Keynes, C. Molloy.
1884. Montreal ...	Sir Richard Temple, Bart., G.C.S.I., C.I.E., F.R.G.S.	Prof. H. S. Foxwell, J. S. McLennan, Prof. J. Watson.
1885. Aberdeen...	Prof. H. Sidgwick, LL.D., Litt.D.	Rev. W. Cunningham, Prof. H. S. Foxwell, C. McCombie, J. F. Moss.
1886. Birmingham	J. B. Martin, M.A., F.S.S.	F. F. Barham, Rev. W. Cunningham, Prof. H. S. Foxwell, J. F. Moss.

MECHANICAL SCIENCE.

SECTION G.—MECHANICAL SCIENCE.

1836. Bristol	Davies Gilbert, D.C.L., F.R.S.	T. G. Bunt, G. T. Clark, W. West.
1837. Liverpool...	Rev. Dr. Robinson	Charles Vignoles, Thomas Webster.
1838. Newcastle	Charles Babbage, F.R.S.	R. Hawthorn, C. Vignoles, T. Webster.

Date and Place	Presidents	Secretaries
1839. Birmingham	Prof. Willis, F.R.S., and Robt. Stephenson.	W. Carpmael, William Hawkes, T. Webster.
1840. Glasgow	Sir John Robinson	J. Scott Russell, J. Thomson, J. Tod, C. Vignoles.
1841. Plymouth	John Taylor, F.R.S.	Henry Chatfield, Thomas Webster.
1842. Manchester	Rev. Prof. Willis, F.R.S.	J. F. Bateman, J. Scott Russell, J. Thomson, Charles Vignoles.
1843. Cork	Prof. J. Macneill, M.R.I.A....	James Thomson, Robert Mallet.
1844. York	John Taylor, F.R.S.	Charles Vignoles, Thomas Webster.
1845. Cambridge	George Rennie, F.R.S.........	Rev. W. T. Kingsley.
1846. Southampton.	Rev. Prof. Willis, M.A., F.R.S.	William Betts, jun., Charles Manby.
1847. Oxford	Rev. Prof. Walker, M.A., F.R.S.	J. Glynn, R. A. Le Mesurier.
1848. Swansea ...	Rev. Prof. Walker, M.A., F.R.S.	R. A. Le Mesurier, W. P. Struvé.
1849. Birmingham	Robt. Stephenson, M.P., F.R.S.	Charles Manby, W. P. Marshall.
1850. Edinburgh	Rev. R. Robinson	Dr. Lees, David Stephenson.
1851. Ipswich	William Cubitt, F.R.S.........	John Head, Charles Manby.
1852. Belfast	John Walker, C.E., LL.D., F.R.S.	John F. Bateman, C. B Hancock, Charles Manby, James Thomson.
1853. Hull	William Fairbairn, C.E., F.R.S.	James Oldham, J. Thomson, W. Sykes Ward.
1854. Liverpool...	John Scott Russell, F.R.S. ...	John Grantham, J. Oldham, J. Thomson.
1855. Glasgow ...	W. J. Macquorn Rankine, C.E., F.R.S.	L. Hill, jun., William Ramsay, J. Thomson.
1856. Cheltenham	George Rennie, F.R.S.	C. Atherton, B. Jones, jun., H. M. Jeffery.
1857. Dublin	Rt. Hon. the Earl of Rosse, F.R.S.	Prof. Downing, W.T. Doyne, A. Tate, James Thomson, Henry Wright.
1858. Leeds	William Fairbairn, F.R.S. ...	J. C. Dennis, J. Dixon, H. Wright.
1859. Aberdeen...	Rev. Prof. Willis, M.A., F.R.S.	R. Abernethy, P. Le Neve Foster, H. Wright.
1860. Oxford	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	P. Le Neve Foster, Rev. F. Harrison, Henry Wright.
1861. Manchester	J. F. Bateman, C.E., F.R.S....	P. Le Neve Foster, John Robinson, H. Wright.
1862. Cambridge	Wm. Fairbairn, LL.D., F.R.S.	W. M. Fawcett, P. Le Neve Foster.
1863. Newcastle	Rev. Prof. Willis, M.A., F.R.S.	P. Le Neve Foster, P. Westmacott, J. F. Spencer.
1864. Bath	J. Hawkshaw, F.R.S.	P. Le Neve Foster, Robert Pitt.
1865. Birmingham	Sir W. G. Armstrong, LL.D., F.R.S.	P. Le Neve Foster, Henry Lea, W. P. Marshall, Walter May.
1866. Nottingham	Thomas Hawksley, V.P.Inst. C.E., F.G.S.	P. Le Neve Foster, J. F. Iselin, M. O. Tarbotton.
1867. Dundee......	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	P. Le Neve Foster, John P. Smith, W. W. Urquhart.
1868. Norwich ...	G. P. Bidder, C.E., F.R.G.S.	P. Le Neve Foster, J. F. Iselin, C. Manby, W. Smith.
1869. Exeter	C. W. Siemens, F.R.S.........	P. Le Neve Foster, H. Bauerman.
1870. Liverpool...	Chas. B. Vignoles, C.E., F.R.S.	H. Bauerman, P. Le Neve Foster, T. King, J. N. Shoolbred.
1871. Edinburgh	Prof. Fleeming Jenkin, F.R.S.	H. Bauerman, Alexander Leslie, J. P. Smith.
1872. Brighton ...	F. J. Bramwell, C.E.	H. M. Brunel, P. Le Neve Foster, J. G. Gamble, J. N. Shoolbred.
1873. Bradford ...	W. H. Barlow, F.R.S.	Crawford Barlow, H. Bauerman, E. H. Carbutt, J. C. Hawkshaw, J. N. Shoolbred.
1874. Belfast	Prof. James Thomson, LL.D., C.E., F.R.S.E.	A. T. Atchison, J. N. Shoolbred, John Smyth, jun.

Date and Place	Presidents	Secretaries
1875. Bristol	W. Froude, C.E., M.A., F.R.S.	W. R. Browne, H. M. Brunel, J. G. Gamble, J. N. Shoolbred.
1876. Glasgow	C. W. Merrifield, F.R.S.	W. Bottomley, jun., W. J. Millar, J. N. Shoolbred, J. P. Smith.
1877. Plymouth	Edward Woods, C.E.	A. T. Atchison, Dr. Merrifield, J. N. Shoolbred.
1878. Dublin	Edward Easton, C.E.	A. T. Atchison, R. G. Symes, H. T. Wood.
1879. Sheffield	J. Robinson, Pres. Inst. Mech. Eng.	A. T. Atchison, Emerson Bainbridge, H. T. Wood.
1880. Swansea	James Abernethy, V.P. Inst. C.E., F.R.S.E.	A. T. Atchison, H. T. Wood.
1881. York	Sir W. G. Armstrong, C.B., LL.D., D.C.L., F.R.S.	A. T. Atchison, J. F. Stephenson, H. T. Wood.
1882. Southampton.	John Fowler, C.E., F.G.S.	A. T. Atchison, F. Churton, H. T. Wood.
1883. Southport	James Brunlees, F.R.S.E., Pres.Inst.C.E.	A. T. Atchison, E. Rigg, H. T. Wood.
1884. Montreal	Sir F. J. Bramwell, F.R.S., V.P.Inst.C.E.	A. T. Atchison, W. B. Dawson, J. Kennedy, H. T. Wood.
1885. Aberdeen	B. Baker, M.Inst.C.E.	A. T. Atchison, F. G. Ogilvie, E. Rigg, J. N. Shoolbred.
1886. Birmingham	Sir J. N. Douglass, M.Inst. C.E.	C. W. Cooke, J. Kenward, W. B. Marshall, E. Rigg.

ANTHROPOLOGICAL SCIENCE.

SECTION H.—ANTHROPOLOGY.

Date and Place	Presidents	Secretaries
1884. Montreal	E. B. Tylor, D.C.L., F.R.S.	G. W. Bloxam, W. Hurst.
1885. Aberdeen	Francis Galton, M.A., F.R.S.	G. W. Bloxam, Dr. J. G. Garson, W. Hurst, Dr. A. Macgregor.
1886. Birmingham	Sir G. Campbell, K.C.S.I., M.P., D.C.L., F.R.G.S.	G. W. Bloxam, Dr. J. G. Garson, W. Hurst, Dr. R. Saundby

LIST OF EVENING LECTURES.

Date and Place	Lecturer	Subject of Discourse
1842. Manchester	Charles Vignoles, F.R.S.	The Principles and Construction of Atmospheric Railways.
	Sir M. I. Brunel	The Thames Tunnel.
	R. I. Murchison	The Geology of Russia.
1843. Cork	Prof. Owen, M.D., F.R.S.	The Dinornis of New Zealand.
	Prof. E. Forbes, F.R.S.	The Distribution of Animal Life in the Ægean Sea.
	Dr. Robinson	The Earl of Rosse's Telescope.
1844. York	Charles Lyell, F.R.S.	Geology of North America.
	Dr. Falconer, F.R.S.	The Gigantic Tortoise of the Siwalik Hills in India.
1845. Cambridge	G.B.Airy, F.R.S., Astron.Royal	Progress of Terrestrial Magnetism.
	R. I. Murchison, F.R.S.	Geology of Russia.
1846. Southampton.	Prof. Owen, M.D., F.R.S.	Fossil Mammalia of the British Isles.
	Charles Lyell, F.R.S.	Valley and Delta of the Mississippi.
	W. R. Grove, F.R.S.	Properties of the Explosive substance discovered by Dr. Schönbein; also some Researches of his own on the Decomposition of Water by Heat.

Date and Place	Lecturer	Subject of Discourse
1847. Oxford......	Rev. Prof. B. Powell, F.R.S.	Shooting Stars.
	Prof. M. Faraday, F.R.S.......	Magnetic and Diamagnetic Phenomena.
	Hugh E. Strickland, F.G.S....	The Dodo (*Didus ineptus*).
1848. Swansea ...	John Percy, M.D., F.R.S.......	Metallurgical Operations of Swansea and its neighbourhood.
	W. Carpenter, M.D., F.R.S....	Recent Microscopical Discoveries.
1849. Birmingham	Dr. Faraday, F.R.S.	Mr. Gassiot's Battery.
	Rev. Prof. Willis, M.A., F.R.S.	Transit of different Weights with varying velocities on Railways.
1850. Edinburgh	Prof. J. H. Bennett, M.D., F.R.S.E.	Passage of the Blood through the minute vessels of Animals in connexion with Nutrition.
	Dr. Mantell, F.R.S.	Extinct Birds of New Zealand.
1851. Ipswich ...	Prof. R. Owen, M.D., F.R.S.	Distinction between Plants and Animals, and their changes of Form.
	G.B.Airy, F.R.S., Astron. Royal	Total Solar Eclipse of July 28, 1851.
1852. Belfast......	Prof. G. G. Stokes, D.C.L., F.R.S.	Recent discoveries in the properties of Light.
	Colonel Portlock, R.E., F.R.S.	Recent discovery of Rock-salt at Carrickfergus, and geological and practical considerations connected with it.
1853. Hull	Prof. J. Phillips, LL.D., F.R.S., F.G.S.	Some peculiar Phenomena in the Geology and Physical Geography of Yorkshire.
	Robert Hunt, F.R.S.............	The present state of Photography.
1854. Liverpool...	Prof. R. Owen, M.D., F.R.S.	Anthropomorphous Apes.
	Col. E. Sabine, V.P.R.S.	Progress of researches in Terrestrial Magnetism.
1855. Glasgow ...	Dr. W. B. Carpenter, F.R.S.	Characters of Species.
	Lieut.-Col. H. Rawlinson ...	Assyrian and Babylonian Antiquities and Ethnology.
1856. Cheltenham	Col. Sir H. Rawlinson	Recent Discoveries in Assyria and Babylonia, with the results of Cuneiform research up to the present time.
	W. R. Grove, F.R.S............	Correlation of Physical Forces.
1857. Dublin......	Prof. W. Thomson, F.R.S. ...	The Atlantic Telegraph.
	Rev. Dr. Livingstone, D.C.L.	Recent Discoveries in Africa.
1858. Leeds	Prof. J. Phillips, LL.D., F.R.S.	The Ironstones of Yorkshire.
	Prof. R. Owen, M.D., F.R.S.	The Fossil Mammalia of Australia.
1859. Aberdeen...	Sir R. I. Murchison, D.C.L....	Geology of the Northern Highlands.
	Rev. Dr. Robinson, F.R.S. ...	Electrical Discharges in highly rarefied Media.
1860. Oxford......	Rev. Prof. Walker, F.R.S. ...	Physical Constitution of the Sun.
	Captain Sherard Osborn, R.N.	Arctic Discovery.
1861. Manchester	Prof. W. A. Miller, M.A., F.R.S.	Spectrum Analysis.
	G.B.Airy, F.R.S., Astron. Royal	The late Eclipse of the Sun.
1862. Cambridge	Prof. Tyndall, LL.D., F.R.S.	The Forms and Action of Water.
	Prof. Odling, F.R.S............	Organic Chemistry.
1863. Newcastle	Prof. Williamson, F.R.S.......	The Chemistry of the Galvanic Battery considered in relation to Dynamics.
	James Glaisher, F.R.S.........	The Balloon Ascents made for the British Association.
1864. Bath.........	Prof. Roscoe, F.R.S............	The Chemical Action of Light.
	Dr. Livingstone, F.R.S.	Recent Travels in Africa.

Date and Place	Lecturer	Subject of Discourse
1865. Birmingham	J. Beete Jukes, F.R.S.	Probabilities as to the position and extent of the Coal-measures beneath the red rocks of the Midland Counties.
1866. Nottingham	William Huggins, F.R.S.	The results of Spectrum Analysis applied to Heavenly Bodies.
	Dr. J. D. Hooker, F.R.S.	Insular Floras.
1867. Dundee	Archibald Geikie, F.R.S.	The Geological Origin of the present Scenery of Scotland.
	Alexander Herschel, F.R.A.S.	The present state of knowledge regarding Meteors and Meteorites.
1868. Norwich	J. Fergusson, F.R.S.	Archæology of the early Buddhist Monuments.
	Dr. W. Odling, F.R.S.	Reverse Chemical Actions.
1869. Exeter	Prof. J. Phillips, LL.D., F.R.S.	Vesuvius.
	J. Norman Lockyer, F.R.S.	The Physical Constitution of the Stars and Nebulæ.
1870. Liverpool	Prof. J. Tyndall, LL.D., F.R.S.	The Scientific Use of the Imagination.
	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	Stream-lines and Waves, in connection with Naval Architecture.
1871. Edinburgh	F. A. Abel, F.R.S.	Some recent investigations and applications of Explosive Agents.
	E. B. Tylor, F.R.S.	The Relation of Primitive to Modern Civilization.
1872. Brighton	Prof. P. Martin Duncan, M.B., F.R.S.	Insect Metamorphosis.
	Prof. W. K. Clifford	The Aims and Instruments of Scientific Thought.
1873. Bradford	Prof. W. C. Williamson, F.R.S.	Coal and Coal Plants.
	Prof. Clerk Maxwell, F.R.S.	Molecules.
1874. Belfast	Sir John Lubbock, Bart., M.P., F.R.S.	Common Wild Flowers considered in relation to Insects.
	Prof. Huxley, F.R.S.	The Hypothesis that Animals are Automata, and its History.
1875. Bristol	W. Spottiswoode, LL.D., F.R.S.	The Colours of Polarized Light.
	F. J. Bramwell, F.R.S.	Railway Safety Appliances.
1876. Glasgow	Prof. Tait, F.R.S.E.	Force.
	Sir Wyville Thomson, F.R.S.	The *Challenger* Expedition.
1877. Plymouth	W. Warington Smyth, M.A., F.R.S.	The Physical Phenomena connected with the Mines of Cornwall and Devon.
	Prof. Odling, F.R.S.	The new Element, Gallium.
1878. Dublin	G. J. Romanes, F.L.S.	Animal Intelligence.
	Prof. Dewar, F.R.S.	Dissociation, or Modern Ideas of Chemical Action.
1879. Sheffield	W. Crookes, F.R.S.	Radiant Matter.
	Prof. E. Ray Lankester, F.R.S.	Degeneration.
1880. Swansea	Prof. W. Boyd Dawkins, F.R.S.	Primeval Man.
	Francis Galton, F.R.S.	Mental Imagery.
1881. York	Prof. Huxley, Sec. R.S.	The Rise and Progress of Palæontology.
	W. Spottiswoode, Pres. R.S.	The Electric Discharge, its Forms and its Functions.
1882. Southampton.	Prof. Sir Wm. Thomson, F.R.S.	Tides.
	Prof. H. N. Moseley, F.R.S.	Pelagic Life.
1883. Southport	Prof. R. S. Ball, F.R.S.	Recent Researches on the Distance of the Sun.
	Prof. J. G. McKendrick, F.R.S.E.	Galvani and Animal Electricity.

Date and Place	Lecturer	Subject of Discourse
1884. Montreal ...	Prof. O. J. Lodge, D.Sc.	Dust.
	Rev. W. H. Dallinger, F.R.S.	The Modern Microscope in Researches on the Least and Lowest Forms of Life.
1885. Aberdeen...	Prof. W. G. Adams, F.R.S. ...	The Electric Light and Atmospheric Absorption.
	John Murray, F.R.S.E..........	The Great Ocean Basins.
1886. Birmingham	A. W. Rücker, M.A., F.R.S.	Soap Bubbles.
	Prof. W. Rutherford, M.D. ...	The Sense of Hearing.

LECTURES TO THE OPERATIVE CLASSES.

Date and Place	Lecturer	Subject of Discourse
1867. Dundee......	Prof. J. Tyndall, LL.D., F.R.S.	Matter and Force.
1868. Norwich ...	Prof. Huxley, LL.D., F.R.S.	A Piece of Chalk.
1869. Exeter	Prof. Miller, M.D., F.R.S. ...	Experimental illustrations of the modes of detecting the Composition of the Sun and other Heavenly Bodies by the Spectrum.
1870. Liverpool...	Sir John Lubbock, Bart., M.P., F.R.S.	Savages.
1872. Brighton ...	W. Spottiswoode, LL.D., F.R.S.	Sunshine, Sea, and Sky.
1873. Bradford ...	C. W. Siemens, D.C.L., F.R.S.	Fuel.
1874. Belfast	Prof. Odling, F.R.S.............	The Discovery of Oxygen.
1875. Bristol	Dr. W. B. Carpenter, F.R.S.	A Piece of Limestone.
1876. Glasgow ...	Commander Cameron, C.B., R.N.	A Journey through Africa.
1877. Plymouth...	W. H. Preece......................	Telegraphy and the Telephone.
1879. Sheffield ...	W. E. Ayrton	Electricity as a Motive Power.
1880. Swansea ...	H. Seebohm, F.Z.S.	The North-East Passage.
1881. York	Prof. Osborne Reynolds, F.R.S.	Raindrops, Hailstones, and Snowflakes.
1882. Southampton.	John Evans, D.C.L. Treas. R.S.	Unwritten History, and how to read it.
1883. Southport	Sir F. J. Bramwell, F.R.S. ...	Talking by Electricity—Telephones.
1884. Montreal ...	Prof. R. S. Ball, F.R.S..........	Comets.
1885. Aberdeen...	H. B. Dixon, M.A.	The Nature of Explosions.
1886. Birmingham	Prof. W. C. Roberts-Austen, F.R.S.	The Colours of Metals and their Alloys.

OFFICERS OF SECTIONAL COMMITTEES PRESENT AT THE BIRMINGHAM MEETING.

SECTION A.—MATHEMATICAL AND PHYSICAL SCIENCE.

President.—Professor G. H. Darwin, M.A., LL.D., F.R.S., F.R.A.S.

Vice-Presidents.—Sir R. S. Ball, F.R.S.; Professor Cayley, F.R.S.; Donald MacAlister, M.D.; Lord Rayleigh, Sec.R.S.; Professor Stokes, Pres.R.S.; Rev. H. W. Watson, F.R.S.

Secretaries.—R. E. Baynes, M.A. (*Recorder*); R. T. Glazebrook, F.R.S.; Professor J. H. Poynting, M.A.; W. N. Shaw, M.A.

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President.—William Crookes, F.R.S., V.P.C.S.

Vice-Presidents.—Professor Thomas Carnelley, D.Sc.; Dr. W. H. Perkin, F.R.S.; Professor H. E. Armstrong, F.R.S.; Dr. J. H. Gladstone, F.R.S.; A. G. Vernon Harcourt, F.R.S.; Sir Henry E. Roscoe, F.R.S.; Dr. W. J. Russell, F.R.S.; Professor W. A. Tilden, F.R.S.; Professor A. W. Williamson, F.R.S.

Secretaries.—Professor P. Phillips Bedson, D.Sc. (*Recorder*); H. B. Dixon, F.R.S.; H. Forster Morley, D.Sc.; W. W. J. Nicol, D.Sc.; C. J. Woodward, B.Sc.

SECTION C.—GEOLOGY.

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Vice-Presidents.—Rev. H. W. Crosskey, LL.D.; Sir Julius von Haast, K.C.M.G., F.R.S.; Professor E. Hull, F.R.S.; Professor C. Lapworth, LL.D.; W. Mathews, M.A.; Dr. A. R. Selwyn, C.M.G., F.R.S.; H. Woodward, F.R.S.

Secretaries.—W. Jerome Harrison, F.G.S.; J. J. H. Teall, F.G.S.; W. Topley, F.G.S. (*Recorder*); W. W. Watts, F.G.S.

SECTION D.—BIOLOGY.

President.—William Carruthers, Pres.L.S., F.R.S., F.G.S.

Vice-Presidents.—Professor E. A. Schäfer, F.R.S.; P. L. Sclater, F.R.S.; Professor Michael Foster, Sec.R.S.; Professor Alfred Newton, F.R.S.; Dr. Henry Trimen; Professor W. C. Williamson, F.R.S.

Secretaries.—Professor T. W. Bridge, M.A.; Walter Heape (*Recorder*); Professor W. Hillhouse, M.A.; W. L. Sclater, B.A.; Professor H. Marshall Ward, M.A.

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President.—Major-General Sir F. J. Goldsmid, K.C.S.I., C.B., F.R.G.S.

Vice-Presidents.—H. W. Bates, F.R.S. ; Admiral Sir E. Ommanney, C.B., F.R.S. ; Major-General Sir Lewis Pelly, K.C.B., M.P. ; Colonel Sir Lambert Playfair, K.C.M.G. ; General J. T. Walker, C.B., F.R.S. ; Captain W. J. L. Wharton, R.N., F.R.S. ; Colonel Sir Charles Wilson, K.C.B., F.R.S.

Secretaries.—F. T. S. Houghton, M.A. ; J. S. Keltie ; E. G. Ravenstein (*Recorder*).

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President.—J. B. Martin, M.A., F.S.S., F.Z.S.

Vice-Presidents.—G. W. Hastings, M.P. ; Sir Richard Temple, Bart., G.C.S.I., M.P. ; Sir Rawson W. Rawson, K.C.M.G., C.B. ; Hyde Clarke, F.S.S.

Secretaries.—F. F. Barham ; Rev. W. Cunningham, D.Sc. (*Recorder*) ; Professor H. S. Foxwell, M.A. ; J. F. Moss.

SECTION G.—MECHANICAL SCIENCE.

President.—Sir James N. Douglass, M.Inst.C.E.

Vice-Presidents.—W. Anderson ; Professor H. T. Bovey, M.A. ; Sir Frederick Bramwell, F.R.S. ; W. P. Marshall ; Professor R. H. Smith ; Edward Woods, Pres.Inst.C.E.

Secretaries.—Conrad W. Cooke ; J. Kenward ; W. Bayley Marshall ; Edward Rigg, M.A. (*Recorder*).

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President.—Sir George Campbell, K.C.S.I., M.P., D.C.L., F.R.G.S.

Vice-Presidents.—Professor W. Boyd Dawkins, F.R.S. ; W. Pengelly, F.R.S. ; Colonel Sir Charles Wilson, K.C.B., F.R.S.

Secretaries.—G. W. Bloxam, M.A. (*Recorder*) ; J. G. Garson, M.D. ; Walter Hurst, B.Sc. ; R. Saundby, M.D.

THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

THE GENERAL TREASURER'S ACCOUNT (not including receipts at the Birmingham Meeting).

1885–86.	RECEIPTS.	£	s.	d.
	By Balance of account rendered at Aberdeen	620	11	5
	Received for Life Compositions to date	310	0	0
	,, ,, New Annual Members to date.........	260	0	0
	,, ,, Annual Subscriptions to date	639	0	0
	,, ,, Ladies' Tickets at Aberdeen	447	0	0
	,, ,, Associates' Tickets at Aberdeen	1053	0	0
	By Transfers	46	0	0
	Dividends on Stock	246	10	0
	Interest on Exchequer Bills	48	7	4
	Sale of Publications	115	12	5
	Received for Rent from Mathematical Society, year ending September 29, 1885	12	15	0
	Unexpended balance of grant made for 'Regulation of Wages under Sliding Scales'	6	8	2
		£3805	4	4

1885–86.	PAYMENTS.	£	s.	d.
	By payment of Expenses of Aberdeen Meeting, also sundry Printing, Binding, Advertising, and Incidental Expenses	292	13	5
	By Salaries (1 year, 1885–86)	531	5	0
	By Rent of Office at 22 Albemarle Street	117	0	0

1885.		GRANTS.	£	s.	d.
Nov.	2.	Zoological Record	100	0	0
,,	2.	Exploration of New Guinea	150	0	0
,,	13.	Secretion of Urine	10	0	0
,,	13.	Researches in Food-fishes and Invertebrata at St. Andrews	75	0	0
,, Aug.	21. 3.	Electrical Standards	40	0	0
Dec.	2.	Volcanic Phenomena of Vesuvius..	30	0	0
,,	15.	Naples Zoological Station	50	0	0
,,	30.	Ben Nevis Observatory	100	0	0
,,	31.	Prehistoric Race in Greek Islands	20	0	0
Mar.	15.	Investigation into North-Western Tribes of Canada	50	0	0
April	10.	Fossil Plants of Tertiary and Secondary Beds	20	0	0
May	5.	Regulation of Wages under Sliding Scales	10	0	0
,,	5.	Exploration of Caves in North Wales	25	0	0
July	14.	Migration of Birds	30	0	0
,,	14.	Geological Record	100	0	0
,,	14.	Chemical Nomenclature	5	0	0
,,	22.	Fossil Phyllopoda	10	0	0
,,	24.	Solar Radiation	9	10	6
,,	24.	Magnetic Observations	10	10	0
,,	28.	Tidal Observations	50	0	0
,,	31.	Marine Biological Station at Granton	75	0	0
Aug.	3.	Physical and Chemical Bearings of Electrolysis	20	0	0
,,	3.	Fossil Phyllopoda	5	0	

	£	s.	d.
	995	0	6
Balance at Bank of England, Western Branch ...	1719	3	8
By amount deposited in bank at Birmingham ...	150	1	9
	£3805	4	4

Amount of Exchequer Bills, £2,000; Consols, £8,500.

ALEX. W. WILLIAMSON.

Table showing the Attendance and Receipts

Date of Meeting	Where held	Presidents		
			Old Life Members	New Life Members
1831, Sept. 27	York	The Earl Fitzwilliam, D.C.L.	...	...
1832, June 19	Oxford	The Rev. W. Buckland, F.R.S.	...	...
1833, June 25	Cambridge	The Rev. A. Sedgwick, F.R.S.	...	...
1834, Sept. 8	Edinburgh	Sir T. M. Brisbane, D.C.L.	...	...
1835, Aug. 10	Dublin	The Rev. Provost Lloyd, LL.D.	...	...
1836, Aug. 22	Bristol	The Marquis of Lansdowne	...	...
1837, Sept. 11	Liverpool	The Earl of Burlington, F.R.S.	...	...
1838, Aug. 10	Newcastle-on-Tyne	The Duke of Northumberland	...	...
1839, Aug. 26	Birmingham	The Rev. W. Vernon Harcourt	...	...
1840, Sept. 17	Glasgow	The Marquis of Breadalbane	...	...
1841, July 20	Plymouth	The Rev. W. Whewell, F.R.S.	169	65
1842, June 23	Manchester	The Lord Francis Egerton	303	169
1843, Aug. 17	Cork	The Earl of Rosse, F.R.S.	109	28
1844, Sept. 26	York	The Rev. G. Peacock, D.D.	226	150
1845, June 19	Cambridge	Sir John F. W. Herschel, Bart.	313	36
1846, Sept. 10	Southampton	Sir Roderick I. Murchison, Bart.	241	10
1847, June 23	Oxford	Sir Robert H. Inglis, Bart.	314	18
1848, Aug. 9	Swansea	The Marquis of Northampton	149	3
1849, Sept. 12	Birmingham	The Rev. T. R. Robinson, D.D.	227	12
1850, July 21	Edinburgh	Sir David Brewster, K.H.	235	9
1851, July 2	Ipswich	G. B. Airy, Astronomer Royal	172	8
1852, Sept. 1	Belfast	Lieut.-General Sabine, F.R.S.	164	10
1853, Sept. 3	Hull	William Hopkins, F.R.S.	141	13
1854, Sept. 20	Liverpool	The Earl of Harrowby, F.R.S.	238	23
1855, Sept. 12	Glasgow	The Duke of Argyll, F.R.S.	194	33
1856, Aug. 6	Cheltenham	Prof. C. G. B. Daubeny, M.D.	182	14
1857, Aug. 26	Dublin	The Rev. Humphrey Lloyd, D.D.	236	15
1858, Sept. 22	Leeds	Richard Owen, M.D., D.C.L.	222	42
1859, Sept. 14	Aberdeen	H.R.H. the Prince Consort	184	27
1860, June 27	Oxford	The Lord Wrottesley, M.A.	286	21
1861, Sept. 4	Manchester	William Fairbairn, LL.D., F.R.S.	321	113
1862, Oct. 1	Cambridge	The Rev. Professor Willis, M.A.	239	15
1863, Aug. 26	Newcastle-on-Tyne	Sir William G. Armstrong, C.B.	203	36
1864, Sept. 13	Bath	Sir Charles Lyell, Bart., M.A.	287	40
1865, Sept. 6	Birmingham	Prof. J. Phillips, M.A., LL.D.	292	44
1866, Aug. 22	Nottingham	William R. Grove, Q.C., F.R.S.	207	31
1867, Sept. 4	Dundee	The Duke of Buccleuch, K.C.B.	167	25
1868, Aug. 19	Norwich	Dr. Joseph D. Hooker, F.R.S.	196	18
1869, Aug. 18	Exeter	Prof. G. G. Stokes, D.C.L.	204	21
1870, Sept. 14	Liverpool	Prof. T. H. Huxley, LL.D.	314	39
1871, Aug. 2	Edinburgh	Prof. Sir W. Thomson, LL.D.	246	28
1872, Aug. 14	Brighton	Dr. W. B. Carpenter, F.R.S.	245	36
1873, Sept. 17	Bradford	Prof. A. W. Williamson, F.R.S.	212	27
1874, Aug. 19	Belfast	Prof. J. Tyndall, LL.D., F.R.S.	162	13
1875, Aug. 25	Bristol	Sir John Hawkshaw, C.E., F.R.S.	239	36
1876, Sept. 6	Glasgow	Prof. T. Andrews, M.D., F.R.S.	221	35
1877, Aug. 15	Plymouth	Prof. A. Thomson, M.D., F.R.S.	173	19
1878, Aug. 14	Dublin	W. Spottiswoode, M.A., F.R.S.	201	18
1879, Aug. 20	Sheffield	Prof. G. J. Allman, M.D., F.R.S.	184	16
1880, Aug. 25	Swansea	A. C. Ramsay, LL.D., F.R.S.	144	11
1881, Aug. 31	York	Sir John Lubbock, Bart., F.R.S.	272	28
1882, Aug. 23	Southampton	Dr. C. W. Siemens, F.R.S.	178	17
1883, Sept. 19	Southport	Prof. A. Cayley, D.C.L., F.R.S.	203	60
1884, Aug. 27	Montreal	Prof. Lord Rayleigh, F.R.S.	235	20
1885, Sept. 9	Aberdeen	Sir Lyon Playfair, K.C.B., F.R.S.	225	18
1886, Sept. 1	Birmingham	Sir J.W. Dawson, C.M.G., F.R.S.	314	25

t Annual Meetings of the Association.

Attended by						Amount received during the Meeting	Sums paid on Account of Grants for Scientific Purposes	Year
Old Annual Members	New Annual Members	Associates	Ladies	Foreigners	Total			
...	...	...	...	...	353	....	....	1831
...	...	...	...	...	...	....	....	1832
...	...	...	...	...	900	....	....	1833
...	...	...	...	...	1298	....	£20 0 0	1834
...	...	...	...	...	...	....	167 0 0	1835
...	...	...	...	...	1350	....	435 0 0	1836
...	...	...	...	...	1840	....	922 12 6	1837
...	...	...	1100*	...	2400	....	932 2 2	1838
...	...	...	...	34	1438	....	1595 11 0	1839
...	...	...	...	40	1353	....	1546 16 4	1840
46	317	...	60*	...	891	....	1235 10 11	1841
75	376	33†	331*	28	1315	....	1449 17 8	1842
71	185	...	160	...	...	....	1565 10 2	1843
45	190	9†	260	...	...	....	981 12 8	1844
94	22	407	172	35	1079	....	831 9 9	1845
65	39	270	196	36	857	....	685 16 0	1846
197	40	495	203	53	1320	....	208 5 4	1847
54	25	376	197	15	819	£707 0 0	275 1 8	1848
93	33	447	237	22	1071	963 0 0	159 19 6	1849
128	42	510	273	44	1241	1085 0 0	345 18 0	1850
61	47	244	141	37	710	620 0 0	391 9 7	1851
63	60	510	292	9	1108	1085 0 0	304 6 7	1852
56	57	367	236	6	876	903 0 0	205 0 0	1853
121	121	765	524	10	1802	1882 0 0	380 19 7	1854
142	101	1094	543	26	2133	2311 0 0	480 16 4	1855
104	48	412	346	9	1115	1098 0 0	734 13 9	1856
156	120	900	569	26	2022	2015 0 0	507 15 4	1857
111	91	710	509	13	1698	1931 0 0	618 18 2	1858
125	179	1206	821	22	2564	2782 0 0	684 11 1	1859
177	59	636	463	47	1689	1604 0 0	766 19 6	1860
184	125	1589	791	15	3138	3944 0 0	1111 5 10	1861
150	57	433	242	25	1161	1089 0 0	1293 16 6	1862
154	209	1704	1004	25	3335	3640 0 0	1608 3 10	1863
182	103	1119	1058	13	2802	2965 0 0	1289 15 8	1864
215	149	766	508	23	1997	2227 0 0	1591 7 10	1865
218	105	960	771	11	2303	2469 0 0	1750 13 4	1866
193	118	1163	771	7	2444	2613 0 0	1739 4 0	1867
226	117	720	682	45‡	2004	2042 0 0	1940 0 0	1868
229	107	678	600	17	1856	1931 0 0	1622 0 0	1869
303	195	1103	910	14	2878	3096 0 0	1572 0 0	1870
311	127	976	754	21	2463	2575 0 0	1472 2 6	1871
280	80	937	912	43	2533	2649 0 0	1285 0 0	1872
237	99	796	601	11	1983	2120 0 0	1685 0 0	1873
232	85	817	630	12	1951	1979 0 0	1151 16 0	1874
307	93	884	672	17	2248	2397 0 0	960 0 0	1875
331	185	1265	712	25	2774	3023 0 0	1092 4 2	1876
238	59	446	283	11	1229	1268 0 0	1128 9 7	1877
290	93	1285	674	17	2578	2615 0 0	725 16 6	1878
239	74	529	349	13	1404	1425 0 0	1080 11 11	1879
171	41	389	147	12	915	899 0 0	731 7 7	1880
313	176	1230	514	24	2557	2689 0 0	476 3 1	1881
253	79	516	189	21	1253	1286 0 0	1126 1 11	1882
330	323	952	841	5	2714	3369 0 0	1083 3 3	1883
317	219	826	74	26 & 60 H.§	1777	1538 0 0	1173 4 0	1884
332	122	1053	447	6	2203	2256 0 0	1385 0 0	1885
428	179	1067	429	11	2453	2532 0 0	995 0 6	1886

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* Ladies were not admitted by purchased Tickets until 1843.

† Tickets of Admission to Sections only.

‡ Including Ladies.

§ Fellows of the American Association were admitted as Honorary Members for this Meeting.

OFFICERS AND COUNCIL, 1886-87.

PRESIDENT.

Sir J. William Dawson, C.M.G., M.A., LL.D., F.R.S. F.G.S.,
Principal and Vice-Chancellor of McGill University, Montreal, Canada.

VICE-PRESIDENTS.

The Right Hon. the Earl of Bradford, Lord-Lieutenant of Shropshire.
The Right Hon. Lord Leigh, D.C.L., Lord-Lieutenant of Warwickshire.
The Right Hon. Lord Norton, K.C.M.G.
The Right Hon. Lord Wrottesley, Lord-Lieutenant of Staffordshire.
The Rt. Rev. the Lord Bishop of Worcester, D.D
Thomas Martineau, Esq., Mayor of Birmingham.
Professor G. G. Stokes, M.A., D.C.L., LL.D. Pres.R.S.
Professor W. A. Tilden, D.Sc., F.R S., F.C.S
Rev. A. R. Vardy, M.A.
Rev. H. W. Watson, D.Sc., F.R.S

PRESIDENT ELECT.

Sir H. E. Roscoe, M.P., LL.D., Ph.D., F.R.S., V.P.C.S.

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The Right Hon. the Earl of Derby, K.G., M.A., LL.D., F.R.S., F.R.G.S.
The Right Rev. the Lord Bishop of Manchester, D.D.
The Right Rev. the Bishop of Salford.
The Right Worshipful the Mayor of Manchester.
The Right Worshipful the Mayor of Salford.
The Vice-Chancellor of Victoria University, Manchester.
The Principal of Owens College, Manchester.
Sir William Roberts, B.A., M.D., F.R.S.
Thomas Ashton, Esq., J.P., D.L.
Oliver Heywood, Esq., J.P.. D.L. (*nominated by the Council*).
James Prescott Joule, Esq., D.C.L., LL.D., F.R.S., F.R.S.E., F.C.S.

LOCAL SECRETARIES FOR THE MEETING AT MANCHESTER.

F. J. Faraday, Esq., F.L.S., F.S.S.
Charles Hopkinson, Esq., B.Sc.
Professor A. Milnes Marshall, M.D., D.Sc., F.R.S
Professor A. H. Young, M.B., F.R.C.S.

LOCAL TREASURER FOR THE MEETING AT MANCHESTER

Alderman Joseph Thompson J.P.

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Abney, Capt. W. de W., F.R.S.
Ball, Professor Sir R. S., F.R.S.
Barlow, W. H., Esq., F.R.S.
Blanford, W. T. Esq., F.R.S.
Bramwell, Sir F. J., F.R.S.
Crookes, W., Esq., F.R.S.
Darwin, Professor G. H., F.R.S.
Dawkins, Professor W. Boyd, F.R.S.
De La Rue, Dr. Warren, F.R.S.
Dewar, Professor J., F.R.S.
Flower, Professor W. H., F.R.S.
Gladstone, Dr. J. H., F.R.S.
Godwin-Austen, Lieut.-Col. H. H., F.R.S.
Hawkshaw, J. Clarke, Esq., F.G.S.
Henrici, Professor O., F.R.S.
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Thorpe, Professor T. E., F.R.S.

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Capt. Douglas Galton, C.B., D.C.L., LL.D., F.R.S., F.G.S., 12 Chester Street, London, S.W.
A. G. Vernon Harcourt, Esq., M.A., LL.D., F.R.S., F.C.S., Cowley Grange, Oxford.

SECRETARY.

Arthur T. Atchison, Esq., M.A., 22 Albemarle Street, London, W.

GENERAL TREASURER.

Professor A. W. Williamson, Ph.D., LL.D., F.R.S., F.C.S., University College, London, W.C.

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REPORT OF THE COUNCIL.

Report of the Council for the year 1885–86, *presented to the General Committee at Birmingham, on Wednesday, September* 1, 1886.

The Council have received reports during the past year from the General Treasurer, and his account for the year will be laid before the General Committee this day.

Since the Meeting at Aberdeen the following have been elected Corresponding Members of the Association:—

Professor Putnam.
Rev. Dr. Renard.
Dr. Max Schuster.
M. Jules Vuylsteke.

As Professor Huxley was unable to accept the office of a Vice-President for the present meeting, the Council have nominated in his stead Professor Stokes, Pres.R.S.

The Council have received a letter from Sir Charles Tupper, High Commissioner for the Dominion of Canada, enclosing important communications from the Government of that Dominion, in reference to the record and preservation from obliteration of such traces as still remain of the indigenous characteristics of the native races of America, which subject, the General Committee will recollect, was mentioned in the Report of the Council at the Aberdeen Meeting. Copies of this correspondence will be communicated to the Sections interested in the subject.

Invitations have been received from Bath and from Sydney for the year 1888; and the invitation from Melbourne, given at Montreal, has been renewed.

The following resolutions were referred by the General Committee to the Council for consideration, and action if desirable:—

(*a*) 'That the Council be requested to consider the desirability of admitting ladies as Officers of the Association, or as Members of the General or Sectional Committees.'

The Council, after careful consideration of the question, are of opinion that the time has not yet come when it would be for the advantage of the Association to depart from the established custom.

(*b*) 'That the Council be requested to consider the advisability of rendering the special Reports of the Association more accessible to the scientific public by placing them on sale in separate form.'

(*c*) 'That the printed Reports on Special Subjects be offered for sale to the general public at the time of the Meeting, or as soon afterwards as possible.'

There are several matters of detail, requiring careful consideration, in the subject of these two resolutions, and the Council, owing to exceptional circumstances during the past year, have not been able to come to a decision regarding them. They recommend that the question should be referred to the next Council.

(*d*) 'That the Council be requested to so modify the Rules of the Association as to permit of a Sectional Meeting being held at an earlier hour than eleven, and the Sectional Committee previously, due notice being given to the Section on the previous day.'

The Council have considered this recommendation, and think it undesirable to alter the general rules, the resolution passed at Southport three years ago meeting the particular case of Saturday.

(*e*) 'That a memorial be presented to H.M. Government requesting them to enlarge the existing Agricultural Department of the Privy Council, with the view of concentrating all administrative functions relating to Agriculture in one fully equipped Board and Department of Agriculture.'

The Council, after a full consideration of this difficult and intricate question, are not at present prepared to memorialise the Government on the subject of the enlargement of the Agricultural Department of the Privy Council.

(*f*) 'That the Council be requested to consider and take steps, if they think it desirable, to memorialise the Government to undertake the more systematic collection and annual publication of Statistics of Wages, and a periodical industrial census.'

The Council, in view of the recent promise of the late President of the Board of Trade in Parliament as to the collection of Statistics of Wages, are of opinion that it is inexpedient at present to memorialise H.M. Government on the subject, but they empowered a committee of their members to communicate, if necessary, with the Department engaged in the collection of Statistics of Wages, with the view of eliciting information as to the method proposed to be employed, and to make such suggestions as appear to be expedient.

(*g*) 'That a memorial be presented to H.M. Government in favour of the establishment of a National School of Forestry.'

A Committee was appointed to consider this subject, but has made no report to the Council.

The General Committee will remember that the question of the feasibility of instituting a scheme for promoting an International Scientific Congress, described in the Report of the Council presented at Aberdeen, was in effect referred back to the Council to consider whether it would be possible to devise such a scheme. The question has been further considered during the past year, and the Council are of opinion that the difficulties and objections foreseen by several members of the Association have not been met in any of the communications which have been laid before them, and are, in their judgment, so great that they cannot at present recommend any further steps being taken in the matter.

In accordance with the regulations the five retiring Members of the Council will be—

Mr. J. W. L. Glaisher.
Professor T. McK. Hughes.
Dr. H. C. Sorby.
D. W. H. Perkin.
Mr. J. F. La Trobe Bateman.

The Council recommend the re-election of the other ordinary Members of Council, with the addition of the gentlemen whose names are distinguished by an asterisk in the following list:—

Abney, Capt. W. de W., F.R.S.
Ball, Sir R. S., F.R.S.
*Barlow, W. H., Esq., F.R.S.
Blanford, W. T., Esq., F.R.S.
Bramwell, Sir F. J., F.R.S.
Crookes, W., Esq., F.R.S.
*Darwin, G. H., F.R.S.
Dawkins, Prof. W. Boyd, F.R.S.
De La Rue, Dr. Warren, F.R.S.
Dewar, Prof. J., F.R.S.
Flower, Prof. W. H., F.R.S.
Gladstone, Dr. J. H., F.R.S.
Godwin-Austen, Lieut.-Col. H. H., F.R.S.
Hawkshaw, J. Clarke, Esq., F.G.S.
Henrici, Prof. O., F.R.S.
*Judd, J. W., F.R.S.
Martin, J. B., Esq., F.S.S.
M'Leod, Prof. H., F.R.S.
Moseley, Prof. H. N., F.R.S.
Ommanney, Admiral Sir E., C.B., F.R.S.
Pengelly, W., Esq., F.R.S.
*Roberts-Austen, Prof. W. C., F.R.S.
Temple, Sir R., Bart., G.C.S.I.
Thiselton-Dyer, W. T., Esq., C.M.G., F.R.S.
*Thorpe, T. E., F.R.S.

RECOMMENDATIONS ADOPTED BY THE GENERAL COMMITTEE AT THE BIRMINGHAM MEETING IN SEPTEMBER 1886.

[When Committees are appointed, the Member first named is regarded as the Secretary, except there is a specific nomination.]

Involving Grants of Money.

That Professors Balfour Stewart, Schuster, and Stokes, Mr. G. Johnstone Stoney, Professor Sir H. E. Roscoe, Captain Abney, and Mr. G. J. Symons be reappointed a Committee for the purpose of considering the best methods of recording the direct intensity of Solar Radiation; that Professor Balfour Stewart be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That the Committee consisting of Professors Armstrong, Lodge, and Sir William Thomson, Lord Rayleigh, Professors Fitzgerald, J. J. Thomson, Schuster, Poynting, Crum Brown, Ramsay, Frankland, Tilden, Hartley, S. P. Thompson, McLeod, Roberts-Austen, Rücker, Reinold, and Carey Foster, Captain Abney, Drs. Gladstone, Hopkinson, and Fleming, and Messrs. Crookes, Shelford Bidwell, W. N. Shaw, J. Larmor, J. T. Bottomley, and H. B. Dixon, with the addition of the names of Messrs. R. T. Glazebrook, J. Brown, E. J. Love, and John M. Thomson, be reappointed a Committee for the purpose of considering the subject of Electrolysis in its Physical and Chemical bearings; that Professor Armstrong be the Chemical Secretary and Professor Lodge the Physical Secretary, and that the sum of 50*l.* be placed at their disposal for the purpose.

That Professor Crum Brown, Mr. Milne-Holme, Mr. John Murray, Mr. Buchan, and Lord McLaren be reappointed a Committee for the purpose of co-operating with the Scottish Meteorological Society in making meteorological observations on Ben Nevis; that Professor Crum Brown be the Secretary, and that the sum of 75*l.* be placed at their disposal for the purpose.

That Professor G. Forbes, Captain Abney, Dr. J. Hopkinson, Professor W. G. Adams, Professor G. C. Foster, Lord Rayleigh, Mr. Preece, Professor Schuster, Professor Dewar, Mr. A. Vernon Harcourt, Professor Ayrton, Sir James Douglass, and Mr. H. B. Dixon be reappointed a Committee for the purpose of reporting on Standards of Light; that Professor G. Forbes be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

That Professor G. H. Darwin, Sir W. Thomson, and Major Baird be a Committee for the purpose of preparing instructions for the practical work of Tidal Observation; that Professor Darwin be the Secretary, and that the sum of 15*l.* be placed at their disposal for the purpose.

That Professor Balfour Stewart (Secretary), Mr. Knox Laughton, Mr.

G. J. Symons, Mr. R. H. Scott, and Mr. Johnstone Stoney be reappointed a Committee, with power to add to their number, for the purpose of co-operating with Mr. E. J. Lowe in his project of establishing a Meteorological Observatory near Chepstow on a permanent and scientific basis, and that the unexpended sum of 20*l.* be placed at their disposal for the purpose.

That Professors Balfour Stewart and Sir W. Thomson, Sir J. H. Lefroy, Professors G. H. Darwin, G. Chrystal, and S. J. Perry, Mr. C. H. Carpmael, Professor Schuster, Mr. G. M. Whipple, Captain Creak, the Astronomer Royal, Mr. William Ellis, Professor W. G. Adams, and Mr. W. Lant Carpenter be reappointed a Committee for the purpose of considering the best means of comparing and reducing Magnetic Observations; that Professor Balfour Stewart be the Secretary, and that the sum of 40*l.* be placed at their disposal for the purpose.

That Professor G. Carey Foster, Sir William Thomson, Professor Ayrton, Professor J. Perry, Professor W. G. Adams, Lord Rayleigh, Dr. O. J. Lodge, Dr. John Hopkinson, Dr. A. Muirhead, Mr. W. H. Preece, Mr. Herbert Taylor, Professor Everett, Professor Schuster, Dr. J. A. Fleming, Professor G. F. Fitzgerald, Mr. R. T. Glazebrook, Professor Chrystal, Mr. H. Tomlinson, Professor W. Garnett, Professor J. J. Thomson, Mr. W. N. Shaw, and Mr. J. T. Bottomley be reappointed a Committee for the purpose of making experiments for improving the construction of practical Standards for use in Electrical Measurements; that Mr. Glazebrook be the Secretary, and that the sum of 50*l.* be placed at their disposal for the purpose.

That Professors McLeod and Ramsay, Mr. J. T. Cundall, and Mr. W. A. Shenstone be a Committee for the further investigation of the Influence of the Silent Discharge of Electricity on oxygen and other gases; that Mr. W. A. Shenstone be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Captain Abney, General Festing, and Professors W. N. Hartley and H. E. Armstrong be a Committee for the purpose of investigating the Absorption Spectra of Pure Compounds; that Professor Armstrong be the Secretary, and that the sum of 40*l.* be placed at their disposal for the purpose.

That Professors Williamson, Armstrong, Tilden, Reinold, J. Perry, O. J. Lodge, Stirling, Bower, D'Arcy Thompson, and Milnes Marshall, and Messrs. A. V. Harcourt, Dixon, Crookes, and E. J. Love be a Committee for the purpose of considering the desirability of combined action for the purpose of Translation of Foreign Memoirs and for reporting thereon; and that the sum of 5*l.* be placed at their disposal for the purpose.

That Professors Tilden and W. Ramsay and Dr. W. W. J. Nicol be a Committee for the purpose of investigating the Nature of Solution; that Dr. W. W. J. Nicol be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Professors Tilden and W. Chandler Roberts-Austen, and Mr. T. Turner be a Committee for the purpose of investigating the Influence of Silicon on the Properties of Steel; that Mr. T. Turner be the Secretary, and that the sum of 30*l.* be placed at their disposal for the purpose.

That Messrs. H. Bauerman, F. W. Rudler, J. J. H. Teall, and H. J. Johnston-Lavis be reappointed a Committee for the purpose of investigating the Volcanic Phenomena of Vesuvius and its neighbourhood; that

Dr. H. J. Johnston-Lavis be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Mr. R. Etheridge, Mr. T. Gray, and Professor John Milne be reappointed a Committee for the purpose of investigating the Volcanic Phenomena of Japan; that Professor J. Milne be the Secretary, and that the sum of 50*l.* be placed at their disposal for the purpose.

That Professor T. McK. Hughes, Dr. H. Hicks, Dr. H. Woodward, and Messrs. E. B. Luxmoore, P. Pennant, and Edwin Morgan be reappointed a Committee for the purpose of exploring the Cae Gwyn Cave, North Wales; that Dr. H. Hicks be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Professors J. Prestwich, W. Boyd Dawkins, T. McK. Hughes, and T. G. Bonney, Dr. H. W. Crosskey, and Messrs. C. E. De Rance, H. G. Fordham, J. E. Lee, D. Mackintosh, W. Pengelly, J. Plant, and R. H. Tiddeman be reappointed a Committee for the purpose of recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England, Wales, and Ireland, reporting other matters of interest connected with the same, and taking measures for their preservation; that Dr. Crosskey be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

That Mr. R. Etheridge, Dr. H. Woodward, and Professor T. R. Jones be reappointed a Committee for the purpose of reporting on the Fossil Phyllopoda of the Palæozoic Rocks; that Professor T. R. Jones be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Professor W. C. Williamson and Mr. Cash be a Committee for the purpose of investigating the Carboniferous Flora of Halifax and its neighbourhood; that Mr. Cash be the Secretary, and that the sum of 25*l.* be placed at their disposal for the purpose.

That Professor T. G. Bonney, Mr. J. J. H. Teall, and Professor J. F. Blake be a Committee for the purpose of investigating the Microscopic Structure of the older Rocks of Anglesea; that Professor J. F. Blake be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

That Dr. H. Woodward, Mr. H. Keeping, and Mr. J. Starkie Gardner be a Committee for the purpose of exploring the Higher Eocene Beds of the Isle of Wight; that Mr. J. S. Gardner be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Professor E. Hull, Dr. H. W. Crosskey, Captain Douglas Galton, Professor J. Prestwich, and Messrs. James Glaisher, E. B. Marten, G. H. Morton, James Parker, W. Pengelly, James Plant, I. Roberts, Fox Strangways, T. S. Stooke, G. J. Symons, W. Topley, Tylden-Wright, E. Wethered, W. Whitaker, and C. E. De Rance be reappointed a Committee for the purpose of investigating the Circulation of the Underground Waters in the Permeable Formations of England, and the Quality and Quantity of the Waters supplied to various towns and districts from these formations; that Mr. De Rance be the Secretary, and that the sum of 5*l.* be placed at their disposal for the purpose.

That Messrs. R. B. Grantham, C. E. De Rance, J. B. Redman, W. Topley, W. Whitaker, and J. W. Woodall, Major-General Sir A. Clarke, Admiral Sir E. Ommanney, Sir J. N. Douglass, Captain Sir George Nares, Captain J. Parsons, Captain W. J. L. Wharton, Professor J. Prestwich, and Messrs. E. Easton, J. S. Valentine, and L. F. Vernon

Harcourt be reappointed a Committee for the purpose of inquiring into the Rate of Erosion of the Sea-coasts of England and Wales, and the Influence of the Artificial Abstraction of Shingle or other material in that Action; that Messrs. De Rance and Topley be the Secretaries, and that the sum of 15*l.* be placed at their disposal for the purpose.

That Mr. R. Etheridge, Dr. H. Woodward, and Mr. A. Bell be a Committee for the purpose of reporting upon the 'Manure' Gravels of Wexford; that Mr. A. Bell be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

That Mr. Valentine Ball, Mr. H. G. Fordham, Professor Haddon, Professor Hillhouse, Mr. John Hopkinson, Dr. Macfarlane, Professor Milnes Marshall, Mr. F. T. Mott, Dr. Traquair, and Dr. H. Woodward be a Committee for the purpose of preparing a report upon the Provincial Museums of the United Kingdom; that Mr. Mott be the Secretary, and that the sum of 5*l.* be placed at their disposal for the purpose.

That Professors Schäfer, Michael Foster, and Lankester, and Dr. W. D. Halliburton be a Committee for the purpose of investigating the Physiology of the Lymphatic System; that Professor Schäfer be the Secretary, and that the sum of 25*l.* be placed at their disposal for the purpose.

That Professor Ray Lankester, Mr. P. L. Sclater, Professor M. Foster, Mr. A. Sedgwick, Professor A. M. Marshall, Professor A. C. Haddon, Professor Moseley, and Mr. Percy Sladen be reappointed a Committee for the purpose of arranging for the occupation of a table at the Zoological Station at Naples; that Mr. Percy Sladen be the Secretary, and that the sum of 100*l.* be placed at their disposal for the purpose.

That Professor Lankester, Mr. P. L. Sclater, Professor M. Foster, Mr. A. Sedgwick, Professor A. M. Marshall, Professor A. C. Haddon, Professor Moseley, and Mr. Percy Sladen be a Committee for the purpose of making arrangements for assisting the Marine Biological Association Laboratory at Plymouth; that Mr. Percy Sladen be the Secretary, and that the sum of 50*l.* be placed at their disposal for the purpose.

That Professors McKendrick, Struthers, Young, McIntosh, A. Nicholson, and Cossar Ewart and Mr. John Murray be reappointed a Committee for the purpose of aiding in the maintenance of the establishment of a Marine Biological Station at Granton, Scotland; that Mr. John Murray be the Secretary, and that the sum of 75*l.* be placed at their disposal for the purpose.

That Mr. Stainton, Sir John Lubbock, and Mr. McLachlan be reappointed a Committee for the purpose of continuing a Record of Zoological Literature; that Mr. Stainton be the Secretary, and that the sum of 100*l.* be placed at their disposal for the purpose.

That Mr. Thiselton Dyer, Mr. Carruthers, Mr. Ball, Professor Oliver, and Mr. Forbes be a Committee for the purpose of continuing the preparation of a report on our present knowledge of the Flora of China; that Mr. Thiselton-Dyer be the Secretary, and that the sum of 75*l.* be placed at their disposal for the purpose.

That Mr. Sclater, Mr. Seebohm, Mr. Carruthers, and Mr. R. Trimen be a Committee for the purpose of investigating the Fauna and Flora of the Cameroon Mountains; that Mr. Sclater be the Secretary, and that the sum of 75*l.* be placed at their disposal for the purpose.

That Mr. John Cordeaux, Professor A. Newton, Mr. J. A. Harvie-Brown, Mr. W. E. Clarke, Mr. R. M. Barrington, and Mr. A. G. More be reappointed a Committee for the purpose of obtaining (with the consent of the Master and Elder Brethren of the Trinity House and the Commissioners of Northern and Irish Lights) observations on the Migration of Birds at Lighthouses and Light-vessels, and of reporting on the same; that Mr. John Cordeaux be the Secretary, and that the sum of 30*l.* be placed at their disposal for the purpose.

That Canon A. M. Norman, Mr. H. B. Brady, Mr. W. Carruthers, Professor Herdman, Professor McIntosh, Mr. J. Murray, Professor A. Newton, Mr. P. L. Sclater, and Professor A. C. Haddon be a Committee for the purpose of considering the question of accurately defining the term 'British' as applied to the Marine Fauna and Flora of our Islands, and bringing forward a definite proposal on the subject at a future meeting. The Committee to be called the 'British Marine Area Committee.' That Professor A. C. Haddon be the Secretary, and that the sum of 5*l.* be placed at their disposal for the purpose.

That General J. T. Walker, General Sir J. H. Lefroy, Professor Sir William Thomson, Mr. Francis Galton, Mr. Alexander Buchan, Mr. J. Y. Buchanan, Mr. John Murray, Mr. H. W. Bates, and Mr. E. G. Ravenstein be a Committee for the purpose of taking into consideration the combination of the Ordnance and Admiralty Surveys, and the production of a Bathy-hypsographical Map of the British Isles; that Mr. E. G. Ravenstein be the Secretary, and that the sum of 25*l.* be placed at their disposal for the purpose.

That General J. T. Walker, General Sir J. H. Lefroy, Professor Sir William Thomson, Mr. Alexander Buchan, Mr. J. Y. Buchanan, Mr. John Murray, Dr. J. Rae, Mr. H. W. Bates, Captain W. J. Dawson, Dr. A. Selwyn, and Professor C. Carpmael be reappointed a Committee for the purpose of reporting upon the Depth of permanently Frozen Soil in the Polar Regions, its geographical limits, and relation to the present poles of greatest cold; that Sir Henry Lefroy be the Reporter and Mr. H. W. Bates the Secretary, and that the sum of 5*l.* be placed at their disposal for the purpose.

That Professor Sidgwick, Professor Foxwell, the Rev. W. Cunningham, Professor Munro, and Mr. A. H. D. Acland be a Committee for the purpose of further inquiring into the Regulation of Wages under the Sliding Scales and under the Lists in the Cotton Industry; that Professor Munro be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

That Dr. Garson, Mr. Pengelly, Mr. F. W. Rudler, and Mr. G. W. Bloxam be reappointed a Committee for the purpose of investigating the Prehistoric Race in the Greek Islands; that Mr. Bloxam be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Mr. Pengelly, Dr. John Evans, Sir John Lubbock, Professor Alexander Macalister, Mr. W. Cunnington, and Dr. Garson be a Committee for the purpose of exploring Ancient Barrows in Wiltshire; that Dr. Garson be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Dr. E. B. Tylor, Dr. G. M. Dawson, General Sir J. H. Lefroy, Dr. Daniel Wilson, Mr. R. G. Haliburton, and Mr. George W. Bloxam be reappointed a Committee for the purpose of investigating and publishing reports on the physical characters, languages, and industrial and social condition of the North-Western Tribes of the Dominion of Canada; that

Mr. Bloxam be the Secretary, and that the sum of 50*l.* be placed at their disposal for the purpose.

That Mr. F. Galton, General Pitt-Rivers, Professor Flower, Professor A. Macalister, Mr. F. W. Rudler, Mr. R. Stuart Poole, and Mr. Bloxam be a Committee for the purpose of procuring, with the help of Mr. Flinders Petrie, Racial Photographs from the Ancient Egyptian Pictures and Sculptures; that Mr. Bloxam be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That General Pitt-Rivers, Dr. Beddoe, Professor Flower, Mr. Francis Galton, Dr. E. B. Tylor, and Dr. Garson be a Committee for the purpose of editing a new edition of 'Anthropological Notes and Queries,' with authority to distribute gratuitously the unsold copies of the present edition; that Dr. Garson be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

Not involving Grants of Money.

That Professor Cayley, Sir William Thomson, Mr. James Glaisher, and Mr. J. W. L. Glaisher (Secretary) be reappointed a Committee for the purpose of calculating certain tables in the Theory of Numbers connected with the divisors of a number.

That Professor G. H. Darwin and Professor J. C. Adams be reappointed a Committee for the Harmonic Analysis of Tidal Observations; and that Professor Darwin be the Secretary.

That Professors Everett and Sir William Thomson, Mr. G. J. Symons, Sir A. C. Ramsay, Dr. A. Geikie, Mr. J. Glaisher, Mr. Pengelly, Professor Edward Hull, Professor Prestwich, Dr. C. Le Neve Foster, Professor A. S. Herschel, Professor G. A. Lebour, Mr. A. B. Wynne, Mr. Galloway, Mr. Joseph Dickinson, Mr. G. F. Deacon, Mr. E. Wethered, and Mr. A. Strahan be reappointed a Committee for the purpose of investigating the Rate of Increase of Underground Temperature downwards in various Localities of Dry Land and under Water; and that Professor Everett be the Secretary.

That Professor Sylvester, Professor Cayley, and Professor Salmon be reappointed a Committee for the purpose of calculating Tables of the Fundamental Invariants of Algebraic Forms; and that Professor Cayley be the Secretary.

That Professors A. Johnson, MacGregor, J. B. Cherriman, and H. T. Bovey and Mr. C. Carpmael be reappointed a Committee for the purpose of promoting Tidal Observations in Canada; and that Professor Johnson be the Secretary.

That Mr. John Murray, Professor Schuster, Sir William Thomson, the Abbé Renard, Mr. A. Buchan, the Hon. R. Abercromby, and Dr. M. Grabham be reappointed a Committee for the purpose of investigating the practicability of collecting and identifying Meteoric Dust, and of considering the question of undertaking regular observations in various localities; and that Mr. John Murray be the Secretary.

That Professor Sir H. E. Roscoe, Mr. Lockyer, Professors Dewar, Liveing, Schuster, W. N. Hartley, and Wolcott Gibbs, Captain Abney, and Dr. Marshall Watts be a Committee for the purpose of preparing a new series of Wave-length Tables of the Spectra of the Elements; and that Dr. Marshall Watts be the Secretary.

That Professors W. A. Tilden and H. E. Armstrong be a Committee for the purpose of investigating Isomeric Naphthalene Derivatives; and that Professor H. E. Armstrong be the Secretary.

That Professors Dewar and A. W. Williamson, Dr. Marshall Watts, Captain Abney, Dr. Johnstone Stoney, Professors W. N. Hartley, McLeod, Carey Foster, A. K. Huntington, Emerson Reynolds, Reinold, and Liveing, Lord Rayleigh, Professor Schuster, and Professor W. C. Roberts-Austen be a Committee for the purpose of reporting upon the present state of our knowledge of Spectrum Analysis; and that Professor W. C. Roberts-Austen be the Secretary.

That Professors Ramsay, Tilden, Marshall, and W. L. Goodwin be a Committee for the purpose of investigating certain Physical Constants of Solution, especially the expansion of saline solutions; and that Professor W. L. Goodwin be the Secretary.

That Professors Tilden, McLeod, Pickering, and Ramsay and Drs. Young, A. R. Leeds, and Nicol be a Committee for the purpose of reporting on the Bibliography of Solution; and that Dr. Nicol be the Secretary.

That Dr. J. Evans, Professor W. J. Sollas, Dr. G. J. Hinde, and Messrs. W. Carruthers, R. B. Newton, J. J. H. Teall, F. W. Rudler, W. Topley, W. Whitaker, and E. Wethered be reappointed a Committee for the purpose of carrying on the Geological Record; and that Mr. W. Topley be the Secretary.

That Dr. W. T. Blanford, Professor J. W. Judd, Mr. W. Carruthers, Dr. H. Woodward, and Mr. J. S. Gardner be reappointed a Committee for the purpose of reporting on the Fossil Plants of the Tertiary and Secondary Beds of the United Kingdom; and that Mr. J. S. Gardner be the Secretary.

That Professor Hillhouse, Mr. E. W. Badger, and Mr. A. W. Wills be a Committee for the purpose of collecting information as to the Disappearance of Native Plants from their local habitats; and that Professor Hillhouse be the Secretary.

That Professor Milnes Marshall, Dr. Sclater, Canon Tristram, Dr. Muirhead, Mr. W. R. Hughes, Mr. E. de Hamel, and Professor Bridge be a Committee for the purpose of preparing a report on the Herds of Wild Cattle in Chartley Park and other parks in Great Britain; and that Mr. W. R. Hughes be the Secretary.

That Professor M. Foster, Professor Bayley Balfour, Mr. Thiselton-Dyer, Dr. Trimen, Professor Bower, Professor Marshall Ward, Mr. Carruthers, and Professor Hartog be a Committee for the purpose of taking steps for the establishment of a Botanical Station at Peradeniya, Ceylon; and that Professor Bower be the Secretary.

That Professor McKendrick, Professor Cleland, and Dr. McGregor-Robertson be a Committee for the purpose of investigating the Mechanism of the Secretion of Urine; and that Dr. McGregor-Robertson be the Secretary.

That Sir Joseph Hooker, Captain Sir George Nares, Admiral Sir Leopold McClintock, Mr. Clements R. Markham, General Sir Henry Lefroy, General J. T. Walker, Professor Flower, Professor Huxley, Sir William Thomson, General Strachey, Sir John Lubbock, Mr. John Murray, and Admiral Sir Erasmus Ommanney be reappointed a Committee for the purpose of drawing attention to the desirability of further research in the Antarctic Regions; and that Admiral Sir Erasmus Ommanney be the Secretary.

That the Rev. Canon Carver, the Rev. H. B. George, Captain Douglas Galton, Professor Bonney, Mr. A. G. Vernon Harcourt, Professor T. McKenny Hughes, the Rev. H. W. Watson, the Rev. E. F. M. McCarthy, the Rev. A. R. Vardy, Professor Alfred Newton, the Rev. Canon Tristram, Professor Moseley, and Mr. E. G. Ravenstein be a Committee for the purpose of co-operating with the Royal Geographical Society in endeavouring to bring before the authorities of the Universities of Oxford and Cambridge the advisability of promoting the study of Geography by establishing special chairs for the purpose; and that Mr. E. G. Ravenstein be the Secretary.

That Mr. J. B. Martin, Mr. F. Y. Edgeworth, Mr. S. Bourne, Professor H. S. Foxwell, Professor Marshall, Professor Nicholson, Mr. R. H. Inglis Palgrave, and Professor Sidgwick be a Committee for the purpose of investigating the best methods of ascertaining and measuring Variations in the Value of the Monetary Standard; and that Mr. F. Y. Edgeworth be the Secretary.

That Dr. J. H. Gladstone, Professor Armstrong, Mr. William Shaen, Mr. Stephen Bourne, Miss Lydia Becker, Sir John Lubbock, Dr. H. W. Crosskey, Sir Richard Temple, Sir Henry E. Roscoe, Mr. James Heywood, and Professor N. Story Maskelyne be reappointed a Committee for the purpose of continuing the inquiries relating to the teaching of Science in Elementary Schools; and that Dr. J. H. Gladstone be the Secretary.

That Mr. W. H. Barlow, Sir F. J. Bramwell, Professor J. Thomson, Captain D. Galton, Mr. B. Baker, Professor W. C. Unwin, Professor A. B. W. Kennedy, Mr. C. Barlow, Mr. A. T. Atchison, and Professor H. S. Hele Shaw be reappointed a Committee for the purpose of obtaining information with reference to the Endurance of Metals under repeated and varying stresses, and the proper working stresses on railway bridges and other structures subject to varying loads; and that Mr. A. T. Atchison be the Secretary.

That Sir John Lubbock, Dr. John Evans, Professor Boyd Dawkins, Dr. R. Munro, Mr. Pengelly, Dr. Hicks, Mr. J. W. Davis, and Dr. Muirhead be a Committee for the purpose of ascertaining and recording the localities in the British Islands in which Evidences of the Existence of Prehistoric Inhabitants of the Country are found; and that Mr. J. W. Davis be the Secretary.

That Professor J. J. Thomson be requested to continue his Report on Electrical Theories.

That Mr. Glazebrook be requested to continue his Report on Optics.

That Mr. P. T. Main be requested to continue his Report on our experimental knowledge of the Properties of Matter with respect to volume, pressure, temperature, and specific heat.

That Mr. Mollison be requested to report on the present state of our knowledge of the Mathematical Theory of Thermal Conduction.

That Professor Armstrong be requested to prepare a Report on the Relation of Physical Properties to Chemical Constitution.

Communications ordered to be printed in extenso *in the Annual Report of the Association.*

Dr. A. König's paper 'On the Modern Development of Thomas Young's Theory of Colour-Vision.'

Mr. Harley's paper containing the explicit form of the Complete Cubic Differential Resolvent.

Professor Tilden's report 'On the Nature of Solution.'

Mr. J. W. Davis's paper 'On the Raygill Fissure.'

Mr. J. Player's paper 'On a Rapid Method of Estimating Silica in Rocks.'

Messrs. W. Shelford and A. H. Shield's paper 'On some Points for the Consideration of English Engineers with reference to the Design of Girder Bridges.'

Professor Hele Shaw and Mr. Edward Shaw's paper 'On the Sphere and Roller Mechanism for Transmitting Power' (with the necessary diagrams).

Mr. J. Wilson Swan's paper 'On Improvements in Electric Safety Lamps.'

Mr. W. S. Till's paper 'On the Birmingham District Drainage.'

Resolutions referred to the Council for Consideration, and Action if desirable.

That the Council be requested to consider the question of rendering the Reports and other papers communicated to the Association more readily accessible to the members and others by issuing a limited number of them in separate form, or in associated parts, in advance of the annual volume.

That the Council be requested to consider whether a memorial should be presented to Her Majesty's Government, urging them to undertake and supervise Agricultural Experiments, and to procure further and more complete Agricultural Statistics.

That the Council be requested to consider the advisability of calling the attention of the proprietor of Stonehenge to the danger in which several of the stones are at the present time from the burrowing of rabbits, and also to the desirability of removing the wooden props which support the horizontal stone of one of the trilithons; and in view of the great value of Stonehenge as an ancient national monument to express the hope of the Association that some steps will be taken to remedy these sources of danger to the stones.

Synopsis of Grants of Money appropriated to Scientific Purposes by the General Committee at the Birmingham Meeting in September 1886. *The Names of the Members entitled to call on the General Treasurer for the respective Grants are prefixed.*

Mathematics and Physics.

	£	*s.*	*d.*
*Stewart, Professor Balfour.—Solar Radiation	20	0	0
*Armstrong, Professor.—Electrolysis	50	0	0
*Brown, Professor Crum.—Ben Nevis Observatory	75	0	0
*Forbes, Professor G.—Standards of Light	10	0	0
*Darwin, Professor G. H.—Tidal Observations: Instructions	15	0	0
*Stewart, Professor Balfour.—Chepstow Meteorological Observatory	20	0	0
*Stewart, Professor Balfour.—Magnetic Observations	40	0	0
*Foster, Professor G. Carey.—Electrical Standards	50	0	0

Chemistry.

*M'Leod, Professor.—Silent Discharge of Electricity	20	0	0
Abney, Captain.—Absorption Spectra	40	0	0
Williamson, Professor A. W.—Translation of Foreign Records	5	0	0
Tilden, Professor.—Nature of Solution	20	0	0
Tilden, Professor.—Influence of Silicon on Steel	30	0	0

Geology.

*Bauerman, Mr. H.—Volcanic Phenomena of Vesuvius	20	0	0
*Etheridge, Mr. R.—Volcanic Phenomena of Japan	50	0	0
*Hughes, Professor T. McK.—Exploration of Cae Gwyn Cave	20	0	0
*Prestwich, Professor J.—Erratic Blocks	10	0	0
*Etheridge, Mr. R.—Fossil Phyllopoda	20	0	0
Williamson, Professor W. C.—Carboniferous Flora of Halifax	25	0	0
Bonney, Professor.—Microscopic Structure of the Rocks of Anglesey	10	0	0
Woodward, Dr. H.—Eocene Beds of the Isle of Wight	20	0	0
*Hull, Professor E.—Circulation of Underground Waters	5	0	0
*Grantham, Mr. R. B.—Erosion of Sea Coasts	15	0	0
Etheridge, Mr. R.—'Manure' Gravels of Wexford	10	0	0
Ball, Mr. Valentine.—Provincial Museum Reports	5	0	0
Carried forward	£605	0	0

* Reappointed.

	£	s.	d.
Brought forward	605	0	0

Biology.

Schäfer, Professor.—Lymphatic System	25	0	0
*Lankester, Professor Ray.—Naples Biological Station	100	0	0
Lankester, Professor Ray.—Plymouth Biological Station	50	0	0
*McKendrick, Professor.—Granton Biological Station	75	0	0
*Stainton, Mr. H. T.—Zoological Record	100	0	0
Thiselton-Dyer, Mr.—Flora of China	75	0	0
Sclater, Mr.—Flora and Fauna of the Cameroons	75	0	0
*Cordeaux, Mr. J.—Migration of Birds	30	0	0
Norman, Canon A. M.—British Marine Area	5	0	0

Geography.

*Walker, General J. T.—Bathy-Hypsographical Map	25	0	0
*Walker, General J. T.—Depth of Permanently Frozen Soil	5	0	0

Economic Science and Statistics.

*Sidgwick, Professor.—Regulation of Wages	10	0	0

Anthropology.

*Garson, Dr.—Prehistoric Races of Greek Islands	20	0	0
Pengelly, Mr.—British Barrows	20	0	0
*Tylor, Dr. E. B.—North-Western Tribes of Canada	50	0	0
*Galton, Mr. F.—Racial Photographs: Egyptian	20	0	0
Pitt-Rivers, General.—Anthropological Notes and Queries	10	0	0
	£1300	0	0

* Reappointed.

The Annual Meeting in 1887.

The Meeting at Manchester will commence on Wednesday, August 31.

Place of Meeting in 1888.

The Annual Meeting of the Association will be held at Bath.

General Statement of Sums which have been paid on account of Grants for Scientific Purposes.

1834.

	£	s.	d.
Tide Discussions	20	0	0

1835.

	£	s.	d.
Tide Discussions	62	0	0
British Fossil Ichthyology	105	0	0
	£167	0	0

1836.

	£	s.	d.
Tide Discussions	163	0	0
British Fossil Ichthyology	105	0	0
Thermometric Observations, &c.	50	0	0
Experiments on long-continued Heat	17	1	0
Rain-Gauges	9	13	0
Refraction Experiments	15	0	0
Lunar Nutation	60	0	0
Thermometers	15	6	0
	£435	0	0

1837.

	£	s.	d.
Tide Discussions	284	1	0
Chemical Constants	24	13	6
Lunar Nutation	70	0	0
Observations on Waves	100	12	0
Tides at Bristol	150	0	0
Meteorology and Subterranean Temperature	93	3	0
Vitrification Experiments	150	0	0
Heart Experiments	8	4	6
Barometric Observations	30	0	0
Barometers	11	18	6
	£922	12	6

1838.

	£	s.	d.
Tide Discussions	29	0	0
British Fossil Fishes	100	0	0
Meteorological Observations and Anemometer (construction)	100	0	0
Cast Iron (Strength of)	60	0	0
Animal and Vegetable Substances (Preservation of)	19	1	10
Railway Constants	41	12	10
Bristol Tides	50	0	0
Growth of Plants	75	0	0
Mud in Rivers	3	6	6
Education Committee	50	0	0
Heart Experiments	5	3	0
Land and Sea Level	267	8	7
Steam-vessels	100	0	0
Meteorological Committee	31	9	5
	£932	2	2

1839.

	£	s.	d.
Fossil Ichthyology	110	0	0
Meteorological Observations at Plymouth, &c.	63	10	0
Mechanism of Waves	144	2	0
Bristol Tides	35	18	6
Meteorology and Subterranean Temperature	21	11	0
Vitrification Experiments	9	4	7
Cast-Iron Experiments	103	0	0
Railway Constants	28	7	2
Land and Sea Level	274	1	4
Steam-vessels' Engines	100	0	0
Stars in Histoire Céleste	171	18	6
Stars in Lacaille	11	0	0
Stars in R.A.S. Catalogue	166	16	6
Animal Secretions	10	10	0
Steam Engines in Cornwall	50	0	0
Atmospheric Air	16	1	0
Cast and Wrought Iron	40	0	0
Heat on Organic Bodies	3	0	0
Gases on Solar Spectrum	22	0	0
Hourly Meteorological Observations, Inverness and Kingussie	49	7	8
Fossil Reptiles	118	2	9
Mining Statistics	50	0	0
	£1595	11	0

1840.

	£	s.	d.
Bristol Tides	100	0	0
Subterranean Temperature	13	13	6
Heart Experiments	18	19	0
Lungs Experiments	8	13	0
Tide Discussions	50	0	0
Land and Sea Level	6	11	1
Stars (Histoire Céleste)	242	10	0
Stars (Lacaille)	4	15	0
Stars (Catalogue)	264	0	0
Atmospheric Air	15	15	0
Water on Iron	10	0	0
Heat on Organic Bodies	7	0	0
Meteorological Observations	52	17	6
Foreign Scientific Memoirs	112	1	6
Working Population	100	0	0
School Statistics	50	0	0
Forms of Vessels	184	7	0
Chemical and Electrical Phenomena	40	0	0
Meteorological Observations at Plymouth	80	0	0
Magnetical Observations	185	13	9
	£1546	16	4

1841.

	£	s.	d.
Observations on Waves	30	0	0
Meteorology and Subterranean Temperature	8	8	0
Actinometers	10	0	0
Earthquake Shocks	17	7	0
Acrid Poisons	6	0	0
Veins and Absorbents	3	0	0
Mud in Rivers	5	0	0

	£	s.	d.
Marine Zoology	15	12	8
Skeleton Maps	20	0	0
Mountain Barometers	6	18	6
Stars (Histoire Céleste)	185	0	0
Stars (Lacaille)	79	5	0
Stars (Nomenclature of)	17	19	6
Stars (Catalogue of)	40	0	0
Water on Iron	50	0	0
Meteorological Observations at Inverness	20	0	0
Meteorological Observations (reduction of)	25	0	0
Fossil Reptiles	50	0	0
Foreign Memoirs	62	0	6
Railway Sections	38	1	0
Forms of Vessels	193	12	0
Meteorological Observations at Plymouth	55	0	0
Magnetical Observations	61	18	8
Fishes of the Old Red Sandstone	100	0	0
Tides at Leith	50	0	0
Anemometer at Edinburgh	69	1	10
Tabulating Observations	9	6	3
Races of Men	5	0	0
Radiate Animals	2	0	0
	£1235	10	11

1842.

	£	s.	d.
Dynamometric Instruments	113	11	2
Anoplura Britanniæ	52	12	0
Tides at Bristol	59	8	0
Gases on Light	30	14	7
Chronometers	26	17	6
Marine Zoology	1	5	0
British Fossil Mammalia	100	0	0
Statistics of Education	20	0	0
Marine Steam-vessels' Engines	28	0	0
Stars (Histoire Céleste)	59	0	0
Stars (Brit. Assoc. Cat. of)	110	0	0
Railway Sections	161	10	0
British Belemnites	50	0	0
Fossil Reptiles (publication of Report)	210	0	0
Forms of Vessels	180	0	0
Galvanic Experiments on Rocks	5	8	6
Meteorological Experiments at Plymouth	68	0	0
Constant Indicator and Dynamometric Instruments	90	0	0
Force of Wind	10	0	0
Light on Growth of Seeds	8	0	0
Vital Statistics	50	0	0
Vegetative Power of Seeds	8	1	11
Questions on Human Race	7	9	0
	£1449	17	8

1843.

	£	s.	d.
Revision of the Nomenclature of Stars	2	0	0
Reduction of Stars, British Association Catalogue	25	0	0
Anomalous Tides, Frith of Forth	120	0	0
Hourly Meteorological Observations at Kingussie and Inverness	77	12	8
Meteorological Observations at Plymouth	55	0	0
Whewell's Meteorological Anemometer at Plymouth	10	0	0
Meteorological Observations, Osler's Anemometer at Plymouth	20	0	0
Reduction of Meteorological Observations	30	0	0
Meteorological Instruments and Gratuities	39	6	0
Construction of Anemometer at Inverness	56	12	2
Magnetic Co-operation	10	8	10
Meteorological Recorder for Kew Observatory	50	0	0
Action of Gases on Light	18	16	1
Establishment at Kew Observatory, Wages, Repairs Furniture, and Sundries	133	4	7
Experiments by Captive Balloons	81	8	0
Oxidation of the Rails of Railways	20	0	0
Publication of Report on Fossil Reptiles	40	0	0
Coloured Drawings of Railway Sections	147	18	3
Registration of Earthquake Shocks	30	0	0
Report on Zoological Nomenclature	10	0	0
Uncovering Lower Red Sandstone near Manchester	4	4	6
Vegetative Power of Seeds	5	3	8
Marine Testacea (Habits of)	10	0	0
Marine Zoology	10	0	0
Marine Zoology	2	14	11
Preparation of Report on British Fossil Mammalia	100	0	0
Physiological Operations of Medicinal Agents	20	0	0
Vital Statistics	36	5	8
Additional Experiments on the Forms of Vessels	70	0	0
Additional Experiments on the forms of Vessels	100	0	0
Reduction of Experiments on the Forms of Vessels	100	0	0
Morin's Instrument and Constant Indicator	69	14	10
Experiments on the Strength of Materials	60	0	0
	£1565	10	2

1844.

	£	s.	d.
Meteorological Observations at Kingussie and Inverness	12	0	0
Completing Observations at Plymouth	35	0	0
Magnetic and Meteorological Co-operation	25	8	4
Publication of the British Association Catalogue of Stars	35	0	0
Observations on Tides on the East Coast of Scotland	100	0	0
Revision of the Nomenclature of Stars 1842	2	9	6
Maintaining the Establishment in Kew Observatory	117	17	3
Instruments for Kew Observatory	56	7	3
Influence of Light on Plants	10	0	0
Subterraneous Temperature in Ireland	5	0	0
Coloured Drawings of Railway Sections	15	17	6
Investigation of Fossil Fishes of the Lower Tertiary Strata	100	0	0
Registering the Shocks of Earthquakes 1842	23	11	10
Structure of Fossil Shells	20	0	0
Radiata and Mollusca of the Ægean and Red Seas 1842	100	0	0
Geographical Distributions of Marine Zoology......1842	0	10	0
Marine Zoology of Devon and Cornwall	10	0	0
Marine Zoology of Corfu	10	0	0
Experiments on the Vitality of Seeds	9	0	0
Experiments on the Vitality of Seeds 1842	8	7	3
Exotic Anoplura	15	0	0
Strength of Materials	100	0	0
Completing Experiments on the Forms of Ships	100	0	0
Inquiries into Asphyxia	10	0	0
Investigations on the Internal Constitution of Metals	50	0	0
Constant Indicator and Morin's Instrument 1842	10	0	0
	£981	12	8

1845.

	£	s.	d.
Publication of the British Association Catalogue of Stars	351	14	6
Meteorological Observations at Inverness	30	18	11
Magnetic and Meteorological Co-operation	16	16	8
Meteorological Instruments at Edinburgh	18	11	9
Reduction of Anemometrical Observations at Plymouth	25	0	0
Electrical Experiments at Kew Observatory	43	17	8
Maintaining the Establishment in Kew Observatory	149	15	0
For Kreil's Barometrograph	25	0	0
Gases from Iron Furnaces	50	0	0
The Actinograph	15	0	0
Microscopic Structure of Shells	20	0	0
Exotic Anoplura 1843	10	0	0
Vitality of Seeds 1843	2	0	7
Vitality of Seeds 1844	7	0	0
Marine Zoology of Cornwall	10	0	0
Physiological Action of Medicines	20	0	0
Statistics of Sickness and Mortality in York	20	0	0
Earthquake Shocks 1843	15	14	8
	£831	9	9

1846.

	£	s.	d.
British Association Catalogue of Stars 1844	211	15	0
Fossil Fishes of the London Clay	100	0	0
Computation of the Gaussian Constants for 1829	5	0	0
Maintaining the Establishment at Kew Observatory	146	16	7
Strength of Materials	60	0	0
Researches in Asphyxia	6	16	2
Examination of Fossil Shells	10	0	0
Vitality of Seeds 1844	2	15	10
Vitality of Seeds 1845	7	12	3
Marine Zoology of Cornwall	10	0	0
Marine Zoology of Britain	10	0	0
Exotic Anoplura 1844	25	0	0
Expenses attending Anemometers	11	7	6
Anemometers' Repairs	2	3	6
Atmospheric Waves	3	3	3
Captive Balloons 1844	8	19	8
Varieties of the Human Race 1844	7	6	3
Statistics of Sickness and Mortality in York	12	0	0
	£685	16	0

1847.

	£	s.	d.
Computation of the Gaussian Constants for 1829	50	0	0
Habits of Marine Animals	10	0	0
Physiological Action of Medicines	20	0	0
Marine Zoology of Cornwall	10	0	0
Atmospheric Waves	6	9	3
Vitality of Seeds	4	7	7
Maintaining the Establishment at Kew Observatory	107	8	6
	£208	5	4

1848.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	171	15	11
Atmospheric Waves	3	10	9
Vitality of Seeds	9	15	0
Completion of Catalogue of Stars	70	0	0
On Colouring Matters	5	0	0
On Growth of Plants	15	0	0
	£275	1	8

1849.

	£	s.	d.
Electrical Observations at Kew Observatory	50	0	0
Maintaining the Establishment at ditto	76	2	5
Vitality of Seeds	5	8	1
On Growth of Plants	5	0	0
Registration of Periodical Phenomena	10	0	0
Bill on Account of Anemometrical Observations	13	9	0
	£159	19	6

1850.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	255	18	0
Transit of Earthquake Waves	50	0	0
Periodical Phenomena	15	0	0
Meteorological Instruments, Azores	25	0	0
	£345	18	0

1851.

	£	s.	d.
Maintaining the Establishment at Kew Observatory (includes part of grant in 1849)	309	2	2
Theory of Heat	20	1	1
Periodical Phenomena of Animals and Plants	5	0	0
Vitality of Seeds	5	6	4
Influence of Solar Radiation	30	0	0
Ethnological Inquiries	12	0	0
Researches on Annelida	10	0	0
	£391	9	7

1852.

	£	s.	d.
Maintaining the Establishment at Kew Observatory (including balance of grant for 1850)	233	17	8
Experiments on the Conduction of Heat	5	2	9
Influence of Solar Radiations	20	0	0
Geological Map of Ireland	15	0	0
Researches on the British Annelida	10	0	0
Vitality of Seeds	10	6	2
Strength of Boiler Plates	10	0	0
	£304	6	7

1853.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	165	0	0
Experiments on the Influence of Solar Radiation	15	0	0
Researches on the British Annelida	10	0	0
Dredging on the East Coast of Scotland	10	0	0
Ethnological Queries	5	0	0
	£205	0	0

1854.

	£	s.	d.
Maintaining the Establishment at Kew Observatory (including balance of former grant)	330	15	4
Investigations on Flax	11	0	0
Effects of Temperature on Wrought Iron	10	0	0
Registration of Periodical Phenomena	10	0	0
British Annelida	10	0	0
Vitality of Seeds	5	2	3
Conduction of Heat	4	2	0
	£380	19	7

1855.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	425	0	0
Earthquake Movements	10	0	0
Physical Aspect of the Moon	11	8	5
Vitality of Seeds	10	7	11
Map of the World	15	0	0
Ethnological Queries	5	0	0
Dredging near Belfast	4	0	0
	£480	16	4

1856.

	£	s.	d.
Maintaining the Establishment at Kew Observatory:— 1854 £ 75 0 0 1855 £500 0 0	575	0	0
Strickland's Ornithological Synonyms	100	0	0
Dredging and Dredging Forms	9	13	0
Chemical Action of Light	20	0	0
Strength of Iron Plates	10	0	0
Registration of Periodical Phenomena	10	0	0
Propagation of Salmon	10	0	0
	£734	13	9

1857.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	350	0	0
Earthquake Wave Experiments	40	0	0
Dredging near Belfast	10	0	0
Dredging on the West Coast of Scotland	10	0	0

	£	s.	d.
Investigations into the Mollusca of California	10	0	0
Experiments on Flax	5	0	0
Natural History of Madagascar	20	0	0
Researches on British Annelida	25	0	0
Report on Natural Products imported into Liverpool	10	0	0
Artificial Propagation of Salmon	10	0	0
Temperature of Mines	7	8	0
Thermometers for Subterranean Observations	5	7	4
Life-boats	5	0	0
	£507	15	4

1858.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Earthquake Wave Experiments	25	0	0
Dredging on the West Coast of Scotland	10	0	0
Dredging near Dublin	5	0	0
Vitality of Seeds	5	5	0
Dredging near Belfast	18	13	2
Report on the British Annelida	25	0	0
Experiments on the production of Heat by Motion in Fluids	20	0	0
Report on the Natural Products imported into Scotland	10	0	0
	£618	18	2

1859.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Dredging near Dublin	15	0	0
Osteology of Birds	50	0	0
Irish Tunicata	5	0	0
Manure Experiments	20	0	0
British Medusidæ	5	0	0
Dredging Committee	5	0	0
Steam-vessels' Performance	5	0	0
Marine Fauna of South and West of Ireland	10	0	0
Photographic Chemistry	10	0	0
Lanarkshire Fossils	20	0	1
Balloon Ascents	39	11	0
	£684	11	1

1860.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Dredging near Belfast	16	6	0
Dredging in Dublin Bay	15	0	0
Inquiry into the Performance of Steam-vessels	124	0	0
Explorations in the Yellow Sandstone of Dura Don	20	0	0
Chemico-mechanical Analysis of Rocks and Minerals	25	0	0
Researches on the Growth of Plants	10	0	0
Researches on the Solubility of Salts	30	0	0
Researches on the Constituents of Manures	25	0	0
Balance of Captive Balloon Accounts	1	13	6
	£766	19	6

1861.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	500	0	0
Earthquake Experiments	25	0	0
Dredging North and East Coasts of Scotland	23	0	0
Dredging Committee:— 1860......£50 0 0 1861......£22 0 0	72	0	0
Excavations at Dura Den	20	0	0
Solubility of Salts	20	0	0
Steam-vessel Performance	150	0	0
Fossils of Lesmahago	15	0	0
Explorations at Uriconium	20	0	0
Chemical Alloys	20	0	0
Classified Index to the Transactions	100	0	0
Dredging in the Mersey and Dee	5	0	0
Dip Circle	30	0	0
Photoheliographic Observations	50	0	0
Prison Diet	20	0	0
Gauging of Water	10	0	0
Alpine Ascents	6	5	10
Constituents of Manures	25	0	0
	£1111	5	10

1862.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	500	0	0
Patent Laws	21	6	0
Mollusca of N.-W. of America	10	0	0
Natural History by Mercantile Marine	5	0	0
Tidal Observations	25	0	0
Photoheliometer at Kew	40	0	0
Photographic Pictures of the Sun	150	0	0
Rocks of Donegal	25	0	0
Dredging Durham and Northumberland	25	0	0
Connexion of Storms	20	0	0
Dredging North-east Coast of Scotland	6	9	6
Ravages of Teredo	3	11	0
Standards of Electrical Resistance	50	0	0
Railway Accidents	10	0	0
Balloon Committee	200	0	0
Dredging Dublin Bay	10	0	0

	£	s.	d.
Dredging the Mersey	5	0	0
Prison Diet	20	0	0
Gauging of Water	12	10	0
Steamships' Performance	150	0	0
Thermo-Electric Currents	5	0	0
	£1293	16	6

1863.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Balloon Committee deficiency	70	0	0
Balloon Ascents (other expenses)	25	0	0
Entozoa	25	0	0
Coal Fossils	20	0	0
Herrings	20	0	0
Granites of Donegal	5	0	0
Prison Diet	20	0	0
Vertical Atmospheric Movements	13	0	0
Dredging Shetland	50	0	0
Dredging North-east coast of Scotland	25	0	0
Dredging Northumberland and Durham	17	3	10
Dredging Committee superintendence	10	0	0
Steamship Performance	100	0	0
Balloon Committee	200	0	0
Carbon under pressure	10	0	0
Volcanic Temperature	100	0	0
Bromide of Ammonium	8	0	0
Electrical Standards	100	0	0
Electrical Construction and Distribution	40	0	0
Luminous Meteors	17	0	0
Kew Additional Buildings for Photoheliograph	100	0	0
Thermo-Electricity	15	0	0
Analysis of Rocks	8	0	0
Hydroida	10	0	0
	£1608	3	10

1864.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Coal Fossils	20	0	0
Vertical Atmospheric Movements	20	0	0
Dredging Shetland	75	0	0
Dredging Northumberland	25	0	0
Balloon Committee	200	0	0
Carbon under pressure	10	0	0
Standards of Electric Resistance	100	0	0
Analysis of Rocks	10	0	0
Hydroida	10	0	0
Askham's Gift	50	0	0
Nitrite of Amyle	10	0	0
Nomenclature Committee	5	0	0
Rain-Gauges	19	15	8
Cast-Iron Investigation	20	0	0
Tidal Observations in the Humber	50	0	0
Spectral Rays	45	0	0
Luminous Meteors	20	0	0
	£1289	15	8

1865.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Balloon Committee	100	0	0
Hydroida	13	0	0
Rain-Gauges	30	0	0
Tidal Observations in the Humber	6	8	0
Hexylic Compounds	20	0	0
Amyl Compounds	20	0	0
Irish Flora	25	0	0
American Mollusca	3	9	0
Organic Acids	20	0	0
Lingula Flags Excavation	10	0	0
Eurypterus	50	0	0
Electrical Standards	100	0	0
Malta Caves Researches	30	0	0
Oyster Breeding	25	0	0
Gibraltar Caves Researches	150	0	0
Kent's Hole Excavations	100	0	0
Moon's Surface Observations	35	0	0
Marine Fauna	25	0	0
Dredging Aberdeenshire	25	0	0
Dredging Channel Islands	50	0	0
Zoological Nomenclature	5	0	0
Resistance of Floating Bodies in Water	100	0	0
Bath Waters Analysis	8	10	10
Luminous Meteors	40	0	0
	£1591	7	10

1866.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Lunar Committee	64	13	4
Balloon Committee	50	0	0
Metrical Committee	50	0	0
British Rainfall	50	0	0
Kilkenny Coal Fields	16	0	0
Alum Bay Fossil Leaf-Bed	15	0	0
Luminous Meteors	50	0	0
Lingula Flags Excavation	20	0	0
Chemical Constitution of Cast Iron	50	0	0
Amyl Compounds	25	0	0
Electrical Standards	100	0	0
Malta Caves Exploration	30	0	0
Kent's Hole Exploration	200	0	0
Marine Fauna, &c., Devon and Cornwall	25	0	0
Dredging Aberdeenshire Coast	25	0	0
Dredging Hebrides Coast	50	0	0
Dredging the Mersey	5	0	0
Resistance of Floating Bodies in Water	50	0	0
Polycyanides of Organic Radicals	29	0	0

	£	s.	d.
Rigor Mortis	10	0	0
Irish Annelida	15	0	0
Catalogue of Crania	50	0	0
Didine Birds of Mascarene Islands	50	0	0
Typical Crania Researches	30	0	0
Palestine Exploration Fund	100	0	0
	£1750	13	4

1867.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Meteorological Instruments, Palestine	50	0	0
Lunar Committee	120	0	0
Metrical Committee	30	0	0
Kent's Hole Explorations	100	0	0
Palestine Explorations	50	0	0
Insect Fauna, Palestine	30	0	0
British Rainfall	50	0	0
Kilkenny Coal Fields	25	0	0
Alum Bay Fossil Leaf-Bed	25	0	0
Luminous Meteors	50	0	0
Bournemouth, &c., Leaf-Beds	30	0	0
Dredging Shetland	75	0	0
Steamship Reports Condensation	100	0	0
Electrical Standards	100	0	0
Ethyl and Methyl series	25	0	0
Fossil Crustacea	25	0	0
Sound under Water	24	4	0
North Greenland Fauna	75	0	0
Do. Plant Beds	100	0	0
Iron and Steel Manufacture	25	0	0
Patent Laws	30	0	0
	£1739	4	0

1868.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Lunar Committee	120	0	0
Metrical Committee	50	0	0
Zoological Record	100	0	0
Kent's Hole Explorations	150	0	0
Steamship Performances	100	0	0
British Rainfall	50	0	0
Luminous Meteors	50	0	0
Organic Acids	60	0	0
Fossil Crustacea	25	0	0
Methyl Series	25	0	0
Mercury and Bile	25	0	0
Organic Remains in Limestone Rocks	25	0	0
Scottish Earthquakes	20	0	0
Fauna, Devon and Cornwall	30	0	0
British Fossil Corals	50	0	0
Bagshot Leaf-Beds	50	0	0
Greenland Explorations	100	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	50	0	0
Spectroscopic Investigations of Animal Substances	5	0	0
Secondary Reptiles, &c.	30	0	0
British Marine Invertebrate Fauna	100	0	0
	£1940	0	0

1869.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Lunar Committee	50	0	0
Metrical Committee	25	0	0
Zoological Record	100	0	0
Committee on Gases in Deep-well Water	25	0	0
British Rainfall	50	0	0
Thermal Conductivity of Iron, &c.	30	0	0
Kent's Hole Explorations	150	0	0
Steamship Performances	30	0	0
Chemical Constitution of Cast Iron	80	0	0
Iron and Steel Manufacture	100	0	0
Methyl Series	30	0	0
Organic Remains in Limestone Rocks	10	0	0
Earthquakes in Scotland	10	0	0
British Fossil Corals	50	0	0
Bagshot Leaf-Beds	30	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	30	0	0
Spectroscopic Investigations of Animal Substances	5	0	0
Organic Acids	12	0	0
Kiltorcan Fossils	20	0	0
Chemical Constitution and Physiological Action Relations	15	0	0
Mountain Limestone Fossils	25	0	0
Utilization of Sewage	10	0	0
Products of Digestion	10	0	0
	£1622	0	0

1870.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Metrical Committee	25	0	0
Zoological Record	100	0	0
Committee on Marine Fauna	20	0	0
Ears in Fishes	10	0	0
Chemical Nature of Cast Iron	80	0	0
Luminous Meteors	30	0	0
Heat in the Blood	15	0	0
British Rainfall	100	0	0
Thermal Conductivity of Iron, &c.	20	0	0
British Fossil Corals	50	0	0
Kent's Hole Explorations	150	0	0
Scottish Earthquakes	4	0	0
Bagshot Leaf-Beds	15	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	50	0	0
Kiltorcan Quarries Fossils	20	0	0

	£	s.	d.
Mountain Limestone Fossils	25	0	0
Utilization of Sewage	50	0	0
Organic Chemical Compounds	30	0	0
Onny River Sediment	3	0	0
Mechanical Equivalent of Heat	50	0	0
	£1572	0	0

1871.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Monthly Reports of Progress in Chemistry	100	0	0
Metrical Committee	25	0	0
Zoological Record	100	0	0
Thermal Equivalents of the Oxides of Chlorine	10	0	0
Tidal Observations	100	0	0
Fossil Flora	25	0	0
Luminous Meteors	30	0	0
British Fossil Corals	25	0	0
Heat in the Blood	7	2	6
British Rainfall	50	0	0
Kent's Hole Explorations	150	0	0
Fossil Crustacea	25	0	0
Methyl Compounds	25	0	0
Lunar Objects	20	0	0
Fossil Coral Sections, for Photographing	20	0	0
Bagshot Leaf-Beds	20	0	0
Moab Explorations	100	0	0
Gaussian Constants	40	0	0
	£1472	2	6

1872.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	300	0	0
Metrical Committee	75	0	0
Zoological Record	100	0	0
Tidal Committee	200	0	0
Carboniferous Corals	25	0	0
Organic Chemical Compounds	25	0	0
Exploration of Moab	100	0	0
Terato-Embryological Inquiries	10	0	0
Kent's Cavern Exploration	100	0	0
Luminous Meteors	20	0	0
Heat in the Blood	15	0	0
Fossil Crustacea	25	0	0
Fossil Elephants of Malta	25	0	0
Lunar Objects	20	0	0
Inverse Wave-Lengths	20	0	0
British Rainfall	100	0	0
Poisonous Substances Antagonism	10	0	0
Essential Oils, Chemical Constitution, &c.	40	0	0
Mathematical Tables	50	0	0
Thermal Conductivity of Metals	25	0	0
	£1285	0	0

1873.

	£	s.	d.
Zoological Record	100	0	0
Chemistry Record	200	0	0
Tidal Committee	400	0	0
Sewage Committee	100	0	0
Kent's Cavern Exploration	150	0	0
Carboniferous Corals	25	0	0
Fossil Elephants	25	0	0
Wave-Lengths	150	0	0
British Rainfall	100	0	0
Essential Oils	30	0	0
Mathematical Tables	100	0	0
Gaussian Constants	10	0	0
Sub-Wealden Explorations	25	0	0
Underground Temperature	150	0	0
Settle Cave Exploration	50	0	0
Fossil Flora, Ireland	20	0	0
Timber Denudation and Rainfall	20	0	0
Luminous Meteors	30	0	0
	£1685	0	0

1874.

	£	s.	d.
Zoological Record	100	0	0
Chemistry Record	100	0	0
Mathematical Tables	100	0	0
Elliptic Functions	100	0	0
Lightning Conductors	10	0	0
Thermal Conductivity of Rocks	10	0	0
Anthropological Instructions, &c.	50	0	0
Kent's Cavern Exploration	150	0	0
Luminous Meteors	30	0	0
Intestinal Secretions	15	0	0
British Rainfall	100	0	0
Essential Oils	10	0	0
Sub-Wealden Explorations	25	0	0
Settle Cave Exploration	50	0	0
Mauritius Meteorological Research	100	0	0
Magnetization of Iron	20	0	0
Marine Organisms	30	0	0
Fossils, North-West of Scotland	2	10	0
Physiological Action of Light	20	0	0
Trades Unions	25	0	0
Mountain Limestone-Corals	25	0	0
Erratic Blocks	10	0	0
Dredging, Durham and Yorkshire Coasts	28	5	0
High Temperature of Bodies	30	0	0
Siemens's Pyrometer	3	6	0
Labyrinthodonts of Coal-Measures	7	15	0
	£1151	16	0

1875.

	£	s.	d.
Elliptic Functions	100	0	0
Magnetization of Iron	20	0	0
British Rainfall	120	0	0
Luminous Meteors	30	0	0
Chemistry Record	100	0	0

	£	s.	d.
Specific Volume of Liquids...	25	0	0
Estimation of Potash and Phosphoric Acid..............	10	0	0
Isometric Cresols	20	0	0
Sub-Wealden Explorations ...	100	0	0
Kent's Cavern Exploration...	100	0	0
Settle Cave Exploration	50	0	0
Earthquakes in Scotland	15	0	0
Underground Waters	10	0	0
Development of Myxinoid Fishes	20	0	0
Zoological Record..............	100	0	0
Instructions for Travellers ...	20	0	0
Intestinal Secretions	20	0	0
Palestine Exploration	100	0	0
	£960	0	0

1876.

	£	s.	d.
Printing Mathematical Tables	159	4	2
British Rainfall.................	100	0	0
Ohm's Law.......................	9	15	0
Tide Calculating Machine ...	200	0	0
Specific Volume of Liquids...	25	0	0
Isomeric Cresols	10	0	0
Action of Ethyl Bromobutyrate on Ethyl Sodacetoacetate..........................	5	0	0
Estimation of Potash and Phosphoric Acid..............	13	0	0
Exploration of Victoria Cave, Settle	100	0	0
Geological Record..............	100	0	0
Kent's Cavern Exploration ...	100	0	0
Thermal Conductivities of Rocks	10	0	0
Underground Waters	10	0	0
Earthquakes in Scotland......	1	10	0
Zoological Record..............	100	0	0
Close Time	5	0	0
Physiological Action of Sound	25	0	0
Zoological Station..............	75	0	0
Intestinal Secretions	15	0	0
Physical Characters of Inhabitants of British Isles......	13	15	0
Measuring Speed of Ships ...	10	0	0
Effect of Propeller on turning of Steam Vessels	5	0	0
	£1092	4	2

1877.

	£	s.	d.
Liquid Carbonic Acids in Minerals	20	0	0
Elliptic Functions	250	0	0
Thermal Conductivity of Rocks	9	11	7
Zoological Record..............	100	0	0
Kent's Cavern	100	0	0
Zoological Station at Naples	75	0	0
Luminous Meteors	30	0	0
Elasticity of Wires	100	0	0
Dipterocarpæ, Report on	20	0	0
Mechanical Equivalent of Heat............................	35	0	0
Double Compounds of Cobalt and Nickel	8	0	0
Underground Temperatures	50	0	0
Settle Cave Exploration	100	0	0
Underground Waters in New Red Sandstone	10	0	0
Action of Ethyl Bromobutyrate on Ethyl Sodacetoacetate	10	0	0
British Earthworks	25	0	0
Atmospheric Elasticity in India	15	0	0
Development of Light from Coal-gas	20	0	0
Estimation of Potash and Phosphoric Acid..............	1	18	0
Geological Record..............	100	0	0
Anthropometric Committee	34	0	0
Physiological Action of Phosphoric Acid, &c...............	15	0	0
	£1128	9	7

1878.

	£	s.	d.
Exploration of Settle Caves	100	0	0
Geological Record..............	100	0	0
Investigation of Pulse Phenomena by means of Syphon Recorder	10	0	0
Zoological Station at Naples	75	0	0
Investigation of Underground Waters..........................	15	0	0
Transmission of Electrical Impulses through Nerve Structure.......................	30	0	0
Calculation of Factor Table of Fourth Million	100	0	0
Anthropometric Committee...	66	0	0
Chemical Composition and Structure of less known Alkaloids...........	25	0	0
Exploration of Kent's Cavern	50	0	0
Zoological Record	100	0	0
Fermanagh Caves Exploration	15	0	0
Thermal Conductivity of Rocks	4	16	6
Luminous Meteors...............	10	0	0
Ancient Earthworks	25	0	0
	£725	16	6

1879.

	£	s.	d.
Table at the Zoological Station, Naples	75	0	0
Miocene Flora of the Basalt of the North of Ireland ...	20	0	0
Illustrations for a Monograph on the Mammoth	17	0	0
Record of Zoological Literature	100	0	0
Composition and Structure of less-known Alkaloids	25	0	0

	£	s.	d.
Exploration of Caves in Borneo	50	0	0
Kent's Cavern Exploration	100	0	0
Record of the Progress of Geology	100	0	0
Fermanagh Caves Exploration	5	0	0
Electrolysis of Metallic Solutions and Solutions of Compound Salts	25	0	0
Anthropometric Committee	50	0	0
Natural History of Socotra	100	0	0
Calculation of Factor Tables for 5th and 6th Millions	150	0	0
Circulation of Underground Waters	10	0	0
Steering of Screw Steamers	10	0	0
Improvements in Astronomical Clocks	30	0	0
Marine Zoology of South Devon	20	0	0
Determination of Mechanical Equivalent of Heat	12	15	6
Specific Inductive Capacity of Sprengel Vacuum	40	0	0
Tables of Sun-heat Coefficients	30	0	0
Datum Level of the Ordnance Survey	10	0	0
Tables of Fundamental Invariants of Algebraic Forms	36	14	9
Atmospheric Electricity Observations in Madeira	15	0	0
Instrument for Detecting Fire-damp in Mines	22	0	0
Instruments for Measuring the Speed of Ships	17	1	8
Tidal Observations in the English Channel	10	0	0
	£1080	11	11

1880.

	£	s.	d.
New Form of High Insulation Key	10	0	0
Underground Temperature	10	0	0
Determination of the Mechanical Equivalent of Heat	8	5	0
Elasticity of Wires	50	0	0
Luminous Meteors	30	0	0
Lunar Disturbance of Gravity	30	0	0
Fundamental Invariants	8	5	0
Laws of Water Friction	20	0	0
Specific Inductive Capacity of Sprengel Vacuum	20	0	0
Completion of Tables of Sun-heat Coefficients	50	0	0
Instrument for Detection of Fire-damp in Mines	10	0	0
Inductive Capacity of Crystals and Paraffines	4	17	7
Report on Carboniferous Polyzoa	10	0	0
Caves of South Ireland	10	0	0
Viviparous Nature of Ichthyosaurus	10	0	0
Kent's Cavern Exploration	50	0	0
Geological Record	100	0	0
Miocene Flora of the Basalt of North Ireland	15	0	0
Underground Waters of Permian Formations	5	0	0
Record of Zoological Literature	100	0	0
Table at Zoological Station at Naples	75	0	0
Investigation of the Geology and Zoology of Mexico	50	0	0
Anthropometry	50	0	0
Patent Laws	5	0	0
	£731	7	7

1881.

	£	s.	d.
Lunar Disturbance of Gravity	30	0	0
Underground Temperature	20	0	0
High Insulation Key	5	0	0
Tidal Observations	10	0	0
Fossil Polyzoa	10	0	0
Underground Waters	10	0	0
Earthquakes in Japan	25	0	0
Tertiary Flora	20	0	0
Scottish Zoological Station	50	0	0
Naples Zoological Station	75	0	0
Natural History of Socotra	50	0	0
Zoological Record	100	0	0
Weights and Heights of Human Beings	30	0	0
Electrical Standards	25	0	0
Anthropological Notes and Queries	9	0	0
Specific Refractions	7	3	1
	£476	3	1

1882.

	£	s.	d.
Tertiary Flora of North of Ireland	20	0	0
Exploration of Caves of South of Ireland	10	0	0
Fossil Plants of Halifax	15	0	0
Fundamental Invariants of Algebraical Forms	76	1	11
Record of Zoological Literature	100	0	0
British Polyzoa	10	0	0
Naples Zoological Station	80	0	0
Natural History of Timor-laut	100	0	0
Conversion of Sedimentary Materials into Metamorphic Rocks	10	0	0
Natural History of Socotra	100	0	0
Circulation of Underground Waters	15	0	0
Migration of Birds	15	0	0
Earthquake Phenomena of Japan	25	0	0

	£	s.	d.
Geological Map of Europe ...	25	0	0
Elimination of Nitrogen by Bodily Exercise..............	50	0	0
Anthropometric Committee...	50	0	0
Photographing Ultra-Violet Spark Spectra	25	0	0
Exploration of Raygill Fissure	20	0	0
Calibration of Mercurial Thermometers	20	0	0
Wave-length Tables of Spectra of Elements..............	50	0	0
Geological Record..............	100	0	0
Standards for Electrical Measurements	100	0	0
Exploration of Central Africa	100	0	0
Albuminoid Substances of Serum	10	0	0
	£1126	1	11

1883.

Natural History of Timor-laut	50	0	0
British Fossil Polyzoa	10	0	0
Circulation of Underground Waters..........................	15	0	0
Zoological Literature Record	100	0	0
Exploration of Mount Kilima-njaro.......................	500	0	0
Erosion of Sea-coast of England and Wales	10	0	0
Fossil Plants of Halifax	20	0	0
Elimination of Nitrogen by Bodily Exercise...............	38	3	3
Isomeric Naphthalene Derivatives........................	15	0	0
Zoological Station at Naples	80	0	0
Investigation of Loughton Camp	10	0	0
Earthquake Phenomena of Japan	50	0	0
Meteorological Observations on Ben Nevis	50	0	0
Fossil Phyllopoda of Palæozoic Rocks	25	0	0
Migration of Birds	20	0	0
Geological Record..............	50	0	0
Exploration of Caves in South of Ireland	10	0	0
Scottish Zoological Station ...	25	0	0
Screw Gauges.....................	5	0	0
	£1083	3	3

1884.

	£	s.	d.
Zoological Literature Record	100	0	0
Fossil Polyzoa....................	10	0	0
Exploration of Mount Kilima-njaro, East Africa	500	0	0
Anthropometric Committee...	10	0	0
Fossil Plants of Halifax	15	0	0
International Geological Map	20	0	0
Erratic Blocks of England ...	10	0	0
Natural History of Timor-laut	50	0	0
Coagulation of Blood...........	100	0	0
Naples Zoological Station ...	80	0	0
Bibliography of Groups of Invertebrata	50	0	0
Earthquake Phenomena of Japan	75	0	0
Fossil Phyllopoda of Palæozoic Rocks	15	0	0
Meteorological Observatory at Chepstow......................	25	0	0
Migration of Birds..............	20	0	0
Collecting and Investigating Meteoric Dust.................	20	0	0
Circulation of Underground Waters........................	5	0	0
Ultra-Violet Spark Spectra ...	8	4	0
Tidal Observations..............	10	0	0
Meteorological Observations on Ben Nevis	50	0	0
	£1173	4	0

1885.

Zoological Literature Record.	100	0	0
Vapour Pressures, &c., of Salt Solutions.......................	25	0	0
Physical Constants of Solutions............................	20	0	0
Recent Polyzoa	10	0	0
Naples Zoological Station ...	100	0	0
Exploration of Mount Kilimanjaro	25	0	0
Fossil Plants of British Tertiary and Secondary Beds .	50	0	0
Calculating Tables in Theory of Numbers....................	100	0	0
Exploration of New Guinea...	200	0	0
Exploration of Mount Roraima	100	0	0
Meteorological Observations on Ben Nevis	50	0	0
Volcanic Phenomena of Vesuvius	25	0	0
Biological Stations on Coasts of United Kingdom	150	0	0
Meteoric Dust	70	0	0
Marine Biological Station at Granton	100	0	0
Fossil Phyllopoda of Palæozoic Rocks	25	0	0
Migration of Birds	30	0	0
Synoptic Chart of Indian Ocean	50	0	0
Circulation of Underground Waters........................	10	0	0
Geological Record	50	0	0
Reduction of Tidal Observations............................	10	0	0
Earthquake Phenomena of Japan	70	0	0
Raygill Fissure	15	0	0
	£1385	0	0

1886.	£	s.	d.
Zoological Literature Record	100	0	0
Exploration of New Guinea	150	0	0
Secretion of Urine	10	0	0
Researches in Food-Fishes and Invertebrata at St. Andrews	75	0	0
Electrical Standards	40	0	0
Volcanic Phenomena of Vesuvius	30	0	0
Naples Zoological Station	50	0	0
Meteorological Observations on Ben Nevis	100	0	0
Prehistoric Race in Greek Islands	20	0	0
North-Western Tribes of Canada	50	0	0
Fossil Plants of British Tertiary and Secondary Beds	20	0	0
Regulation of Wages under Sliding Scales	10	0	0
Exploration of Caves in North Wales	25	0	0
Migration of Birds	30	0	0
Geological Record	100	0	0
Chemical Nomenclature	5	0	0
Fossil Phyllopoda of Palæozoic Rocks	15	0	0
Solar Radiation	9	10	6
Magnetic Observations	10	10	0
Tidal Observations	50	0	0
Marine Biological Station at Granton	75	0	0
Physical and Chemical Bearings of Electrolysis	20	0	0
	£995	0	6

General Meetings.

On Wednesday, September 1, at 8 P.M., in the Town Hall, the Right Hon. Sir Lyon Playfair, K.C.B., M.P., Ph.D., LL.D., F.R.S.L. & E., F.C.S., resigned the office of President to Principal Sir J. William Dawson, C.M.G., M.A., LL.D., F.R.S., F.G.S., who took the Chair, and delivered an Address, for which see page 1.

On Thursday, September 2, at 8 P.M., a Soirée took place at the Exhibition, Bingley Hall.

On Friday, September 3, at 8.30 P.M., in the Town Hall, Mr. A. W. Rücker, M.A., F.R.S., delivered a Discourse on ‘Soap Bubbles.’

On Monday, September 6, at 8.30 P.M., in the Town Hall, Professor W. Rutherford, M.D., delivered a Discourse on ‘The Sense of Hearing.’

On Tuesday, September 7, at 8 P.M., a Soirée took place in the Council House and Museum and Art Gallery.

On Wednesday, September 8, at 2.30 P.M., the concluding General Meeting took place in the Town Hall, when the Proceedings of the General Committee and the Grants of Money for Scientific purposes were explained to the Members.

The Meeting was then adjourned to Manchester. [The Meeting is appointed to commence on Wednesday, August 31, 1887.]

PRESIDENT'S ADDRESS.

ADDRESS

BY

SIR J. WILLIAM DAWSON,

C.M.G., M.A., LL.D., F.R.S., F.G.S., Principal and Vice-Chancellor
of McGill University, Montreal, Canada,

PRESIDENT.

TWENTY-ONE years have passed away since the last meeting of the British Association in this great central city of England. At the third Birmingham meeting—that of 1865—I had the pleasure of being present, and had the honour of being one of the Vice-Presidents of Section C. At that meeting my friend John Phillips, one of the founders of the Association, occupied the Presidential chair, and I cannot better introduce what I have to say this evening than by the eloquent words in which he then addressed you:—'Assembled for the third time in this busy centre of industrious England, amid the roar of engines and clang of hammers, where the strongest powers of nature are trained to work in the fairy chains of art, how softly and fittingly falls upon the ear the accent of Science, the friend of that art, and the guide of that industry! Here where Priestley analysed the air, and Watt obtained the mastery over steam, it well becomes the students of nature to gather round the standard which they carried so far into the fields of knowledge. And when on other occasions we meet in quiet colleges and academic halls, how gladly welcome is the union of fresh discoveries and new inventions with the solid and venerable truths which are there treasured and taught. Long may such union last; the fair alliance of cultivated thought and practical skill; for by it labour is dignified and science fertilised, and the condition of human society exalted.' These were the words of a man who, while earnest in the pursuit of science, was full of broad and kindly sympathy for his fellow-men, and of hopeful confidence in the future. We have but to turn to the twenty Reports of this Association, issued since 1865, to see the realisation of that union of science and art to which he so confidently looked forward, and to appreciate the stupendous results which it has achieved. In one department alone—that to which my predecessor in this chair so eloquently adverted in Aberdeen, the department of education in science—how much has been accomplished since 1865. Phillips himself lived to see a great revolution in this respect at Oxford. But no one in 1865 could have anticipated that immense development of local schools of science of which your own Mason College and your admirable technical, industrial, and art schools are eminent examples. Based on the general education given by the new system of Board schools, with which the name of the late W. E. Forster will ever be honourably connected, and extending its influence upward to special training and to the highest university examinations, this new scientific culture is opening paths of honourable ambition to the men and women of England scarcely dreamed of in 1865. I sympathise with the earnest appeal of Sir Lyon Playfair, in his Aberdeen address, in favour of scientific education; but visiting England at rare intervals, I am naturally more impressed with the progress that has been made than with the vexatious delays which have occurred, and am perhaps better able to appreciate the vast strides that have been taken in the direction of that complete and all-pervading culture in science which he has so ably advocated.

No one could have anticipated twenty years ago that a Birmingham manufacturer, in whose youthful days there were no schools of science for the people, was about to endow a college, not only worthy of this great city, but one of its brightest ornaments.[1] Nor could anyone have foreseen the great development of local scientific societies, like your Midland Institute and Philosophical Society, which are now flourishing in every large town and in many of those of less magnitude. The period of twenty-one years that has elapsed since the last Birmingham meeting has also been an era of public museums and laboratories for the teaching of science, from the magnificent national institutions at South Kensington and those of the great universities and their colleges down to those of the schools and field clubs in country towns. It has besides been an era of gigantic progress in original work and in publication, —a progress so rapid that workers in every branch of study have been reluctantly obliged to narrow in more and more their range of reading and of effort to keep abreast of the advance in their several departments. Lastly these twenty-one years have been characterised as the 'coming of age' of that great system of philosophy with which the names of three Englishmen, Darwin, Spencer, and Wallace, are associated as its founders. Whatever opinions one may entertain as to the sufficiency and finality of this philosophy there can be no question as to its influence on scientific thought. On the one hand it is inaccurate to compare it with so entirely different things as the discovery of the chemical elements and of the law of gravitation; on the other, it is scarcely fair to characterise it as a

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[1] It was in 1865 that Sir Josiah Mason was, quietly and without any public note, beginning to lay the foundation of his orphanage at Erdington.

mere 'confused development' of the mind of the age. It is indeed a new attempt of science in its maturer years to grapple with those mysterious questions of origins which occupied it in the days of its infancy, and it is to be hoped that it may not, like the Titans of ancient fable, be hurled back from heaven, or like the first mother find the knowledge to which it aspires a bitter thing. In any case we should fully understand the responsibility which we incur when in these times of full-grown science we venture to deal with the great problem of origins, and should be prepared to find that in this field the new philosophy, like those which have preceded it, may meet with very imperfect success. The agitation of these subjects has already brought science into close relations, sometimes friendly, sometimes hostile, it is to be hoped in the end helpful, with those great and awful questions of the ultimate destiny of humanity, and its relations to its Creator, which must always be nearer to the human heart than any of the achievements of science on its own ground. In entering on such questions we should proceed with caution and reverence, feeling that we are on holy ground, and that though, like Moses of old, we may be armed with all the learning of our time, we are in the presence of that which while it burns is not consumed; of a mystery which neither observation, experiment, nor induction can ever fully solve.

In a recent address, the late President of the Royal Society called attention to the fact that within the lifetime of the older men of science of the present day, the greater part of the vast body of knowledge included in the modern sciences of physics, chemistry, biology, and geology, has been accumulated, and the most important advances made in its application to such common and familiar things as the railway, ocean navigation, the electric telegraph, electric lighting, the telephone, the germ theory of disease, the use of anæsthetics, the processes of metallurgy, and the dyeing of fabrics. Even since the last meeting in this city, much of this great work has been done, and has led to general results of the most marvellous kind. What at that time could have appeared more chimerical than the opening up by the enterprise of one British colony of a shorter road to the East by way of the extreme west, realising what was happily called by Milton and Cheadle 'the new North-west Passage,' making Japan the next neighbour of Canada on the west, and offering to Britain a new way to her Eastern possessions; or than the possibility of this Association holding a successful meeting on the other side of the Atlantic? To have ventured to predict such things in 1865, would have appeared quite visionary, yet we are now invited to meet in Australia, and may proceed thither by the Canadian Pacific Railway and its new lines of steamers, returning by the Suez Canal.[1] To-day this is quite as feasible as the Canadian

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[1] It is expected that, on the completion of the connections of the Canadian Pacific Railway, the time from ocean to ocean may be reduced to 116 hours, and from London to Hong Kong to twenty-seven days.

visit would have been in 1865. It is science that has thus brought the once widely separated parts of the world nearer to each other, and is breaking down those geographical barriers which have separated the different portions of our widely extended British race. Its work in this is not yet complete. Its goal to-day is its starting-point to-morrow. It is as far as at any previous time from seeing the limit of its conquests, and every victory gained is but the opening of the way for a farther advance.

By its visit to Canada the British Association has asserted its imperial character, and has consolidated the scientific interests of Her Majesty's dominions, in advance of that great gathering of the industrial products of all parts of the empire now on exhibition in London, and in advance of any political plans of Imperial federation.[1] There has even been a project before us for an international scientific convention, in which the great English republic of America shall take part, a project the realisation of which was to some extent anticipated in the fusion of the members of the British and American Associations at Montreal and Philadelphia in 1884. As a Canadian, as a past President of the American Association, and now honoured with the Presidency of this Association, I may be held to represent in my own person this scientific union of the British Islands, of the various Colonies, and of the great Republic, which, whatever the difficulties attending its formal accomplishment at present, is certain to lead to an actual and real union for scientific work. In furtherance of this I am glad to see here to-day influential representatives of most of the British Colonies, of India, and of the United States. We welcome here also delegates from other countries, and though the barrier of language may at present prevent a larger union, we may entertain the hope that Britain, America, India, and the Colonies, working together in the interest of science, may ultimately render our English tongue the most general vehicle of scientific thought and discovery, a consummation of which I think there are, at present, many indications.

But, while science marches on from victory to victory, its path is marked by the resting-places of those who have fought its battles and assured its advance. In looking back to 1865 there rise before me the once familiar countenances of Phillips, Murchison, Lyell, Forbes, Jeffreys, Jukes, Rolleston, Miller, Spottiswoode, Fairbairn, Gassiot, Carpenter, and a host of others, present in full vigour at that meeting, but no more with us. These were veterans of science; but, alas! many then young and rising in fame are also numbered with the dead. It may be that before another Birmingham meeting many of us, the older members now, will also have passed away. But these men have left behind them ineffaceable monuments of their work, in which they still survive, and we rejoice to believe that, though dead to us, they live in that company of the great and

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[1] I should note here, in connection with this, the valuable volume of *Canadian Economics*, which was one of the results of the Montreal meeting.

good of all ages who have entered into that unseen universe where all that is high and holy and beautiful must go on accumulating till the time of the restitution of all things. Let us follow their example and carry on their work, as God may give us power and opportunity, gathering in precious stores of knowledge and of thought, in the belief that all truth is immortal, and must go on for ever bestowing blessings on mankind. Thus will the memory of the mighty dead remain to us as a power which—

> Like a star
> Beacons from the abode where the eternal are.

I do not wish, however, to occupy your time longer with general or personal matters, but rather to take the opportunity afforded by this address to invite your attention to some topics of scientific interest. In attempting to do this I must have before me the warning conveyed by Professor Huxley, in the address to which I have already referred, that in our time science, like Tarpeia, may be crushed with the weight of the rewards bestowed on her. In other words, it is impossible for any man to keep pace with the progress of more than one limited branch of science, and it is equally impossible to find an audience of scientific men of whom anything more than a mere fraction can be expected to take an interest in any one subject. There is, however, some consolation in the knowledge that a speaker who is sufficiently simple for those who are advanced specialists in other departments, will of necessity be also sufficiently simple to be understood by the general public who are specialists in nothing. On this principle a geologist of the old school, accustomed to a great variety of work, may hope so to scatter his fire as to reach the greater part of the audience. In endeavouring to secure this end, I have sought inspiration from that ocean which connects rather than separates Britain and America, and may almost be said to be an English sea—the North Atlantic. The geological history of this depression of the earth's crust, and its relation to the continental masses which limit it, may furnish a theme at once generally intelligible and connected with great questions as to the structure and history of the earth, which have excited the attention alike of physicists, geologists, biologists, geographers, and ethnologists. Should I, in treating of these questions, appear to be somewhat abrupt and dogmatic, and to indicate rather than state the evidence of the general views announced, I trust you will kindly attribute this to the exigencies of a short address.

If we imagine an observer contemplating the earth from a convenient distance in space, and scrutinising its features as it rolls before him, we may suppose him to be struck with the fact that eleven-sixteenths of its surface are covered with water, and that the land is so unequally distributed that from one point of view he would see a hemisphere almost exclusively oceanic, while nearly the whole of the dry land is gathered in the opposite hemisphere. He might observe that the great oceanic area of the Pacific and Antarctic Oceans is dotted with islands—like a shallow pool with stones rising above its surface—as if its general depth were small in comparison with its area. He might also notice that a mass or belt of land surrounds each pole, and that the northern ring sends off to the southward three vast tongues of land and of mountain chains, terminating respectively in South America, South Africa, and Australia, towards which feebler and insular processes are given off by the Antarctic continental mass. This, as some geographers have observed,[1] gives a rudely three-ribbed aspect to the earth, though two of the three ribs are crowded together and form the Europ-asian mass or double continent, while the third is isolated in the single continent of America. He might also observe that the northern girdle is cut across, so that the Atlantic opens by a wide space into the Arctic Sea, while the Pacific is contracted toward the north, but confluent with the Antarctic Ocean. The Atlantic is also relatively deeper and less cumbered with islands than the Pacific, which has the higher ridges near its shores, constituting what some visitors to the Pacific coast of America have not inaptly called the 'back of the world,' while the wider slopes face the narrower ocean, into which for this reason the greater part of the drainage of the land is poured.[2] The Pacific and Atlantic, though both depressions or flattenings of the earth, are, as we shall find, different in age, character, and conditions; and the Atlantic, though the smaller, is the older, and from the geological point of view, in some respects, the more important of the two.

If our imaginary observer had the means of knowing anything of the rock formations of the continents, he would notice that those bounding the North Atlantic are in general of great age, some belonging to the Laurentian system. On the other hand, he would see that many of the mountain ranges along the Pacific are comparatively new, and that modern igneous action occurs in connection with them. Thus he might be led to believe that the Atlantic, though comparatively narrow, is an older feature of the earth's surface, while the Pacific belongs to more modern times. But he would note in connection with this that the oldest rocks of the great continental masses are mostly toward their northern ends, and that the borders of the northern ring of land and certain ridges extending southwards from it constitute the most ancient and permanent elevations of the earth's crust, though now greatly surpassed by mountains of more recent age nearer the equator. Before leaving this general survey we may make one further remark. An observer looking at the earth from without would notice that the margins of the Atlantic and the main lines of direction of its mountain chains are north-east and south-west, and north-west and south-east, as if some early causes had

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[1] Dana, *Manual of Geology*, introductory part. Green, *Vestiges of a Molten Globe*, has summed up these facts.

[2] Mr. Mellard Reade, in two Presidential addresses before the Geological Society of Liverpool, has well illustrated this point and its geological consequence.

determined the occurrence of elevations along great circles of the earth's surface tangent to the polar circles.

We are invited by the preceding general glance at the surface of the earth to ask certain questions respecting the Atlantic. (1) What has at first determined its position and form? (2) What changes has it experienced in the lapse of geological time? (3) What relations have these changes borne to the development of life on the land and in the water? (4) What is its probable future?

Before attempting to answer these questions, which I shall not take up formally in succession, but rather in connection with each other, it is necessary to state as briefly as possible certain general conclusions respecting the interior of the earth. It is popularly supposed that we know nothing of this beyond a superficial crust perhaps averaging 50,000 to 100,000 feet in thickness. It is true we have no means of exploration in the earth's interior, but the conjoined labours of physicists and geologists have now proceeded sufficiently far to throw much inferential light on the subject, and to enable us to make some general affirmations with certainty; and these it is the more necessary to state distinctly, since they are often treated as mere subjects of speculation and fruitless discussion.

(1) Since the dawn of geological science, it has been evident that the crust on which we live must be supported on a plastic or partially liquid mass of heated rock, approximately uniform in quality under the whole of its area. This is a legitimate conclusion from the wide distribution of volcanic phenomena, and from the fact that the ejections of volcanoes, while locally of various kinds, are similar in every part of the world. It led to the old idea of a fluid interior of the earth, but this is now generally abandoned, and this interior heated and plastic layer is regarded as merely an under-crust.

(2) We have reason to believe, as the result of astronomical investigations,[1] that, notwithstanding the plasticity or liquidity of the under-crust, the mass of the earth—its nucleus as we may call it—is practically solid and of great density and hardness. Thus we have the apparent paradox of a solid yet fluid earth; solid in its astronomical relations, liquid or plastic for the purposes of volcanic action and superficial movements.[2]

(3) The plastic sub-crust is not in a state of dry igneous fusion, but in that condition of aqueo-igneous or hydro-thermic fusion which

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[1] Hopkins, Mallet, Sir William Thomson, and Prof. G. H. Darwin maintain the solidity and rigidity of the earth on astronomical grounds; but different conclusions have been reached by Hennessy, Delaunay, and Airy. In America it was taught from 1858 by Sterry Hunt, and later by Shaler and Le Conte.

[2] An objection has been taken to the effect that the supposed ellipsoidal form of the equator is inconsistent with a plastic sub-crust. But this ellipsoidal form is not absolutely certain, or, if it exists, is very minute. Bonney has in a recent lecture suggested the important consideration that a mass may be slowly mobile under long-continued pressure, while yet rigid with reference to more sudden movements.

arises from the action of heat on moist substances, and which may either be regarded as a fusion or as a species of solution at a very high temperature. This we learn from the phenomena of volcanic action, and from the composition of the volcanic and plutonic rocks, as well as from such chemical experiments as those of Daubrée and of Tilden and Shenstone.[1]

(4) The interior sub-crust is not perfectly homogeneous, but may be roughly divided into two layers or magmas, as they have been called: an upper, highly siliceous or acidic, of low specific gravity and light-coloured, and corresponding to such kinds of plutonic and volcanic rocks as granite and trachyte; and a lower, less siliceous or more basic, more dense, and more highly charged with iron, and corresponding to such igneous rocks as the dolerites, basalts, and kindred lavas. It is interesting here to note that this conclusion, elaborated by Durocher and von Waltershausen, and usually connected with their names, appears to have been first announced by John Phillips, in his 'Geological Manual,' and as a mere common sense deduction from the observed phenomena of volcanic action and the probable results of the gradual cooling of the earth.[2] It receives striking confirmation from the observed succession of acidic and basic volcanic rocks of all geological periods and in all localities. It would even seem, from recent spectroscopic investigations of Lockyer, that there is evidence of a similar succession of magmas in the heavenly bodies, and the discovery by Nordenskiöld of native iron in Greenland basalts, affords a probability that the inner magma is in part metallic.[3]

(5) Where rents or fissures form in the upper crust, the material of the lower crust is forced upward by the pressure of the less supported portions of the former, giving rise to volcanic phenomena either of an explosive or quiet character, as may be determined by contact with water. The underlying material may also be carried to the surface by the agency of heated water, producing those quiet discharges which Hunt has

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[1] *Phil. Trans.* 1884. Also Crosby in *Proc. Boston Soc. Nat. Hist.* 1883.

[2] Phillips says (*Manual of Geology*, 1855, p. 493): 'If we regard them (the internal crystalline rocks) as acquiring solidification by cooling in zones parallel to the surface, we should have sheets of granitic and basaltic rocks generated below, the first uppermost, the last undermost, while above the several strata were produced in a series beginning at the bottom. In this sense the rocks of fusion may be called with Lyell *hypogene*. Certainly under particular areas of country are found evidence of the liquefaction of one set of igneous products after the solidification of others. Many dykes of basalt traversing granite show themselves to have been in fusion after the solidification of the granite.' In various forms Phillips returns to this idea, as at pp. 556 and 564, in that unpretending manner which was his wont. Dr. Sterry Hunt has kindly directed my attention to the fact of Phillips's right of priority in this matter. Durocher in 1857 elaborated the theory of magmas in the *Annales des Mines*, and we are indebted to Dutton, of the United States Geological Survey, for its detailed application to the remarkable volcanic outflows of Western America.

[3] These basalts occur at Ovifak, Greenland. Andrews has found small particles of iron in British basalts. Prestwich and Judd have referred to the bearing on general geology of these facts, and of Lockyer's suggestions.

named crenitic. It is to be observed here that explosive volcanic phenomena, and the formation of cones, are, as Prestwich has well remarked, characteristic of an old and thickened crust; quiet ejection from fissures and hydro-thermal action may have been more common in earlier periods and with a thinner over-crust.

(6) The contraction of the earth's interior by cooling and by the emission of material from below the over-crust, has caused this crust to press downward, and therefore laterally, and so to effect great bends, folds, and plications; and these modified subsequently by surface denudation constitute mountain chains and continental plateaus. As Hall long ago pointed out,[1] such lines of folding have been produced more especially where thick sediments had been laid down on the sea-bottom. Thus we have here another apparent paradox, namely, that the elevations of the earth's crust occur in the places where the greatest burden of detritus has been laid down upon it, and where consequently the crust has been softened and depressed. We must beware, in this connection, of exaggerated notions of the extent of contraction and of crumpling required to form mountains. Bonney has well shown, in lectures delivered at the London Institution, that an amount of contraction, almost inappreciable in comparison with the diameter of the earth, would be sufficient; and that as the greatest mountain chains are less than $\frac{1}{600}$th of the earth's radius in height, they would on an artificial globe a foot in diameter be no more important than the slight inequalities that might result from the paper gores overlapping each other at the edges.

(7) The crushing and sliding of the over-crust implied in these movements raise some serious questions of a physical character. One of these relates to the rapidity or slowness of such movements, and the consequent degree of intensity of the heat developed, as a possible cause of metamorphism of rocks. Another has reference to the possibility of changes in the equilibrium of the earth itself as resulting from local collapse and ridging. These questions in connection with the present dissociation of the axis of rotation from the magnetic poles, and with changes of climate, have attracted some attention,[2] and probably deserve further consideration on the part of physicists. In so far as geological evidence is concerned, it would seem that the general association of crumpling with metamorphism indicates a certain rapidity in the process of mountain-making, and consequent development of heat, and the arrangement of the older rocks around the Arctic basin forbids us from assuming any extensive movement of the axis of rotation, though it does not exclude changes to a limited extent. I hope that Professor Darwin will discuss these points in his address to the Physical Section.

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[1] Hall (American Association Address, 1857, subsequently republished, with additions, as *Contributions to the Geological History of the American Continent*), Mallet, Rogers, Dana, Le Conte, &c.

[2] See recent papers of Oldham and Fisher in *Geological Magazine* and *Philosophical Magazine*, July 1886. Also Léroche, *Revol. Polaires*. Paris, 1886.

I wish to formulate these principles as distinctly as possible, and as the result of all the long series of observations, calculations, and discussions since the time of Werner and Hutton, and in which a vast number of able physicists and naturalists have borne a part, because they may be considered as certain deductions from our actual knowledge, and because they lie at the foundation of a rational physical geology.

We may popularise these deductions by comparing the earth to a drupe or stone-fruit, such as a plum or peach, somewhat dried up. It has a large and intensely hard stone and kernel, a thin pulp made up of two layers, an inner more dense and dark-coloured, and an outer less dense and lighter-coloured. These constitute the under-crust. On the outside it has a thin membrane or over-crust. In the process of drying it has slightly shrunk, so as to produce ridges and hollows of the outer crust, and this outer crust has cracked in some places, allowing portions of the pulp to ooze out—in some of these its lower dark substance, in others its upper and lighter material. The analogy extends no farther, for there is nothing in our withered fruit to represent the oceans occupying the lower parts of the surface or the deposits which they have laid down.

Keeping in view these general conclusions, let us now turn to their bearing on the origin and history of the North Atlantic.

Though the Atlantic is a deep ocean, its basin does not constitute so much a depression of the crust of the earth as a flattening of it, and this, as recent soundings have shown, with a slight ridge or elevation along its middle, and banks or terraces fringing the edges, so that its form is not so much that of a basin as that of a shallow plate with its middle a little raised. Its true permanent margins are composed of portions of the over-crust folded, ridged up and crushed, as if by lateral pressure emanating from the sea itself. We cannot, for example, look at a geological map of America without perceiving that the Appalachian ridges, which intervene between the Atlantic and the St. Lawrence valley, have been driven bodily back by a force acting from the east, and that they have resisted this pressure only where, as in the Gulf of St. Lawrence and the Catskill region of New York, they have been protected by outlying masses of very old rocks, as, for example, by that of the island of Newfoundland and that of the Adirondack Mountains. The admirable work begun by my friend and fellow-student Professor James Nicol, followed up by Hicks, Lapworth, and others, and now, after long controversy, fully confirmed by the recent observations of the Geological Survey of Scotland, has shown the most intense action of the same kind on the east side of the ocean in the Scottish highlands; and the more widely distributed Eozoic rocks of Scandinavia may be appealed to in further evidence of this.[1]

If we now inquire as to the cause of the Atlantic depression, we

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[1] Address to the Geological Section, by Prof. Judd, Aberdeen Meeting, 1885. According to Rogers, the Crumpling of the Appalachians has reduced a breadth of 158 miles to about 60.

must go back to a time when the areas occupied by the Atlantic and its bounding coasts were parts of a shoreless sea in which the earliest gneisses or stratified granites of the Laurentian age were being laid down in vastly extended beds. These ancient crystalline rocks have been the subject of much discussion and controversy, and as they constitute the lowest and probably the firmest part of the Atlantic sea-bed, it is necessary to inquire as to their origin and history. Dr. Bonney, past President of the Geological Society, in his Anniversary address, and Dr. Sterry Hunt, in an elaborate paper communicated to the Royal Society of Canada, have ably summed up the hypotheses as to the origin of the oldest Laurentian beds. At the basis of these hypotheses lies the admission that the immensely thick beds of orthoclase gneiss, which are the oldest stratified rocks known to us, are substantially the same in composition with the upper or siliceous magma or layer of the under-crust. They are, in short, its materials either in their primitive condition or merely rearranged. One theory considers them as original products of cooling, owing their lamination merely to the successive stages of the process. Another view refers them to the waste and rearrangement of the materials of a previously massive granite. Still another holds that all our granites really arise from the fusion of old gneisses of originally aqueous origin, while a fourth refers the gneisses themselves to molecular changes effected in granite by pressure. These several views, in so far as they relate to the oldest or fundamental Laurentian gneiss, may be arranged under the following heads: (1) *Endoplutonic*, or that which regards all the old gneisses as molten rocks cooled from without inward in successive layers.[1] (2) *Exoplutonic*, or that which considers them as made up of matter ejected from below the upper crust in the manner of volcanic action.[2] (3) *Metamorphic*, which supposes the old gneisses to arise from the crystallisation of detrital matter spread over the sea-bottom, and either igneous or derived from the decay of igneous rocks.[3] (4) *Chaotic* or *Thermo-chaotic*, or the theory of deposit from the turbid waters of a primeval ocean either with or without the aid of heat. In one form this was the old theory of Werner.[4] (5) *Crenitic* or *Hydro-thermic*, which supposes the action of heated waters penetrating below the crust to be constantly bringing up to the surface mineral matters in solution and depositing these so as to form felspathic and other rocks.[5]

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[1] Naumann, Phillips, Durocher, McFarlane, &c.

[2] Clarence King, Tornebohm, Marr, &c.

[3] Lyell, Kopp, Reusch, Judd, &c.

[4] Scrope, De la Beche, Daubrée.

[5] Hunt, *loc. cit.* The following is Dr. Hunt's summary statement of this theory: 'The globe consolidating at the centre left, it is conceived, a superficial layer of basic silicates, which has yielded all the fixed elements of the earth's crust. This layer formed the first land and the floor of the primeval sea, the acid waters of which, permeating and partially decomposing it, became thereby chemically neutralised. This last-cooled layer, mechanically disintegrated, saturated with water, and heated

It will be observed, in regard to these theories, that none of them supposes that the old gneiss is an ordinary sediment, but that all regard it as formed in exceptional circumstances, these circumstances being the absence of land and of sub-aërial decay of rock, and the presence wholly or principally of the material of the upper surface of the recently hardened crust. This being granted, the question arises,—ought we not to combine these several theories, and to believe that the cooling crust has hardened in successive layers from without inward; that at the same time fissures were locally discharging igneous matter to the surface; that matter held in suspension in the ocean and matter held in solution by heated waters rising from beneath the outer crust were mingling their materials in the deposits of the primitive ocean? It would seem that the combination of all these agencies may safely be invoked as causes of the pre-Atlantic deposits. This is the eclectic position which I endeavoured to maintain in my address before the Minneapolis Meeting of the American Association in 1883, and which I still hold to be in every way probable.

A word here as to metamorphism, a theory which, like many others, has been first run to death and then discredited, but which to the moderate degree in which it was originally held by Lyell is still valid. Nothing can be more certain than that the composition of the Laurentian gneisses forbids us to suppose that they can be ordinary sediments metamorphosed. They are rocks peculiar in their origin, and not paralleled unless exceptionally in later times. On the other hand, they have undoubtedly experienced very important changes, more especially as to crystallisation, the state of combination of their ingredients, and the development of disseminated minerals;[1] and while this may in part be attributed to the mechanical pressure to which they have been subjected, it requires also the action of hydrothermic agencies. Any theory which fails to invoke both of these kinds of force must necessarily be partial and imperfect.

by the central mass, was the source of mineral springs, holding in solution the silicates which built up the ancient gneisses and similar rocks. Granitic veins and zeolites are due to survivals of the process which generated the gneissic rocks. The hypothesis of their formation from materials brought to the surface by mineral springs from the primitive basic layer affords, it is claimed, the elements of a complete and intelligible explanation of the origin of the Eozoic rocks. This upward lixiviation of the primitive mass, and the deposition over it of an acidic granite-like rock, would leave below a highly basic material, and the division of the mass thus established would correspond to that of the trachytic and doleritic magmas, which have been conjectured to be the sources of two great types of eruptive rocks. Inasmuch, however, as according to the present hypothesis these two layers of basic and acidic matters are the results of aqueous action, and not of an original separation in a plutonic mass, as imagined by Phillips and Durocher, their composition would be subject to many local variations.'

[1] The first of these is what Bonney has called *Metastasis*. The second and third come under the name *Metacrasis*. *Methylosis*, or change of substance, is altogether exceptional, and not to be credited except on the best evidence, or in cases where volatile matters have been expelled, as in the change of Hematite into Magnetite, or of bituminous coal into anthracite.

But all metamorphic rocks are not of the same character with the gneisses of the Lower Laurentian. Even in the Middle and Upper Laurentian we have metamorphic rocks, *e.g.*, quartzite and limestone, which must originally have been ordinary aqueous deposits. Still more in the succeeding Huronian and its associated series of beds, and in the Lower Palæozoic, local metamorphic change has been undergone by rocks quite similar to those which in their unaltered state constitute regular sedimentary deposits. In the case of these later rocks it is to be borne in mind that, while some may have been of volcanic origin, others may have been sediments rich in undecomposed fragments of silicates. It is a mistake to suppose that the ordinary decay of stratified siliceous rocks is a process of kaolinisation so perfect as to eliminate all alkaline matters. On the contrary, the fact, which Judd has recently well illustrated in the case of the mud of the Nile, applies to a great number of similar deposits in all parts of the world, and shows that the finest sediments have not always been so completely lixiviated as to be destitute of the basic matters necessary for their conversion into gneiss, mica-schist, and similar rocks when the necessary agencies of metamorphism are applied to them, and this quite independently of any extraneous matters introduced into them by water or otherwise. Still it must be steadily kept in view that many of the old pre-Cambrian crystalline rocks must have been different originally from those succeeding them, and that consequently these last even when metamorphosed present different characters.

I may remark here that, though a palæontologist rather than a lithologist, it gives me great pleasure to find so much attention now given in this country to the old crystalline rocks, and to their study microscopically and chemically as well as in the field, a work in which Sorby and Allport were pioneers. As a pupil of the late Professor Jameson, of Edinburgh, my own attention was early attracted to the study of minerals and rocks as the stable foundations of geological science; and as far back as 1841 I had learnt of the late Mr. Sanderson, of Edinburgh, who worked at Nicol's sections,[1] how to slice rocks and fossils; and since that time I have been in the habit of examining everything with the microscope. The modern developments in this direction are therefore very gratifying to me, even though, as is natural, they may sometimes appear to be pushed too far or their value over-estimated.

That these old gneisses were deposited not only in what is now the bed of the Atlantic, but also on the great continental areas of America and Europe, anyone who considers the wide extent of these rocks represented on the map recently published by Professor Hull can readily understand.[2] It is true that Hull supposes that the basin of the Atlantic itself may have been land at this time, but there is no evidence of this, more especially as the material of the gneiss could not have been detritus derived from sub-aërial decay of rock.

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[1] And I believe at Witham's also.

[2] *Trans. Royal Irish Academy.*

Let us suppose, then, the floor of old ocean covered with a flat pavement of gneiss, or of that material which is now gneiss, the next question is how and when did this original bed become converted into sea and land. Here we have some things certain, others most debatable. That the cooling mass, especially if it was sending out volumes of softened rocky material, either in the exoplutonic or in the crenitic way, and piling this on the surface, must soon become too small for its shell, is apparent; but when and where would the collapse, crushing, and wrinkling inevitable from this cause begin? Where they did begin is indicated by the lines of mountain-chains which traverse the Laurentian districts; but the reason why is less apparent. The more or less unequal cooling, hardening and conductive power of the outer crust we may readily assume. The driftage unequally of water-borne detritus to the south-west by the bottom currents of the sea is another cause, and, as we shall soon see, most effective. Still another is the greater cooling and hardening of the crust in the polar regions, and the tendency to collapse of the equatorial protuberance from the slackening of the earth's rotation. Besides these the internal tides of the earth's substance at the times of solstice would exert an oblique pulling force on the crust, which might tend to crack it along diagonal lines. From whichever of these causes or the combination of the whole, we know that within the Laurentian time folded portions of the earth's crust began to rise above the general surface in broad belts running from N.E. to S.W., and from N.W. to S.E., where the older mountains of Eastern America and Western Europe now stand, and that the subsidence of the oceanic areas allowed by this crumpling of the crust permitted other areas on both sides of what is now the Atlantic to form limited table-lands.[1] This was the beginning of a process repeated again and again in subsequent times, and which began in the Middle Laurentian, when for the first time we find beds of quartzite, limestone, and iron ore, and graphitic beds, indicating that there was already land and water, and that the sea, and perhaps the land, swarmed with animal and plant life of forms unknown to us, for the most part, now. Independently of the questions as to the animal nature of Eozoon, I hold that we know, as certainly as we can know anything inferentially, the existence of these primitive forms of life. If I were to conjecture what were the early forms of plant and animal life, I would suppose that just as in the Palæozoic the acrogens culminated in gigantic and complex forest trees, so in the Laurentian the algæ, the lichens, and the mosses grew to dimensions and assumed complexity of structure unexampled in later times, and that in the sea the humbler forms of Protozoa and Hydrozoa were the dominant types, but in gigantic and complex forms. The land of this period was probably limited, for the most part, to high latitudes,

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[1] Daubrée's curious experiments on the contraction of caoutchouc balloons, partially hardened by coating with varnish, shows how small inequalities of the crust, from whatever cause arising, might affect the formation of wrinkles, and also that transverse as well as longitudinal wrinkling might occur.

and its aspect, though more rugged and abrupt, and of greater elevation, must have been of that character which we still see in the Laurentian hills. The distribution of this ancient land is indicated by the long lines of old Laurentian rock extending from the Labrador coast and the north shore of the St. Lawrence, and along the eastern slopes of the Appalachians in America, and the like rocks of the Hebrides, the Western Highlands, and the Scandinavian mountains. A small but interesting remnant is that in the Malvern Hills, so well described by Holl. It will be well to note here and to fix on our minds that these ancient ridges of Eastern America and Western Europe have been greatly denuded and wasted since Laurentian times, and that it is along their eastern sides that the greatest sedimentary accumulations have been deposited.

From this time dates the introduction of that dominance of existing causes which forms the basis of uniformitarianism in geology, and which had to go on with various and great modifications of detail, through the successive stages of the geological history, till the land and water of the northern hemisphere attained to their present complex structure.

So soon as we have a circumpolar belt or patches of Eozoic[1] land and ridges running southward from it, we enter on new and more complicated methods of growth of the continents and seas, depending on the new conditions established by the elevation of the earliest continents and the consequent determination of ocean currents and of sedimentation along the continental margins. Portions of the oldest crystalline rocks, raised out of the protecting water, were now eroded by atmospheric agents, and especially by the carbonic acid, then existing in the atmosphere perhaps more abundantly than at present, under whose influence the hardest of the gneissic rocks gradually decay. The Arctic lands were subjected in addition to the powerful mechanical force of frost and thaw. Thus every shower of rain and every swollen stream would carry into the sea the products of the waste of land, sorting them into fine clays and coarser sands; and the cold currents which cling to the ocean bottom, now determined in their courses, not merely by the earth's rotation, but also by the lines of folding on both sides of the Atlantic, would carry south-westward, and pile up in marginal banks of great thickness, the *débris* produced from the rapid waste of the land already existing in the Arctic regions. The Atlantic, opening widely to the north, and having large rivers pouring into it, was especially the ocean characterised, as time advanced, by the prevalence of these phenomena. Thus throughout the geological history it has happened that, while the middle of the Atlantic has received merely organic deposits of shells of Foraminifera and similar organisms, and this probably only to a small amount, its margins have had piled upon them beds of detritus of immense thickness. Professor Hall, of Albany, was the first geologist who pointed out the vast cosmic importance of these deposits, and that the mountains

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[1] Or Archæan, or pre-Cambrian, if these terms are preferred.

of both sides of the Atlantic owe their origin to these great lines of deposition, along with the fact, afterwards more fully insisted on by Rogers, that the portions of the crust which received these masses of *débris* became thereby weighted down and softened, and were more liable than other parts to lateral crushing.[1]

Thus in the later Eozoic and early Palæozoic times, which succeeded the first foldings of the oldest Laurentian, great ridges were thrown up, along the edges of which were beds of limestone, and on their summits and sides thick masses of ejected igneous rocks. In the bed of the central Atlantic there are no such accumulations. It must have been a flat, or slightly ridged, plate of the ancient gneiss, hard and resisting, though perhaps with a few cracks, through which igneous matter welled up, as in Iceland and the Azores in more modern times. In this condition of things we have causes tending to perpetuate and extend the distinctions of ocean and continent, mountain and plain, already begun; and of these we may more especially note the continued subsidence of the areas of greatest marine deposition. This has long attracted attention, and affords very convincing evidence of the connection of sedimentary deposit as a cause with the subsidence of the crust.[2]

We are indebted to a French physicist, M. Faye,[3] for an important suggestion on this subject. It is that the sediment accumulated along the shores of the ocean presented an obstacle to radiation, and consequently to cooling of the crust, while the ocean floor, unprotected and unweighted, and constantly bathed with currents of cold water, having great power of convection of heat, would be more rapidly cooled, and so would become thicker and stronger. This suggestion is complementary to the theory of Professor Hall, that the areas of greatest deposit on the

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[1] The connection of accumulation with subsidence was always a familiar consideration with geologists; but Hall seems to have been the first to state its true significance as a geological factor, and to see that those portions of the crust which are weighted down by great detrital accumulations are necessarily those which, in succeeding movements, were elevated into mountains. Other American geologists, as Dana, Rogers, Hunt, Le Conte, Crosby, &c., have followed up Hall's primary suggestion, and in England, Hicks, Fisher, Starkie Gardner, Hull, and others, have brought it under notice, and it enters into the great generalisations of Lyell on these subjects.

[2] Dutton in *Report of U.S. Geological Survey*, 1881. From facts stated in this report and in my *Arcadian Geology*, it is apparent that in the Western States and in the coalfield of Nova Scotia shallow-water deposits have been laid down up to thicknesses of 10,000 to 20,000 feet in connection with continuous subsidence. See also a paper by Ricketts in the *Geol. Mag.* 1883. It may be well to add here that this doctrine of the subsidence of wide areas being caused by deposition does not justify the conclusion of certain glacialists that snow and ice have exercised a like power in glacial periods. In truth, as will appear in the sequel, great accumulations of snow and ice require to be preceded by subsidence, and wide continental areas can never be covered with deep snow, while of course ice can cause no addition of weight to submerged areas.

[3] *Revue Scientifique*, 1886.

margins of the ocean are necessarily those of greatest folding and consequent elevation. We have thus a hard, thick, resisting ocean-bottom which, as it settles down toward the interior, under the influence of gravity, squeezes upward and folds and plicates all the soft sediments deposited on its edges. The Atlantic area is almost an unbroken cake of this kind. The Pacific area has cracked in many places, allowing the interior fluid matter to ooze out in volcanic ejections.

It may be said that all this supposes a permanent continuance of the ocean-basins, whereas many geologists postulate a mid-Atlantic continent[1] to give the thick masses of detritus found in the older formations both in Eastern America and Western Europe, and which thin off in proceeding into the interior of both continents. I prefer, with Hall, to consider these belts of sediment as in the main the deposits of northern currents, and derived from Arctic land, and that like the great banks of the American coast at the present day, which are being built up by the present Arctic current, they had little to do with any direct drainage from the adjacent shore. We need not deny, however, that such ridges of land as existed along the Atlantic margins were contributing their quota of river-borne material, just as on a still greater scale the Amazon and Mississippi are doing now, and this especially on the sides toward the present continental plateaus, though the greater part must have been derived from the wide tracts of Laurentian land within the Arctic Circle or near to it. It is further obvious that the ordinary reasoning respecting the necessity of continental areas in the present ocean basins would actually oblige us to suppose that the whole of the oceans and continents had repeatedly changed places. This consideration opposes enormous physical difficulties to any theory of alternations of the oceanic and continental areas, except locally at their margins. I would, however, refer you for a more full discussion of these points to the address to be delivered to-morrow by the President of the Geological Section.

But the permanence of the Atlantic depression does not exclude the idea of successive submergences of the continental plateaus and marginal slopes, alternating with periods of elevation, when the ocean retreated from the continents and contracted its limits. In this respect the Atlantic of to-day is much smaller than it was in those times when it spread widely over the continental plains and slopes, and much larger than it

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[1] Among American geologists, Dana and Le Conte, though from somewhat different premises, maintain continental permanence. Crosby has argued on the other side. In Britain, Hull has elaborated the idea of interchange of oceanic and continental areas in his memoir in *Trans. Dublin Society*, and in his work entitled *The Physical History of the British Islands*. Godwin-Austen argues powerfully for the permanence of the Atlantic basin, *Q. J. Geol. Society*, vol. xii. p. 42. Mellard Reade ably advocates the theory of mutation. The two views require, in my judgment, to be combined. More especially it is necessary to take into account the existence of an Atlantic ridge of Laurentian rock on the west side of Europe, of which the Hebrides and the oldest rocks of Wales, Ireland, Western France, and Portugal are remnants.

has been in times of continental elevation. This leads us to the further consideration that, while the ocean-beds have been sinking, other areas have been better supported, and constitute the continental plateaus; and that it has been at or near the junctions of these sinking and rising areas that the thickest deposits of detritus, the most extensive foldings, and the greatest ejections of volcanic matter have occurred. There has thus been a permanence of the position of the continents and oceans throughout geological time, but with many oscillations of these areas, producing submergences and emergences of the land. In this way we can reconcile the vast vicissitudes of the continental areas in different geological periods with that continuity of development from north to south, and from the interiors to the margins, which is so marked a feature. We have for this reason to formulate another apparent geological paradox, namely, that while in one sense the continental and oceanic areas are permanent, in another they have been in continual movement. Nor does this view exclude extension of the continental borders or of chains of islands beyond their present limits, at certain periods; and indeed the general principle already stated, that subsidence of the ocean-bed has produced elevation of the land, implies in earlier periods a shallower ocean and many possibilities as to volcanic islands, and low continental margins creeping out into the sea; while it is also to be noted that there are, as already stated, bordering shelves, constituting shallows in the ocean, which at certain periods have emerged as land.

We are thus compelled to believe in the contemporaneous existence in all geological periods, except perhaps the earliest of them, of three distinct conditions of areas on the surface of the earth. (1) Oceanic areas of deep sea, which always continued to occupy in whole or in part the bed of the present ocean. (2) Continental plateaus and marginal shelves, existing as low flats or higher table-lands liable to periodical submergence and emergence. (3) Lines of plication and folding, more especially along the borders of the oceans, forming elevated portions of land, rarely altogether submerged and constantly affording the material of sedimentary accumulations, while they were also the seats of powerful volcanic ejections.

In the successive geological periods the continental plateaus when submerged, owing to their vast extent of warm and shallow sea, have been the great theatres of the development of marine life and of the deposition of organic limestones, and when elevated they have furnished the abodes of the noblest land faunas and floras. The mountain belts, especially in the north, have been the refuge and stronghold of land life in periods of submergence, and the deep ocean basins have been the perennial abodes of pelagic and abyssal creatures, and the refuge of multitudes of other marine animals and plants in times of continental elevation. These general facts are full of importance with reference to the question of the succession of formations and of life in the geological history of the earth.

So much time has been occupied with these general views that it would be impossible to trace the history of the Atlantic in detail through the ages of the Palæozoic, Mesozoic, and Tertiary. We may, however, shortly glance at the changes of the three kinds of surface already referred to. The bed of the ocean seems to have remained on the whole abyssal, but there were probably periods when those shallow reaches of the Atlantic which stretch across its most northern portion, and partly separate it from the Arctic basin, presented connecting coasts or continuous chains of islands sufficient to permit animals and plants to pass over.[1] At certain periods also there were not unlikely groups of volcanic islands, like the Azores, in the temperate or tropical Atlantic. More especially might this be the case in that early time when it was more like the present Pacific; and the line of the great volcanic belt of the Mediterranean, the mid-Atlantic banks, the Azores, and the West India Islands point to the possibility of such partial connections. These were stepping-stones, so to speak, over which land organisms might cross, and some of these may be connected with the fabulous or prehistoric Atlantis.[2]

In the Cambrian and Ordovician periods the distinctions, already referred to, into continental plateaus, mountain ridges, and ocean depths were first developed, and we find already great masses of sediment accumulating on the seaward sides of the old Laurentian ridges, and internal deposits thinning away from these ridges over the submerged continental areas, and presenting very dissimilar conditions of sedimentation. It would seem also that, as Hicks has argued for Europe, and Logan and Hall for America, this Cambrian age was one of slow subsidence of the land previously elevated, accompanied with or caused by thick deposits of detritus along the borders of the subsiding land, which was probably covered with the decomposing rock arising from long ages of sub-aërial waste.

In the coal-formation age, its characteristic swampy flats stretched in some places far into the shallower parts of the ocean.[3] In the Permian the great plicated mountain margins were fully developed on both sides of the Atlantic. In the Jurassic the American continent probably extended further to sea than at present. In the Wealden age there was much land to the west and north of Great Britain, and Professor

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[1] It would seem, from Geikie's description of the Faroe Islands, that they may be a remnant of such connecting land, dating from the Cretaceous or Eocene period.

[2] Dr. Wilson has recently argued that the Atlantis of tradition was really America, and Mr. Hyde Clarke has associated this idea with the early dominance in Western Europe of the Iberian race, which Dawkins connects with the Neolithic and Bronze ages of archæology. My own attention has recently been directed, through specimens presented to the McGill College Museum, to the remarkable resemblances, in cranial characters, wampum, and other particulars, of the Guanches of the Canaries with the aborigines of Eastern America—resemblances which cannot be accidental.

[3] I have shown the evidence of this in the remnants of Carboniferous districts once more extensive on the Atlantic coast of Nova Scotia and Cape Breton (*Arcadian Geology*).

Bonney has directed attention to the evidence of the existence of this land as far back as the Trias, while Mr. Starkie Gardner has insisted on connecting links to the southward as evidenced by fossil plants. So late as the Post-Glacial, or early human period, large tracts now submerged formed portions of the continents. On the other hand the internal plains of America and Europe were often submerged. Such submergences are indicated by the great limestones of the Palæozoic, by the chalk and its representative beds in the Cretaceous, by the Nummulitic formation in the Eocene, and lastly by the great Pleistocene submergence, one of the most remarkable of all, one in which nearly the whole northern hemisphere participated, and which was probably separated from the present time by only a few thousands of years.[1] These submergences and elevations were not always alike on the two sides of the Atlantic. The Salina period of the Silurian, for example, and the Jurassic, show continental elevation in America not shared by Europe. The great subsidences of the Cretaceous and the Eocene were proportionally deeper and wider on the eastern continent, and this and the direction of the land being from north to south cause more ancient forms of life to survive in America. These elevations and submergences of the plateaus alternated with the periods of mountain-making plication, which was going on at intervals at the close of the Eozoic, at the beginning of the Cambrian, at the close of the Siluro-Cambrian, in the Permian, and in Europe and Western America in the Tertiary. The series of changes, however, affecting all these areas was of a highly complex character, and embraces the whole physical history of the geological ages.

We may note here that the unconformities caused by these movements and by subsequent denudation constitute what Le Conte has called 'lost intervals,' one of the most important of which is supposed to have occurred at the end of the Eozoic. It is to be observed, however, that as every such movement is followed by a gradual subsidence, the seeming loss is caused merely by the overlapping of the successive beds deposited.

We may also note a fact which I have long ago insisted on,[2] the regular pulsations of the continental areas, giving us alternations in each great system of formations of deep-sea and shallow-water beds, so that the successive groups of formations may be divided into triplets of shallow-water, deep-water, and shallow-water strata, alternating in each period. This law of succession applies more particularly to the formations of the continental plateaus, rather than to those of the ocean margins, and it shows that, intervening between the great movements of plication, there were subsidences of those plateaus, or elevations of the sea-bottom,

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[1] The recent surveys of the Falls of Niagara coincide with a great many evidences to which I have elsewhere referred in proving that the Pleistocene submergence of America and Europe came to an end not more than ten thousand years ago, and was itself not of very great duration. Thus in Pleistocene times the land must have been submerged and re-elevated in a very rapid manner.

[2] *Arcadian Geology*, 1865.

which allowed the waters to spread themselves over all the inland spaces between the great folded mountain ranges.

In referring to the ocean basins we should bear in mind that there are three of these in the northern hemisphere—the Arctic, the Pacific, and the Atlantic. De Rance has ably summed up in a series of articles published in 'Nature' the known facts as to Arctic geology, and I have myself been favoured with opportunities to study many of the collections brought home by the Arctic voyagers, and which are of much interest when viewed in connection with Canadian geology. From these sources we learn that this area presents from without inwards a succession of older and newer formations from the Eozoic to the Tertiary, and that its extent must have been greater in former periods than at present, while it must have enjoyed a comparatively warm climate. The relations of its deposits and fossils are closer with those of the Atlantic than with those of the Pacific, as might be anticipated from its wider opening into the former. Blanford has recently remarked on the correspondence of the marginal deposits around the Pacific and Indian oceans,[1] and Dr. Dawson informs me that this is equally marked in comparison with the west coast of America,[2] but these marginal areas have not yet gained much on the ocean. In the North Atlantic, on the other hand, there is a wide belt of comparatively modern rocks on both sides, more especially toward the south, and on the American side; but while there appears to be a perfect correspondence on both sides of the Atlantic, and around the Pacific respectively, there seems to be less parallelism between the deposits and forms of life of the two oceans as compared with each other, and less correspondence in forms of life, especially in modern times. Still in the earlier geological ages, as might have been anticipated from the imperfect development of the continents, the same forms of life characterise the whole ocean from Australia to Arctic America, and indicate a grand unity of Pacific and Atlantic life not equalled in later times,[3] and which speaks of contemporaneity rather than of what has been termed homotaxis.

We may pause here for a moment to notice some of the effects of

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[1] A singular example is the recurrence in New Zealand of Triassic rocks and fossils of types corresponding to those of British Columbia. A curious modern analogy appears in the works of art of the Maoris with those of the Haida Indians of the Queen Charlotte Islands, and both are eminently Pacific in contradistinction to Atlantic.

[2] *Journal of Geological Society*, May 1886. Blanford's statements respecting the mechanical deposits of the close of the Palæozoic in the Indian Ocean, whether these are glacial or not, would seem to show a correspondence with the Permian conglomerates and earth-movements of the Atlantic area; but since that time the Atlantic has enjoyed comparative repose. The Pacific also seems to have reproduced the conditions of the Carboniferous in the Cretaceous age, and seems to have been less affected by the great changes of the Pleistocene.

[3] Daintree and Etheridge, 'Queensland Geology,' *Journal Geological Society*, August 1872; R. Etheridge, Junior, 'Australian Fossils,' *Trans. Phys. Soc. Edin.*, 1880.

Atlantic growth on modern geography. It has given us rugged and broken shores composed of old rocks in the north, and newer formations and softer features toward the south. It has given us marginal mountain ridges and internal plateaus on both sides of the sea. It has produced certain curious and by no means accidental correspondences of the eastern and western sides. Thus the solid basis on which the British Islands stand may be compared with Newfoundland and Labrador, the English Channel with the Gulf of St. Lawrence, the Bay of Biscay with the Bay of Maine, Spain with the projection of the American land at Cape Hatteras, the Mediterranean with the Gulf of Mexico. The special conditions of deposition and plication necessary to these results, and their bearing on the character and productions of the Atlantic basin, would require a volume for their detailed elucidation.

Thus far our discussion has been limited almost entirely to physical causes and effects. If we now turn to the life-history of the Atlantic, we are met at the threshold with the question of climate, not as a thing fixed and immutable, but as changing from age to age in harmony with geographical mutations, and producing long cosmic summers and winters of alternate warmth and refrigeration.

We can scarcely doubt that the close connection of the Atlantic and Arctic oceans is one factor in those remarkable vicissitudes of climate experienced by the former, and in which the Pacific area has also shared in connection with the Antarctic Sea. No geological facts are indeed at first sight more strange and inexplicable than the changes of climate in the Atlantic area, even in comparatively modern periods. We know that in the early Tertiary perpetual summer reigned as far north as the middle of Greenland, and that in the Pleistocene the arctic cold advanced, until an almost perennial winter prevailed, half-way to the equator. It is no wonder that nearly every cause available in the heavens and the earth has been invoked to account for these astounding facts.

It will, I hope, meet with the approval of your veteran glaciologist Dr. Crosskey, if, neglecting most of these theoretical views, I venture to invite your attention in connection with this question chiefly to the old Lyellian doctrine of the modification of climate by geographical changes. Let us, at least, consider how much these are able to account for.[1]

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[1] The late Mr. Searles V. Wood, in an able summary of the possible causes of the succession of cold and warm climates in the northern hemisphere, enumerates no fewer than seven theories which have met with more or less acceptance. These are:—

1. The gradual cooling of the earth from a condition of original incandescence.
2. Changes in the obliquity of the ecliptic.
3. Changes in the position of the earth's axis of rotation.
4. The effect of the precession of the equinoxes along with changes of the eccentricity of the earth's orbit.
5. Variations in the amount of heat given off by the sun.
6. Differences in the temperature of portions of space passed through by the earth.
7. Differences in the distribution of land and water in connection with the flow of oceanic currents.

The ocean is a great equaliser of extremes of temperature. It does this by its great capacity for heat and by its cooling and heating power when passing from the solid into the liquid and gaseous states, and the reverse. It also acts by its mobility, its currents serving to convey heat to great distances or to cool the air by the movement of cold icy waters. The land, on the other hand, cools or warms rapidly, and can transmit its influence to a distance only by the winds, and the influence so transmitted is rather in the nature of a disturbing than of an equalising cause. It follows that any change in the distribution of land and water must affect climate, more especially if it changes the character or course of the ocean currents.[1]

At the present time the North Atlantic presents some very peculiar and in some respects exceptional features, which are most instructive with reference to its past history. The great internal plateau of the American continent is now dry land; the passage across Central America between the Atlantic and the Pacific is blocked; the Atlantic opens very widely to the north; the high mass of Greenland towers in its northern part. The effects are that the great equatorial current running across from Africa and embayed in the Gulf of Mexico, is thrown northward and eastward in the Gulf Stream, acting as a hot-water apparatus to heat up to an exceptional degree the western coast of Europe. On the other hand, the cold Arctic current from the polar seas is thrown to the westward, and runs down from Greenland past the American shore.[2] The pilot chart for June of this year shows vast fields of drift ice on the western side of the Atlantic as far south as the latitude of 40°. So far, therefore, the Glacial age in that part of the Atlantic still extends; and this at a time when, on the eastern side of the Ocean, the culture of cereals reaches in Norway beyond the Arctic Circle. Let us inquire into some of the details of these phenomena.

The warm water thrown into the North Atlantic not only increases the temperature of the whole of its water, but gives an exceptionally mild climate to Western Europe. Still the countervailing influence of the Arctic currents and the Greenland ice is sufficient to permit icebergs which creep down to the mouth of the Strait of Belle Isle, in the latitude of the south of England, to remain unmelted till the snows of a succeeding winter fall upon them. Now let us suppose that a subsidence of land in tropical America were to allow the equatorial current to pass through into the Pacific. The effect would at once be to reduce the temperature of Norway and Britain to that of Greenland and Labrador at present, while the latter countries would themselves become colder. The northern ice, drifting down into the Atlantic, would not, as now, be melted rapidly by the warm water which it meets in the Gulf Stream. Much larger

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[1] Von Wœickoff has very strongly put these principles in a review of Croll's recent book, *Climate and Cosmology*; *American Journal of Science*, March 1886.

[2] I may refer here to the admirable expositions of these effects by the late Dr. Carpenter, in his papers on the results of the explorations of the *Challenger*.

quantities of it would remain undissolved in summer, and thus an accumulation of permanent ice would take place, along the American coast at first, but probably at length even on the European side. This would still further chill the atmosphere, glaciers would be established on all the mountains of temperate Europe and America,[1] the summer would be kept cold by melting ice and snow, and at length all Eastern America and Europe might become uninhabitable, except by arctic animals and plants, as far south as perhaps 40° of north latitude. This would be simply a return of the Glacial age. I have assumed only one geographical change; but other and more complete changes of subsidence and elevation might take place, with effects on climate still more decisive; more especially would this be the case if there were a considerable submergence of the land in temperate latitudes.

We may suppose an opposite case. The high plateau of Greenland might subside or be reduced in height, and the openings of Baffin's Bay and the North Atlantic might be closed. At the same time the interior plain of America might be depressed, so that, as we know to have been the case in the Cretaceous period, the warm waters of the Mexican Gulf would circulate as far north as the basins of the present great American lakes. In these circumstances there would be an immense diminution of the sources of floating ice, and a correspondingly vast increase in the surface of warm water. The effects would be to enable a temperate flora to subsist in Greenland, and to bring all the present temperate regions of Europe and America into a condition of subtropical verdure.

It is only necessary to add that we know that vicissitudes not dissimilar from those above sketched have actually occurred in comparatively recent geological times, to enable us to perceive that we can dispense with all other causes of change of climate, though admitting that some of them may have occupied a secondary place.[2] This will give us, in dealing with the distribution of life, the great advantage of not being tied up to definite astronomical cycles of glaciation, which may not always suit the geological facts, and of correlating elevation and subsidence of the land with changes of climate affecting living beings. It will, however, be necessary, as Wallace well insists, that we shall hold to that degree of fixity of the continents in their position, notwithstanding the submergences and emergences they have experienced, to which I have already adverted. Sir Charles Lyell, more than forty years ago, published in his 'Principles of Geology' two imaginary maps which illustrate the extreme effects of various distribution of land and water. In one all the continental masses are grouped around the equator. In the

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[1] According to Bonney, the west coast of Wales is about 12° above the average for its latitude, and if reduced to 12° below the average its mountains would have large glaciers.

[2] More especially the ingenious and elaborate arguments of Croll deserve consideration; and, though I cannot agree with him in his main thesis, I gladly acknowledge the great utility of the work he has done.

other they are all placed around the poles, leaving an open equatorial ocean. In the one case the whole of the land and its inhabitants would enjoy a perpetual summer, and scarcely any ice could exist in the sea. In the other the whole of the land would be subjected to an arctic climate, and it would give off immense quantities of ice to cool the ocean. But Lyell did not suppose that any such distribution as that represented in his maps had actually occurred, though this supposition has been sometimes attributed to him. He merely put what he regarded as an extreme case to illustrate what might occur under conditions less exaggerated. Sir Charles, like other thoughtful geologists, was well aware of the general fixity of the areas of the continents, though with great modifications in the matter of submergence and of land conditions. The union, indeed, of these two great principles of fixity and diversity of the continents lies at the foundation of theoretical geology.

We can now more precisely indicate this than was possible when Lyell produced his 'Principles,' and can reproduce the conditions of our continents in even the more ancient periods of their history. Some examples may be taken from the history of the American continent, which is more simple in its arrangements than the double continent of Europ-asia. We may select the early Devonian or Erian period, in which the magnificent flora of that age—the earliest certainly known to us—made its appearance. Imagine the whole interior plain of North America submerged, so that the continent is reduced to two strips on the east and west, connected by a belt of Laurentian land on the north. In the great mediterranean sea thus produced the tepid water of the equatorial current circulated, and it swarmed with corals, of which we know no less than one hundred and fifty species, and with other forms of life appropriate to warm seas. On the islands and coasts of this sea was introduced the Erian flora, appearing first in the north, and with that vitality and colonising power of which, as Hooker has well shown, the Scandinavian flora is the best modern type, spreading itself to the south.[1] A very similar distribution of land and water in the Cretaceous age gave a warm and equable climate in those portions of North America not submerged, and coincided with the appearance of the multitude of broad-leaved trees of modern types introduced in the early and middle Cretaceous, and which prepared the way for the mammalian life of the Eocene. We may take a still later instance from the second continental period of the later Pleistocene or early Modern, when there would seem to have been a partial or entire closure of the North Atlantic against the Arctic ice, and wide extensions seaward of the European and American land, with possibly considerable tracts of land in the vicinity of the equator, while the Mediterranean

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[1] As I have elsewhere endeavoured to show (*Report on Silurian and Devonian Plants of Canada*), a warm climate in the Arctic region seems to have afforded the necessary conditions for the great colonising floras of all geological periods. Gray had previously illustrated the same fact in the case of the more modern floras.

and the Gulf of Mexico were deep inland lakes.[1] The effect of such conditions on the climates of the northern hemisphere must have been prodigious, and their investigation is rendered all the more interesting because it would seem that this continental period of the post-Glacial age was that in which man made his first acquaintance with the coasts of the Atlantic, and possibly made his way across its waters.

We have in America ancient periods of cold as well as of warmth. I have elsewhere referred to the boulder conglomerates of the Huronian, of the Cambrian and Ordovician, of the Millstone-grit period of the Carboniferous and of the early Permian; but would not venture to affirm that either of these periods was comparable in its cold with the later glacial age, still less with that imaginary age of continental glaciation assumed by certain of the more extreme theorists.[2] These ancient conglomerates were probably produced by floating ice, and this at periods when in areas not very remote temperate floras and faunas could flourish. The glacial periods of our old continent occurred in times when the surface of the submerged land was opened up to the northern currents, drifting over it mud and sand and stones, and rendering nugatory, in so far at least as the bottom of the sea was concerned, the effects of the superficial warm streams. Some of these beds are also peculiar to the eastern margin of the continent, and indicate ice-drift along the Atlantic coast in the same manner as at present, while conditions of greater warmth existed in the interior. Even in the more recent Glacial age, while the mountains were covered with snow and the lowlands submerged under a sea laden with ice, there were interior tracts in somewhat high latitudes of America in which hardy forest trees and herbaceous plants flourished abundantly; and these were by no means exceptional 'interglacial' periods. Thus we can show that while from the remote Huronian period to the Tertiary the American land occupied the same position as at present, and while its changes were merely changes of relative level as compared with the sea, these have so influenced the ocean currents as to cause great vicissitudes of climate.

Without entering on any detailed discussion of that last and greatest Glacial period which is best known to us, and is more immediately connected with the early history of man and the modern animals, it may be proper to make a few general statements bearing on the relative importance of sea-borne and land ice in producing those remarkable phenomena attributable to ice action in this period. In considering this question it must be borne in mind that the greater masses of floating ice are produced at the seaward extremities of land glaciers, and that the heavy field-ice of the Arctic regions is not so much a result of the direct freezing of the surface of the sea as of the accumulation of snow precipitated

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[1] Dawkins, *Popular Science Monthly*, 1873.

[2] *Notes on Post-Pliocene of Canada.* Hicks, 'Pre-Cambrian Glaciers,' *Geol. Mag.*, 1880.

on the frozen surface. In reasoning on the extent of ice action, and especially of glaciers in the Pleistocene age, it is necessary to keep this fully in view. Now in the formation of glaciers at present—and it would seem also in any conceivable former state of the earth—it is necessary that extensive evaporation should conspire with great condensation of water in the solid form. Such conditions exist in mountainous regions sufficiently near to the sea, as in Greenland, Norway, the Alps, and the Himalayas; but they do not exist in low arctic lands like Siberia or Grinnel-land nor in inland mountains. It follows that land glaciation has narrow limits, and that we cannot assume the possibility of great confluent or continental glaciers covering the interior of wide tracts of land. No imaginable increase of cold could render this possible, inasmuch as there could not be a sufficient influx of vapour to produce the necessary condensation; and the greater the cold, the less would be the evaporation. On the other hand, any increase of heat would be felt more rapidly in the thawing and evaporation of land ice and snow than on the surface of the sea.

Applying these very simple geographical truths to the North Atlantic continents, it is easy to perceive that no amount of refrigeration could produce a continental glacier, because there could not be sufficient evaporation and precipitation to afford the necessary snow in the interior. The case of Greenland is often referred to, but this is the case of a high mass of cold land with sea, mostly open, on both sides of it, giving, therefore, the conditions most favourable to precipitation of snow. If Greenland were less elevated, or if there were dry plains around it, the case would be quite different, as Nares has well shown by his observations on the summer verdure of Grinnel-land, which, in the immediate vicinity of North Greenland, presents very different conditions as to glaciation and climate.[1] If the plains were submerged, and the Arctic currents allowed free access to the interior of the continent of America, it is conceivable that the mountainous regions remaining out of water would be covered with snow and ice, and there is the best evidence that this actually occurred in the Glacial period; but with the plains out of water this would be impossible. We see evidence of this at the present day in the fact that in unusually cold winters the great precipitation of snow takes place south of Canada, leaving the north comparatively bare, while as the temperature becomes milder the area of snow-deposit moves farther to the north. Thus a greater extension of the Atlantic, and especially of its cold ice-laden arctic currents, becomes the most potent cause of a glacial age.

I have long maintained these conclusions on general geographical grounds, as well as on the evidence afforded by the Pleistocene deposits of Canada; and in an address the theme of which is the ocean I may be excused for continuing to regard the supposed terminal moraines of great continental

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[1] These views have been admirably illustrated by Von Wœickoff in the paper already referred to and in previous geographical papers.

glaciers as nothing but the southern limit of the ice-drift of a period of submergence. In such a period the southern margin of an ice-laden sea where its floe-ice and bergs grounded, or where its ice was rapidly melted by warmer water, and where consequently its burden of boulders and other *débris* was deposited, would necessarily present the aspect of a moraine, which by the long continuance of such conditions might assume gigantic dimensions. Let it be observed, however, that I fully admit the evidence of the great extension of local glaciers in the Pleistocene age, and especially in the times of partial submergence of the land.

I am quite aware that it has been held by many able American geologists[1] that in North America a continental glacier extended in temperate latitudes from sea to sea, or at least from the Atlantic to the Rocky Mountains, and that this glacier must, in many places, have exceeded a mile in thickness. The reasons above stated appear, however, sufficient to compel us to seek for some other explanation of the observed facts, however difficult this may at first sight appear. With a depression such as we know to have existed, admitting the Arctic currents along the St. Lawrence Valley, through gaps in the Laurentian watershed, and down the great plains between the Laurentian areas and the Rocky Mountains, we can easily understand the covering of the hills of Eastern Canada and New England with ice and snow, and a similar covering of the mountains of the west coast. The sea also in this case might be ice-laden and boulder-bearing as far south as 40°, while there might still be low islands far to the north on which vegetation and animals continued to exist. We should thus have the conditions necessary to explain all the anomalies of the glacial deposits. Even the glaciation of high mountains south of the St. Lawrence Valley would then become explicable by the grounding of floe-ice on the tops of these mountains when reefs in the sea. In like manner we can understand how on the isolated trappean hill of Beloeil, in the St. Lawrence Valley, Laurentian boulders far removed from their native seats to the north are perched at a height of about 1,200 feet on a narrow peak where no glacier could possibly have left them. The so-called moraine, traceable from the great Missouri Coteau in the west, to the coasts of New Jersey, would thus become the mark of the western and southern limit of the subsidence, or of the line along which the cold currents bearing ice were abruptly cut off by warm surface waters. I am glad to find that these considerations are beginning to have weight with European geologists in their explanation of the glacial drift of the great plains of Northern Europe.

Whatever difficulties may attend such a supposition, they are small compared with those attendant on the belief of a continental glacier, moving without the aid of gravity, and depending for its material on the precipitation taking place on the interior plains of a great continent.

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[1] Report of Mr. Carvill Lewis in *Pennsylvania Geological Survey*, 1884; also Dana's *Manual*.

I have elsewhere endeavoured to show, on the evidence found in Canada, that the occurrence of marine shells, land plants, and insects in the glacial deposits of that country indicates not so much the effect of general interglacial periods as the local existence of conditions like those of Grinnel-land and Greenland, in proximity to each other at one and the same period, and depending on the relative levels of land and the distribution of ocean currents and ice-drift.[1]

I am old enough to remember the sensation caused by the delightful revelations of Edward Forbes respecting the zones of animal life in the sea, and the vast insight which they gave into the significance of the work on minute organisms previously done by Ehrenberg, Lonsdale, and Williamson, and into the meaning of fossil remains. A little later the soundings for the Atlantic cable revealed the chalky foraminiferal ooze of the abyssal ocean; still more recently the wealth of facts disclosed by the *Challenger* voyage, which naturalists have not yet had time to digest, have opened up to us new worlds of deep-sea life.

The bed of the deep Atlantic is covered for the most part by a mud or ooze largely made up of the *débris* of foraminifera and other minute organisms mixed with fine clay. In the North Atlantic the Norwegian naturalists call this the Biloculina mud. Further south the *Challenger* naturalists speak of it as Globigerina ooze. In point of fact it contains different species of foraminiferal shells, Globigerina and Orbulina being in some localities dominant, and in others other species, and these changes are more apparent in the shallower portions of the ocean.

On the other hand there are means for disseminating coarse material over parts of the ocean-bed. There are in the line of the Arctic current on the American coast great sand-banks, and off the coast of Norway sand constitutes a considerable part of the bottom material. Soundings and dredgings off Great Britain, and also off the American coast, have shown that fragments of stone referable to Arctic lands are abundantly strewn over the bottom along certain lines, and the Antarctic continent, otherwise almost unknown, makes its presence felt to the dredge by the abundant masses of crystalline rock drifted far from it to the north. These are not altogether new discoveries. I had inferred many years ago, from stones taken up by the hooks of fishermen on the banks of Newfoundland, that rocky material from the north is dropped on these banks by the heavy ice which drifts over them every spring, that these stones are glaciated, and that after they fall to the bottom sand is drifted over them with sufficient velocity to polish the stones and to erode the shelly coverings of Arctic animals attached to them.[2] If then the Atlantic basin were upheaved into land we should see beds of sand, gravel, and boulders with clay flats and layers of marl and limestone. According to the

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[1] *Notes on Post-Pliocene of Canada*, 1872. One well-marked interval only has been established in the glacial deposits of Canada.

[2] *Notes on Post-Pliocene of Canada*, 1872.

Challenger Reports, in the Antarctic seas S. of 64° there is blue mud with fragments of rock in depths of 1,200 to 2,000 fathoms. The stones, some of them glaciated, were granite, diorite, amphibolite, mica schist, gneiss, and quartzite. This deposit ceases and gives place to Globigerina ooze and red clay at 46° to 47° S., but even further north there is sometimes as much as 49 per cent. of crystalline sand. In the Labrador current a block of syenite weighing 490 lbs. was taken up from 1,340 fathoms, and in the Arctic current 100 miles from land was a stony deposit, some stones being glaciated. Among these were smoky quartz, quartzite, limestone, dolomite, mica schist, and serpentine; also particles of monoclinic and triclinic felspar, hornblende, augite, magnetite, mica, and glauconite, the latter no doubt formed in the sea-bottom, the others drifted from Eozoic and Palæozoic formations to the north.[1]

A remarkable fact in this connection is that the great depths of the sea are as impassable to the majority of marine animals as the land itself. According to Murray, while twelve of the *Challenger's* dredgings taken in depths greater than 2,000 fathoms gave 92 species, mostly new to science, a similar number of dredgings in shallower water near the land gave no less than 1,000 species. Hence arises another apparent paradox relating to the distribution of organic beings. While at first sight it might seem that the chances of wide distribution are exceptionally great for marine species, this is not so. Except in the case of those which enjoy a period of free locomotion when young, or are floating and pelagic, the deep ocean sets bounds to their migrations. On the other hand the spores of cryptogamic plants may be carried for vast distances by the wind, and the growth of volcanic islands may effect connections which, though only temporary, may afford opportunity for land animals and plants to pass over.

With reference to the transmission of living beings across the Atlantic, we have before us the remarkable fact that from the Cambrian age onwards there were on the two sides of the ocean many species of invertebrate animals which were either identical or so closely allied as to be possibly varietal forms.[2] In like manner the early plants of the Upper Silurian, Devonian, and Carboniferous present many identical species; but this identity becomes less marked in the vegetation of the more modern times. Even in the latter, however, there are remarkable connections between the floras of oceanic islands and the continents, which establish this conclusively. Thus the Bermudas, altogether recent islands, have been stocked by the agency chiefly of the ocean currents and of birds, with nearly 150 species of continental plants, and the facts collected by Helmsley as to the present facilities of transmission, along with the evidence afforded by older oceanic islands which have been receiving

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[1] *General Report, 'Challenger' Expedition.*

[2] See Davidson's *Monographs on Brachiopods*; Etheridge, *Address to Geological Society of London*; Woodward, *Address to Geologists' Association*; also Barrande's

animal and vegetable colonists for longer periods, go far to show that, time being given, the sea actually affords facilities for the migration of the inhabitants of the land, comparable with those of continuous continents.

In so far as plants are concerned, it is to be observed that the early forests were largely composed of cryptogamous plants, and the spores of these in modern times have proved capable of transmission for great distances. In considering this we cannot fail to conclude that the union of simple cryptogamous fructification with arboreal stems of high complexity, so well illustrated by Dr. Williamson, had a direct relation to the necessity for a rapid and wide distribution of these ancient trees. It seems also certain that some spores, as, for example, those of the Rhizocarps,[1] a type of vegetation abundant in the Palæozoic, and certain kinds of seeds, as those named *Ætheotesta* and *Pachytheca,* were fitted for flotation. Farther, the periods of Arctic warmth permitted the passage around the northern belt of many temperate species of plants, just as now happens with the Arctic flora; and when these were dispersed by colder periods they marched southward along both sides of the sea on the mountain chains.

The same remark applies to northern forms of marine invertebrates, which are much more widely distributed in longitude than those further south. The late Mr. Gwyn Jeffreys, in one of his latest communications to this Association, stated that 54 per cent. of the shallow-water mollusks of New England and Canada are also European, and of the deep-sea forms 30 out of 35; these last of course enjoying greater facilities for migration than those which have to travel slowly along the shallows of the coasts in order to cross the ocean and settle themselves on both sides. Many of these animals, like the common mussel and sand-clam, are old settlers which came over in the Pleistocene period, or even earlier. Others, like the common periwinkle, seem to have been slowly extending themselves in modern times, perhaps even by the agency of man. The older immigrants may possibly have taken advantage of lines of coast now submerged, or of warm periods, when they could creep around by the Arctic shores. Mr. Herbert Carpenter and other naturalists employed on the *Challenger* collections have made similar statements respecting other marine invertebrates, as, for instance, the Echinoderms, of which the deep-sea crinoids present many common species, and my own collections prove that many of the shallow-water forms are common. Dall and Whiteaves[2] have shown that some mollusks and Echinoderms are common even to the Atlantic and Pacific coasts of North America; a remarkable fact, testifying at once to the fixity of these species and to the manner in which they have been able to take advantage of geographical changes. Some of the species of whelks common to the

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Special Memoirs on the Brachiopods, Cephalopods, &c.; and Hall, *Palæontology of New York*; Billings, *Reports on Canadian Fossils*; and Matthews, *Cambrian of New Brunswick, Trans. R.S.C.*

[1] See paper by the author on Palæozoic Rhizocarps, *Chicago Trans.* 1886.

[2] Dall, *Report on Alaska*; Whiteaves, *Trans. R.S.C.*

Gulf of St. Lawrence and the Pacific are animals which have no special locomotive powers even when young, but they are northern forms not proceeding far south, so that they may have passed through the Arctic seas. In this connection it is well to remark that many species of animals have powers of locomotion in youth which they lose when adult, and that others may have special means of transit. I once found at Gaspé a specimen of the Pacific species of Coronula, or whale-barnacle, the *C. reginæ* of Darwin, attached to a whale taken in the Gulf of St. Lawrence, and which had probably succeeded in making that passage around the north of America, which so many navigators have essayed in vain.

But it is to be remarked that while many plants and marine invertebrates are common to the two sides of the Atlantic, it is different with land animals, and especially vertebrates. I do not know that any Palæozoic insects or land snails or millipedes of Europe and America are specifically identical, and of the numerous species of batrachians of the Carboniferous and reptiles of the Mesozoic all seem to be distinct on the two sides. The same appears to be the case with the Tertiary mammals, until in the later stages of that great period we find such genera as the horse, the camel, and the elephant appearing on the two sides of the Atlantic; but even then the species seem different, except in the case of a few northern forms.

Some of the longer-lived mollusks of the Atlantic furnish suggestions which remarkably illustrate the biological aspect of these questions. Our familiar friend the oyster is one of these. The first known oysters appear in the Carboniferous in Belgium and in the United States of America. In the Carboniferous and Permian they are few and small, and they do not culminate till the Cretaceous, in which there are no less than ninety-one so-called species in America alone; but some of the largest known species are found in the Eocene. The oyster, though an inhabitant of shallow water, and very limitedly locomotive when young, has survived all the changes since the Carboniferous age, and has spread itself over the whole northern hemisphere.[1]

I have collected fossil oysters in the Cretaceous clays of the coulées of Western Canada, in the Lias shales of England, in the Eocene and Cretaceous beds of the Alps, of Egypt, of the Red Sea coast, of Judea, and the heights of Lebanon. Everywhere and in all formations they present forms which are so variable and yet so similar that one might suppose all the so-called species to be mere varieties. Did the oyster originate separately on the two sides of the Atlantic, or did it cross over so promptly that its appearance seems to be identical on the two sides? Are all the oysters of a common ancestry, or did the causes, whatever they were, which introduced the oyster in the Carboniferous act over again in later periods? Who can tell? This is one of the cases where

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[1] White, *Report U.S. Geol. Survey*, 1882-83.

causation and development—the two scientific factors which constitute the basis of what is vaguely called evolution—cannot easily be isolated. I would recommend to those biologists who discuss these questions to addict themselves to the oyster. This familiar mollusk has successfully pursued its course and has overcome all its enemies, from the flat-toothed selachians of the Carboniferous to the oyster-dredgers of the present day, has varied almost indefinitely, and yet has continued to be an oyster, unless indeed it may at certain portions of its career have temporarily assumed the disguise of a Gryphæa or an Exogyra. The history of such an animal deserves to be traced with care, and much curious information respecting it will be found in the report which I have cited.

But in these respects the oyster is merely an example of many forms. Similar considerations apply to all those Pliocene and Pleistocene mollusks which are found in the raised sea-bottoms of Norway and Scotland, on the top of Moel Tryfaen in Wales, and at similar great heights on the hills of America, many of which can be traced back to early Tertiary times, and can be found to have extended themselves over all the seas of the northern hemisphere. They apply in like manner to the ferns, the conifers, and the angiosperms, many of which we can now follow without even specific change to the Eocene and Cretaceous. They all show that the forms of living things are more stable than the lands and seas in which they live. If we were to adopt some of the modern ideas of evolution we might cut the Gordian knot by supposing that, as like causes can produce like effects, these types of life have originated more than once in geological time, and need not be genetically connected with each other. But while evolutionists repudiate such an application of their doctrine, however natural and rational, it would seem that nature still more strongly repudiates it, and will not allow us to assume more than one origin for one species. Thus the great question of geographical distribution remains in all its force, and, by still another of our geological paradoxes, mountains become ephemeral things in comparison with the delicate herbage which covers them, and seas are in their present extent but of yesterday when compared with the minute and feeble organisms that creep on their sands or swim in their waters.

The question remains, Has the Atlantic achieved its destiny and finished its course, or are there other changes in store for it in the future? The earth's crust is now thicker and stronger than ever before, and its great ribs of crushed and folded rock are more firm and rigid than in any previous period. The stupendous volcanic phenomena manifested in Mesozoic and early Tertiary times along the borders of the Atlantic have apparently died out. These facts are in so far guarantees of permanence. On the other hand, it is known that movements of elevation along with local depression are in progress in the Arctic regions, and a great weight of new sediment is being deposited along the borders of the Atlantic, especially on its western side, and this is not improbably connected with the earthquake shocks and slight movements of depression which have occurred in North America. It is possible that these slow and secular movements may go on uninterruptedly, or with occasional paroxysmal disturbances, until considerable changes are produced.

It is possible, on the other hand, that after the long period of quiescence which has elapsed there may be a new settlement of the ocean-bed, accompanied with foldings of the crust, especially on the western side of the Atlantic, and possibly with renewed volcanic activity on its eastern margin. In either case a long time relatively to our limited human chronology may intervene before the occurrence of any marked change. On the whole the experience of the past would lead us to expect movements and eruptive discharges in the Pacific rather than in the Atlantic area. It is therefore not unlikely that the Atlantic may remain undisturbed, unless secondarily and indirectly, until after the Pacific area shall have attained to a greater degree of quiescence than at present. But this subject is one too much involved in uncertainty to warrant us in following it farther.

In the meantime the Atlantic is to us a practically permanent ocean, varying only in its tides, its currents, and its winds, which science has already reduced to definite laws, so that we can use if we cannot regulate them. It is ours to take advantage of this precious time of quietude, and to extend the blessings of science and of our Christian civilisation from shore to shore until there shall be no more sea, not in the sense of that final drying-up of old ocean to which some physicists look forward, but in the higher sense of its ceasing to be the emblem of unrest and disturbance, and the cause of isolation.

I must now close this address with a short statement of some general truths which I have had in view in directing your attention to the geological development of the Atlantic. We cannot, I think, consider the topics to which I have referred without perceiving that the history of ocean and continent is an example of progressive design, quite as much as that of living beings. Nor can we fail to see that, while in some important directions we have penetrated the great secret of Nature, in reference to the general plan and structure of the earth and its waters, and the changes through which they have passed, we have still very much to learn, and perhaps quite as much to unlearn, and that the future holds out to us and to our successors higher, grander, and clearer conceptions than those to which we have yet attained. The vastness and the might of ocean and the manner in which it cherishes the feeblest and most fragile beings, alike speak to us of Him who holds it in the hollow of His hand, and gave to it of old its boundaries and its laws; but its teaching ascends to a higher tone when we consider its origin and history, and the manner in which it has been made to build up continents and mountain-chains, and at the same time to nourish and sustain the teeming life of sea and land.

REPORTS

ON THE

STATE OF SCIENCE.

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Second Report of the Committee, consisting of Professor G. FORBES (*Secretary*), Captain ABNEY, Dr. J. HOPKINSON, Professor W. G. ADAMS, Professor G. C. FOSTER, Lord RAYLEIGH, Mr. PREECE, Professor SCHUSTER, Professor DEWAR, Mr. A. VERNON HARCOURT, Professor AYRTON, and Sir JAMES DOUGLASS, *appointed for the purpose of reporting on Standards of Light. Drawn up by* Professor G. FORBES.

THE Committee on Standards of Light met repeatedly during last winter. It had been proposed in last year's report to carry on experiments on electrical standards in the hope of arriving at an absolute standard of light. One of the first steps was to discover a means of reproducing a definite temperature, and certain experiments were proposed for this purpose. At one of the first meetings of the Committee Captain Abney announced that he had already found a means of doing this in a different manner from that proposed in the Committee's report and depending only upon the change of resistance of the carbon filament. Under these circumstances the Committee left this part of the experimental investigation to be reported upon by Captain Abney. His further researches have, however, led him to believe that the law which he had announced to the Committee does not hold with all qualities of carbon filament. He has, however, been engaged upon further experimental researches, which are almost ready for publication, and which have an important bearing upon the labours of the Committee.

In last year's report attention was drawn to the value of the Pentane standard of Mr. Vernon Harcourt as a practical reproducible standard, and Mr. Rawson has been since then engaged in a further examination of this standard. Sir James Douglass has also made some experiments which are not quite completed, but have gone so far as to give great promise. Some account of these experiments in this report had been expected by the Committee, but the absence of Sir James Douglass on official business has interfered with this.

At one of the first meetings of the Committee the Secretary showed what he had done in the way of improving thermopiles such as it was hoped would be of use in the investigations recommended in last year's report; and he was instructed by the Committee to proceed with the construction of the instrument, which has been completed, and is placed before the Section and described in a separate paper.

The Committee respectfully request to be reappointed, with a grant of 25*l.*

Report of the Committee, consisting of Professor G. H. DARWIN, Sir W. THOMSON, *and* Major BAIRD, *for preparing instructions for the practical work of Tidal Observation; and Fourth Report of the Committee, consisting of* Professors G. H. DARWIN *and* J. C. ADAMS, *for the Harmonic Analysis of Tidal Observations. Drawn up by* Professor G. H. DARWIN.

I. RECORD OF WORK DURING THE PAST YEAR. DATUM LEVELS.

MAJOR BAIRD's manual of tidal observations is now printed, and will be sold by Messrs. Taylor & Francis, Fleet Street.

The Indian tidal results of all previous years, and those given in the various Reports to the British Association, have been reduced by Major Baird to the standard form recommended in the Report of 1883. To these have been added the results derived by the United States Coast Survey, and the whole has been published in the 'Proceedings of the Royal Society,' No. 239, 1885, in a paper by Major Baird and Professor Darwin.

In the course of the Indian tidal operations a discussion has arisen as to the determination of a datum level for tide-tables. The custom of the Admiralty is to refer the tides to 'the mean low-water mark of ordinary spring tides.' This datum has not a precise scientific meaning, but, at ports where there are but few observations, has been derived from a mean of the spring-tides available. At some of the Indian ports this datum has been found by taking the mean of all spring-tides on the tide diagram for a year, with the exception of those which occur when the moon is near perigee. The diurnal tides enter into the determination of the datum in an undefined manner. It follows that two determinations of this datum level, both equally defensible, might differ sensibly from one another.

A datum level should be sufficiently low to obviate the frequent occurrence of negative entries in a tide-table, and it should be rigorously determinable from tidal theory. It is now proposed to adopt as the datum level at any new ports in India, for which tide-tables are to be issued, a datum to be called 'the Indian spring low-water mark,' and which is to be below mean sea-level by the sum of the mean semi-ranges of the tides M_2, S_2, K_1, O; or, in the notation used below,

$$H_m + H_s + H' + H_o$$

below mean water mark.

This datum is found to agree pretty nearly with the Admiralty datum, but is usually a few inches lower. The definition is not founded on any precise theoretical considerations, but it satisfies the conditions of a good datum, and is precisely referable to tidal theory.

If, when further observations are made, it is found that the values of the several H's require correction, it is not proposed that the datum level shall be altered accordingly, but when once fixed it is to be always adhered to.

II. ON THE TREATMENT OF A SHORT SERIES OF TIDAL OBSERVATIONS AND ON TIDAL PREDICTION.

§ 1. *Harmonic Analysis.*

Having been asked to write an article on the tides in a new edition of the 'Admiralty Scientific Manual,' now in the press, I thought it would be useful to show how harmonic analysis might be applied to the reduction of a short series of tidal observations, such as might be made when a ship lies for a fortnight or a month in a port.

The process of harmonic analysis, as applicable to a year of continuous observation, needs some modification for a short series, and as it was not possible to explain the reasons for the rules laid down within the limits of the article, it seems desirable to place on record an explanation of the instructions given.

The observations to be treated are supposed to consist of hourly observations extending over a fortnight or a month. In the reduction of a long series of observations the various tides are disentangled from one another by means of an appropriate grouping of the hourly observations. When, however, the series is short, the method of grouping is not sufficient in all cases.

With the amount of observation supposed to be available, a determination of the elliptic tides was not possible, and it was therefore proposed to consider only the tides M_2, S_2, K_2, K_1, O, P—that is to say, the principal lunar, solar, and luni-solar semidiurnal tides, and the luni-solar, lunar, and solar diurnal tides. The luni-solar and solar semidiurnal tides have, however, so nearly the same speed that we cannot hope for a direct separation of them by the grouping of the hourly values, and we must have recourse to theory for completing the process; and the like is true of the luni-solar and solar diurnal tides.

Also, the tides K_1 and P have very nearly half the speed of S_2; hence the diurnal tides K_1 and P will appear together as the diurnal constituent, whilst S_2 and K_2 will appear as the semi-diurnal constituent, from the harmonic analysis of the same table of entries.

It thus appears that three different harmonic analyses will suffice to determine the six tides, viz.:—

First, an analysis for M_2; second, an analysis for O; third, an analysis for S_2, K_2, K_1, P.

The rules therefore begin with instructions for drawing up three schedules, to be called M, O, S, for the entry of hourly tide-heights. Each schedule consists of twenty-four hour columns, and a number of rows for the successive days. In M and O certain squares are marked, in which two successive hourly entries are to be put. The instructions for drawing up the schedules are simply rules for preparing part of the first page of the series M, O, S of the computation forms for a year of observation.

In order to minimise the vitiation of the results derived from the M sheet by the S_2 tide, and *vice versâ*, and similarly to minimise the vitiation of the results from the O sheet by the K_1 tide, it is important to choose the proper number of entries in each of the three sheets.

It was shown in Section III. of the Tidal Report to the British Association for 1885 how these periods were to be determined. The equation by which we find how many rows to take to minimise the effect of the S_2 tide on the M_2 tide is there shown to be

$$1^\circ{\cdot}0158958q=14^\circ{\cdot}4920521r.$$

If $r=1$, $q=14{\cdot}26$; and if $r=2$, $q=28{\cdot}5$.

From a reason similar to that given in 1885 we conclude that, in analysing about a fortnight of observation we must have 14 rows of values on the M sheet, and for a month's observation 29 rows of values.

Similarly, to minimise the effect of the M_2 tide on the S_2 tide the equation is

$$1^\circ{\cdot}0158958q=15^\circ r.$$

If $r=1$, $q=14{\cdot}76$; and if $r=2$, $q=29{\cdot}5$.

Whence we must have 15 rows of values on the S sheet for a fortnight's observation, and 30 rows of values for a month's observation.

These two rules are simply a statement that on the M and S sheets we are to take a period equal to the interval from spring-tide to spring-tide, or twice that period.

Similarly, to minimise the effect of the K_1 tide on the O tide, the equation is

$$1^\circ{\cdot}0980330q=13^\circ{\cdot}9430356r.$$

If $r=1$, $q=12{\cdot}69$; and if $r=2$, $q=25{\cdot}38$.

Whence we must have 13 rows of values on the O sheet for a fortnight's observation, and 25 rows for a month's observation.

Lastly, to minimise the effect of the O tide on the K_1 tide, the equation is

$$1^\circ{\cdot}0980330q=15^\circ{\cdot}0410686r.$$

If $r=1$, $q=13{\cdot}70$; and if $r=2$, $q=26{\cdot}4$.

Hence, in using the numbers on the S sheet for determining the diurnal tides, we must use 14 rows of values for a fortnight's observation, and 26 rows for a month's observation.

Thus, on the S sheet we use more rows for the semidiurnal tides than for the diurnal—namely, one more for a fortnight and three more for a month.

The rules for drawing up the computation forms then specify, in accordance with the above results, where the entries are to stop on the three sheets, and give directions for the dual use of the S sheet, according as it is for finding semidiurnal or diurnal tides.

When the entries have been made, the twenty-four columns on each sheet are summed, and each is divided by the number of entries in the column. On the S sheet there are two sets of sums and divisions, one with and the other without the additional row or rows.

The three sheets thus provide us with four sets of twenty-four mean hourly values; the M sheet corresponds with mean lunar time, the hour being $15\div14{\cdot}49$ of a mean solar hour; both the means on the S sheet correspond with mean solar time; and the O sheet corresponds with a special time, in which the hour is $15\div13{\cdot}94$ of a mean solar hour.

The four sets of means are then submitted to harmonic analysis: the semidiurnal components are only evaluated on the M sheet; the diurnal components are evaluated from the shorter series on S, and the semidiurnal from the longer series; and the diurnal components from the O sheet. We may also evaluate the quaterdiurnal components from the M and S sheets.

It might, perhaps, be useful to evaluate the diurnal component on the M sheet, for if it does not come out small it is certain that the amount of observations analysed is not sufficient to give satisfactory results.

In the article the harmonic analysis is arranged according to a rule devised by General Strachey, which is less laborious than that usually employed, and which is sufficiently accurate for the purpose.

§ 2. *On the Notation employed.*

It will be convenient to collect together the definitions of the principal symbols employed in this paper.

The mean semi-range and angle of lagging of each of the harmonic constituent tides have, in the Tidal Report for 1883, been denoted generically by H, κ; but when several of the H's and κ's occur in the same algebraic expression it is necessary to distinguish between them. The tides to which we shall refer are M_2, S_2, N, L, T, R, O, P, and K_2, K_1; the H and κ for the first eight of these will be distinguished by writing the suffix letters $_m$, $_s$, $_n$, &c., *e.g.*, H_m, κ_m for the M_2 tide. With regard to the K tides, we may put H'', κ'', and H', κ'.

Again, the factors of augmentation f (functions of longitude of moon's node), as applicable to the several tides, will be denoted thus:—for M_2, N, L, simply f; for K_2, K_1, f'', f' respectively; for O, f_o.

The K_2, K_1 tides take their origin jointly from the moon and sun, and it will be necessary in computing the tide-table to separate the lunar from the solar portion of K_2. Now, the ratio of the lunar to the solar tide-generating force is such that $\cdot683H''$ is the lunar portion and $\cdot317H''$ is the solar portion of H''.

In the Report of 1885 a slightly different notation was employed for the H's and κ's, but it is easy to see how the results of that Report are to be transformed into the present notation.

As in the Report of 1883, we write t, h, s for local mean solar hour-angle, sun's and moon's mean longitude, and ν, ξ, ν', $2\nu''$ for functions of the longitude of moon's node depending on the intersection of the equator with the lunar orbit; also $\gamma-\eta$, η, σ, ϖ are the hourly increments of t, h, s and longitude of moon's perigee, and e, $e_{,}$ the eccentricities of lunar and solar orbits.

Let p, $p_{,}$ denote the cubes of the ratios of the moon's and sun's parallaxes to their mean parallaxes; δ, $\delta_{,}$ the moon's and sun's declinations; p' the value of p at a time tan $(\kappa_m-\kappa_n)/(\sigma-\varpi)$, or $105^h\cdot3$ tan $(\kappa_m-\kappa_n)$ earlier than t; δ' the moon's declination at a time tan $(\kappa''-\kappa_m)/2\sigma$, or $52^h\cdot2$ tan $(\kappa''-\kappa_m)$ earlier than t.

Let P, $P_{,}$, P' be the cube roots of p, $p_{,}$, p'.

Let Δ, $\Delta_{,}$ be declinations such that $\cos^2\Delta$, $\cos^2\Delta_{,}$ are respectively the mean values of $\cos^2\delta$, $\cos^2\delta_{,}$: obviously Δ has a small inequality with the longitude of the moon's node.

Let ϵ be an auxiliary angle defined by

$$\tan\epsilon = \frac{H_n \sin\kappa_n - H_l \sin\kappa_l}{H_n \cos\kappa_n - H_l \cos\kappa_l}.$$

Lastly, let ψ, $\psi_{,}$ be the moon's and sun's local hour angles.

§ 3. *The Reduction of the Results of Harmonic Analysis.*

We now suppose the harmonic analysis of the hourly means on the three sheets M, O, S completed.

The deduction of H_m, κ_m and H_o, κ_o from the M and O sheets follows exactly the same rules as in a long series of observations, and the reader is referred to the Report of 1883 for an explanation.

With regard to the S sheet, the results of the harmonic analysis do not separate the S_2 tide from the K_2 tide, nor the K_1 tide from the P tide, and we have to employ theoretical considerations for effecting the separation.

The semidiurnal tides will be taken first.

The solar tide, as derived from a short series of observations, is of course affected by the sun's parallax, and as the sun changes his parallax slowly, the solar tide will follow the equilibrium law and vary as the cube of the sun's parallax. Thus the height of the purely solar semidiurnal tide as derived from our short series of observations will be $\mathrm{p}_{,}\mathrm{H}_s$ instead of H_s, and this will be fused with the luni-solar tide K_2.

The schedules of the Report of 1883 thus show that we shall have as the expression for this tide, compounded of S_2 (with parallactic inequality) and K_2,

$$h_2 = \mathrm{p}_{,}\mathrm{H}_s \cos(2t-\kappa_s) + \mathrm{f}''\,\mathrm{H}''\cos(2t+2h-2\nu''-\kappa'') \quad . \quad . \quad . \quad . \quad (1)$$

The theoretical ratio of H'' to H_s is (see Schedule E, 1883) that of ·12662 to ·45631, or 1 to 3·67; and the tides having nearly the same speed, we may assume $\kappa''=\kappa_s$.

Hence:

$$\begin{aligned} h_2 &= \mathrm{H}_s\left[\mathrm{p}_{,}\cos(2t-\kappa_s)+\frac{\mathrm{f}''}{3{\cdot}67}\cos(2t+2h-2\nu''-\kappa_s)\right] \\ &= \mathrm{R}_s\cos(2t-\kappa_s+\psi) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2) \end{aligned}$$

where

$$\tan\psi = \frac{\mathrm{f}''\sin 2(h-\nu'')}{3{\cdot}67\,\mathrm{p}_{,}+\mathrm{f}''\cos 2(h-\nu'')},\quad \mathrm{R}_s=\frac{3{\cdot}67\mathrm{p}_{,}+\mathrm{f}''\cos 2(h-\nu'')}{3{\cdot}67\cos\psi}\mathrm{H}_s \quad . \quad (3)$$

If, therefore, the harmonic analysis of the S sheet for semidiurnal tides has given the two components A_2, B_2 which are to define R_s, ζ_s by the equations

$$\mathrm{A}_2=\mathrm{R}_s\cos\zeta_s,\quad \mathrm{B}_2=\mathrm{R}_s\sin\zeta_s;$$

and if we put for $\mathrm{p}_{,}$ its value at the middle of the fortnight or month as a mean value, and also put as a mean $h=\odot$, the value of the sun's mean longitude at the middle of the fortnight or month, we get

$$\mathrm{H}_s=\frac{3{\cdot}67\cos\psi}{3{\cdot}67\mathrm{p}_{,}+\mathrm{f}''\cos 2(\odot-\nu'')},\quad \kappa_s=\zeta_s+\psi,$$

$$\text{where }\tan\psi=\frac{\mathrm{f}''\sin 2(\odot-\nu'')}{3{\cdot}67\,\mathrm{p}_{,}+\mathrm{f}''\cos 2(\odot-\nu'')},\quad \text{and }\mathrm{H}''=\frac{1}{3{\cdot}67}\mathrm{H}_s,\quad \kappa''=\kappa_s \quad . \quad (4)$$

We now turn to the diurnal tides derived from the S sheet.

The schedules of the Report of 1883 show that we shall have as the expression for the tide which is compounded of K_1 and P

$$h_1=\mathrm{f}'\mathrm{H}'\cos(t+h-\nu'-\tfrac{1}{2}\pi-\kappa')+\mathrm{H}_p\cos(t-h+\tfrac{1}{2}\pi-\kappa_p) \quad . \quad . \quad . \quad (5)$$

The theoretical ratio of H_p to H' is (see Sched. E 1883) that of ·19317 to ·58385, or 1 to 3, and the tides having nearly the same speed, we may assume $\kappa_p = \kappa_s$. Hence:

$$\begin{aligned} h_1 &= \mathrm{H}\{'\mathrm{f}' \cos(t+h-\nu'-\tfrac{1}{2}\pi-\kappa') - \tfrac{1}{3}\cos[t+h-\nu'-\tfrac{1}{2}\pi-\kappa'-(2h-\nu')]\} \\ &= \mathrm{R}'\cos(t+h-\nu'-\tfrac{1}{2}\pi-\kappa'+\phi), \end{aligned}$$

$$\text{where } \tan\phi = \frac{\sin(2h-\nu')}{3\mathrm{f}'-\cos(2h-\nu')}, \quad \mathrm{R}' = \frac{3\mathrm{f}'-\cos(2h-\nu')}{3\cos\phi}\mathrm{H}' \quad . \quad . \quad . \quad (6)$$

If, therefore, the harmonic analysis for diurnal tides has given the two components A_1, B_1 which are to define R', ζ' by the equations

$$A_1 = R'\cos\zeta', \quad B_1 = R'\sin\zeta';$$

and if we write $V' = h_0 - \nu' - \frac{1}{2}\pi$, where h_0 is the sun's mean longitude at the beginning of the observations, and if we put $\odot$ for the value of the sun's mean longitude at the middle of the fortnight or month, we get

$$\mathrm{H}' = \frac{3\cos\phi}{3\mathrm{f}'-\cos(2\odot-\nu')}, \qquad \kappa' = \zeta' + V' + \phi,$$

$$\text{where } \tan\phi = \frac{\sin(2\odot-\nu')}{3\mathrm{f}'-\cos(2\odot-\nu')}, \quad \text{and } H_p = \tfrac{1}{3}H', \quad \kappa_p = \kappa' \quad . \quad . \quad . \quad (7)$$

In the article in the 'Admiralty Manual' these rules are applied to a series of observations at Port Blair, Andaman Islands, commencing 0^h April 19, 1880, and extending over a fortnight. The observations are taken from a tide-curve registered by a gauge, and were supplied to me by Major Baird.[1]

The result of the reduction is as follows:—

RESULTS OF HARMONIC ANALYSIS OF 15 DAYS' HOURLY OBSERVATIONS AT PORT BLAIR, COMMENCING 0^h, APRIL 19, 1880.

			Mean of Three Years' Hourly Observation.
	A_0	= 4·74 ft.	4·740 ft.
M_2	H_m	= 2·19 ft.	2·022 ft.
	κ_m	= 280°	278°
S_2	H_s	= 0·71 ft.	0·968 ft.
	κ_s	= 314°	315°
K_2	H''	= 0·19 ft.	0·282 ft.
	κ''	= 314°	311°
K_1	H'	= 0·46 ft.	0·397 ft.
	κ'	= 327°	327°
P	H_p	= 0·15 ft.	0·134 ft.
	κ_p	= 327°	326°
O	H_o	= 0·14 ft.	0·160 ft.
	κ_o	= 299°	302°

The second column is inserted for the sake of comparison, and gives the results of three years of continuous hourly observation by the tidal

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[1] Only one place of decimals of a foot was used. In the Indian tidal operations the heights are measured to two places. The second place of decimals was at one time given up, but the computers having got used to the two decimal figures, it was found that there was actually some loss of time in giving up the second place.

department of the Survey of India. An error of 2° in the value of κ_m corresponds to an error of only 4^m in the time of high and low water. The concordance between the two affords evidence of the utility of even so short a series of observations as during a fortnight.

§ 4. *Computation of a Tide-table. Semidiurnal Tides.*

The computation of a tide-table from tidal constants which do not contain the elliptic tides N and L presents some difficulty, because the total neglect of these tides would make the results very considerably in error. On this account it was found necessary to use the moon's hour-angle, declination, and parallax in making the computations.

We shall begin by considering only the semidiurnal tide.

In the Tidal Report of 1885 it was shown how the expression for this tide in the harmonic notation may be transformed so as to involve hour-angles, declinations and parallaxes, instead of mean longitudes and eccentricities of orbits.

The formula (27) of the Report of 1885 for the total semidiurnal tide, when written in the notation of § 2 is

$$\begin{aligned} h_2 = {} & \frac{\cos^2 \Delta}{\cos^2 \Delta_,} \mathrm{H}_m \cos (2\psi - \kappa_m) + \mathrm{H}_s \cos (2\psi_, - \kappa_s) \\ & + \frac{\cos^2 \delta' - \cos^2 \Delta}{\sin^2 \Delta_,} \cdot 683 \mathrm{H}'' \cos (2\psi - \kappa'') \\ & + \frac{\cos^2 \delta_, - \cos^2 \Delta_,}{\sin^2 \Delta_,} \cdot 317 \mathrm{H}'' \cos (2\psi_, - \kappa'') \\ & - \frac{\sin \delta \cos \delta}{\sigma \sin^2 \Delta_,} \frac{d\delta}{dt} \left(\frac{\cdot 683 \mathrm{H}''}{\cos (\kappa'' - \kappa_m)} - \mathrm{H}_m \tan^2 \Delta_, \right) \sin (2\psi - \kappa_m) \\ & + \frac{\cos^2 \Delta}{\cos^2 \Delta_,} (\mathrm{P}' - 1) \frac{\mathrm{H}_n \cos \kappa_n - \mathrm{H}_l \cos \kappa_l}{e \cos \varepsilon} \cos (2\psi - \varepsilon) \\ & + (\mathrm{P}_, - 1) \frac{\mathrm{H}_t - \mathrm{H}_r}{e_,} \cos (2\psi_, - \kappa_s) \\ & + \frac{\cos^2 \Delta}{\cos^2 \Delta_,} \frac{d\mathrm{P}/dt}{\sigma - \varpi} \left(4\mathrm{H}_m - \frac{\mathrm{H}_n \sec (\kappa_m - \kappa_n) + \mathrm{H}_l \sec (\kappa_l - \kappa_m)}{e} \right) \sin (2\psi - \kappa_m) \quad (8) \end{aligned}$$

We shall now proceed to simplify this.

In the first place, the terms depending on $d\delta/dt$ and $d\mathrm{P}/dt$ are certainly small, and may be neglected.

Then let

$$\begin{aligned} \mathrm{M} = {} & \frac{\cos^2 \Delta}{\cos^2 \Delta_,} \mathrm{H}_m + \frac{\cos^2 \delta' - \cos^2 \Delta}{\sin^2 \Delta_,} \cdot 683 \mathrm{H}'' \cos (\kappa'' - \kappa_m) \\ & + \frac{\cos^2 \Delta}{\cos^2 \Delta_,} (\mathrm{P}' - 1) \frac{\mathrm{H}_n \cos \kappa_n - \mathrm{H}_l \cos \kappa_l}{e \cos \varepsilon} \cos (\varepsilon - \kappa_m), \\ \mu = {} & \kappa_m + \frac{\cos^2 \delta' - \cos^2 \Delta}{\sin^2 \Delta_,} \cdot 683 \mathrm{H}'' \sin (\kappa'' - \kappa_m) \\ & + \frac{\cos^2 \Delta}{\cos^2 \Delta_,} (\mathrm{P}' - 1) \frac{\mathrm{H}_n \cos \kappa_n - \mathrm{H}_l \cos \kappa_l}{e \cos \varepsilon} \sin (\varepsilon - \kappa_m), \\ \mathrm{M}_, = {} & \mathrm{H}_s + \frac{\cos^2 \delta_, - \cos^2 \Delta_,}{\sin^2 \Delta_,} \cdot 317 \mathrm{H}'' + (\mathrm{P}_, - 1) \frac{\mathrm{H}_t - \mathrm{H}_r}{e_,}, \\ \mu_, = {} & \kappa_s \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (9) \end{aligned}$$

Now, observation and theory agree in showing that κ'' is very nearly equal to κ_s; hence we are justified in substituting κ_s for κ'' in the small solar declinational term of (8) involving $\cdot 317 H''$.

This being so, (8) becomes

$$h_2 = M\cos(2\psi-\mu) + M_{,}\cos(2\psi_{,}-\mu_{,}) \quad . \quad . \quad . \quad . \quad . \qquad (10)$$

In the equilibrium theory each H is proportional to the corresponding term in the harmonically developed potential. This proportionality holds nearly between tides of nearly the same speed; hence in the solar tides we may assume (see Sched. B, 1883, and note that $\cot^2\Delta_{,}=\frac{1}{2}\cot^2\frac{1}{2}\omega$) that,

$$\frac{\cos^2\Delta_{,}}{\sin^2\Delta_{,}}\cdot 317H'' = \frac{1}{3e_{,}}(H_t - H_r) = H_s,$$

and $M_{,}$ reduces to

$$M_{,} = \frac{\cos^2\delta_{,}}{\cos^2\Delta_{,}}H_s + 3(P_{,}-1)H_s = \frac{\cos^2\delta_{,}}{\cos^2\Delta_{,}}H_s[1+3(P_{,}-1)] \text{ nearly}$$

$$= P_{,}^3\frac{\cos^2\delta_{,}}{\cos^2\Delta_{,}}H_s \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (11)$$

Now, since $\Delta_{,}=16^\circ\cdot 36 = 16^\circ\ 22'$, $\sec^2\Delta_{,}=1\cdot 086$, also $P_{,}^3=p_{,}$, and therefore

$$M_{,} = 1\cdot 086 p_{,}\cos^2\delta_{,} H_s \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (12)$$

In a similar way, according to the equilibrium theory, we should have

$$\frac{1}{3e}(H_n - H_l) = H_m.$$

Although this proportionality is probably not actually very exact, yet in our supposed ignorance of the lunar elliptic tides we have to assume its truth. Also, we must assume that the two elliptic tides N and L suffer the same retardation, and therefore $\kappa_n=\kappa_l=\varepsilon$.

With these assumptions,

$$H_m + (P'-1)\frac{H_n\cos\kappa_n - H_l\cos\kappa_l}{e\cos\varepsilon}\cos(\varepsilon-\kappa_m) = H_m[1+3(P'-1)] = H_m P'^3.$$

Then, since

$$\frac{\cos^2\Delta}{\cos^2\Delta_{,}} = f, \text{ and } P'^3 = p',$$

we have

$$M = f p' H_m + \frac{\cos^2\delta' - \cos^2\Delta}{\sin^2\Delta_{,}}\cdot 683H''\cos(\kappa''-\kappa_m),$$

$$\mu = \kappa_m + \frac{\cos^2\delta' - \cos^2\Delta}{\sin^2\Delta_{,}}\cdot 683H''\sin(\kappa''-\kappa_m) \quad . \quad . \quad . \quad . \qquad (13)$$

If we put

$$C_1 = \frac{\cdot 683}{2\sin^2\Delta_{,}}, \quad C_2 = \frac{\cdot 683}{2\sin^2\Delta_{,}}\times 57^\circ\cdot 3,$$

then

$$\log C_1 = \cdot 6344, \quad \log C_2 = 2\cdot 3925,$$

and C_1, C_2 are absolute constants for all times and places.

Next, if we put

$$\alpha = C_1 H'' \cos(\kappa'' - \kappa_m), \quad \beta = C_2 H'' \cos(\kappa'' - \kappa_m),$$
$$A = \alpha \cos 2\Delta \quad , \quad B = \beta \cos 2\Delta \quad . \; . \; . \; . \; . \; . \; . \quad (14)$$

then obviously α, β are absolute constants for the port, and A and B are nearly constant, for their small variability only depends on the longitude of the moon's node entering through Δ.

Thus we have, from (9), (12), (13), (14),

$$M = fH_m + (p' - 1) fH_m + (\alpha \cos 2\delta' - A),$$
$$\mu = \kappa_m + (\beta \cos 2\delta' - B), \text{ expressed in degrees,}$$
$$M_{,} = 1\cdot086 p_{,} \cos^2 \delta_{,} H_s,$$
$$\mu_{,} = \kappa_s \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (15)$$

where p', δ' are the values of p and δ at a time earlier than that corresponding to ψ by 'the age' $52^{h}\cdot2 \tan(\kappa'' - \kappa_m)$.

In the article fH_m is called R_m; $(p' - 1)fH_m$, the parallactic correction, is called $\delta_1 R_m$; $(\alpha \cos 2\delta' - A)$, the declinational correction, is called $\delta_2 R_m$. Similarly, $\beta \cos 2\delta' - B$, the declinational correction to κ_m, is called $\delta_2 \kappa_m$. Also, $M_{,}$ is called S.

Thus, with this notation the whole semidiurnal tide is

$$h_2 = (R_m + \delta_1 R_m + \delta_2 R_m) \cos(2\psi - \kappa_m - \delta_2 \kappa_m) + S \cos(2\psi_{,} - \kappa_s) \quad . \quad (16)$$

The mean rate of increase of ψ is $\gamma - \sigma$, or $14\cdot^{\circ}49$ per hour; hence the interval from moon's transit to lunar high water is approximately $\frac{1}{29}(\kappa_m + \delta_2 \kappa_m)$ hours, when κ_m is expressed in degrees. If i be the mean interval, and $\delta_2 i$ its declinational correction,

$$i + \delta_2 i = \tfrac{1}{29}\kappa_m + \tfrac{1}{29}\delta_2 \kappa_m \quad . \; . \; . \; . \; . \; . \; . \; . \quad (17)$$

Now, let A be twice the apparent time of moon's transit reduced to angle at 15° per hour, or the apparent time reduced at 30° per hour,

Then the excess of the moon's over the sun's R.A. at lunar high water is $\frac{1}{2}A$ plus the increase of the difference of R.A.'s in the interval i. This increase is approximately $\frac{1}{2}\frac{\sigma - \eta}{\gamma - \sigma}\kappa_m$, and at lunar high water the sun's hour-angle is given by

$$2\psi_{,} = 2\psi + A + \frac{\sigma - \eta}{\gamma - \sigma}\kappa_m . \quad . \; . \; . \; . \; . \; . \; . \quad (18)$$

Since the difference of time between lunar high water and actual high water never exceeds about an hour and a half, if we neglect the separation of the moon from the sun in that time, this relationship also holds at actual luni-solar high water.

Now, let

$$H \cos(\mu - \phi) = M + S \cos\left[A + \frac{\sigma - \eta}{\gamma - \sigma}\kappa_m - \kappa_s + \kappa_m + \delta_2 \kappa_m\right]$$
$$= M + S \cos(A - \kappa_s + \tfrac{30}{29}\kappa_m + \delta_2 \kappa_m),$$
$$H \sin(\mu - \phi) = \quad S \sin(A - \kappa_s + \tfrac{30}{29}\kappa_m + \delta_2 \kappa_m) \quad . \; . \; . \; . \quad (19)$$

and we have for the whole luni-solar semidiurnal tide

$$h_2 = H \cos(2\psi - \phi) . \quad . \; . \; . \; . \; . \; . \; . \; . \quad (20)$$

If we put

$$\gamma+\delta_2\gamma=\kappa_s-\tfrac{30}{29}\kappa_m+\delta_2\kappa_m,$$
$$\mathrm{x}=A-(\gamma+\delta_2\gamma),$$

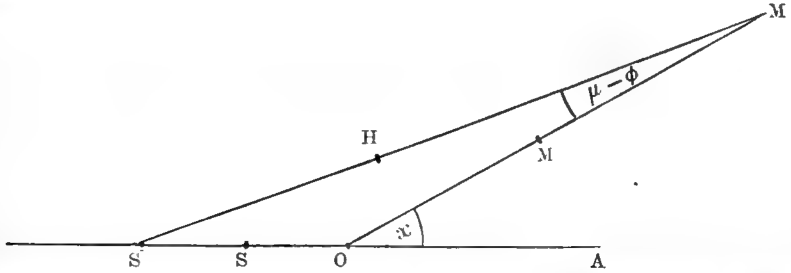
we have, from (19),

$$\left.\begin{aligned}\tan(\mu-\phi)&=\frac{\mathrm{S}\sin\mathrm{x}}{\mathrm{M}+\mathrm{S}\cos\mathrm{x}}\\ \mathrm{H}^2&=\mathrm{M}^2+\mathrm{S}^2+2\mathrm{MS}\cos\mathrm{x}\end{aligned}\right\}\quad\ldots\ldots\ldots\quad(21)$$

High water occurs approximately $\dfrac{\phi}{2(\gamma-\sigma)}$ or $\tfrac{1}{29}\phi$ after moon's transit.

The determination of ϕ and H may be conveniently carried out by a graphical construction. If we take O as a fixed centre, O S as an initial line, and S a point in it such that O S=S, and set off the angle A O M equal to x, and O M equal to M; then O M S is the angle $\mu-\phi$, and S M is the height H.

The angle x increases by 360° from spring-tide to spring-tide, and therefore one revolution in the figure corresponds to 15 days.



As a very rough approximation, M lies on a circle, but the parallactic and declinational corrections $\delta_1\mathrm{R}_m$ and $\delta_2\mathrm{R}_m$ cause a considerable departure from the circle.

The angle ϕ and the height H are also easily computed numerically.

If cos x is positive, let θ be an auxiliary angle determined by

$$\tan^2\theta=\frac{\mathrm{S}}{\mathrm{M}}\cos\mathrm{x},$$

and we have

$$\tan(\mu-\phi)=\sin^2\theta\tan\mathrm{x},\quad \mathrm{H}=\mathrm{S}\operatorname{cosec}(\mu-\phi)\sin\mathrm{x}.$$

If cos x is negative, let θ be an auxiliary angle determined by

$$\sin^2\theta=-\frac{\mathrm{S}}{\mathrm{M}}\cos\mathrm{x},$$

and we have

$$\tan(\mu-\phi)=\tan^2\theta\tan\mathrm{x},\quad \mathrm{H}=\mathrm{S}\operatorname{cosec}(\mu-\phi)\sin\mathrm{x}.$$

These formulæ are adapted for logarithmic computation.

§ 5. *Correction for Diurnal Tides.*

The tide-table has to be corrected for the effect of three diurnal tides, designated O, K_1, P.

If we write

$$\mathrm{V}_o=t+h-2s-\nu+2\xi+\tfrac{1}{2}\pi,$$
$$\mathrm{V}'=t+h-\nu'-\tfrac{1}{2}\pi,$$

then, in accordance with Schedules B of the Report of 1883, the expressions for the three tides are

$$\begin{aligned} O &= f_0 H_0 \cos (V_0 - \kappa_0), \\ K_1 &= f' H' \cos (V' - \kappa'), \\ P &= -H_p \cos [V' - \kappa' - (2h - \nu') + (\kappa' - \kappa_p)] \quad \ldots \ldots \quad (22) \end{aligned}$$

We have already seen in (6) and (7) that

$$K_1 + P = R' \cos (V' - \kappa' + \phi),$$

where

$$\tan \phi = \frac{\sin (2 \odot - \nu')}{3f' - \cos (2 \odot - \nu')}, \quad R' = \frac{3f' - \cos (2 \odot - \nu')}{3 \cos \phi} H',$$

and $\odot$ denotes the sun's mean longitude at the middle of the short period under consideration.

Then, if we write $f_0 H_0 = R_0$, the diurnal tides, reduced to two, are

$$\begin{aligned} O &= R_0 \cos (V_0 - \kappa_0), \\ K_1 + P &= R' \cos (V' - \kappa' - \phi) \quad \ldots \ldots \quad (23) \end{aligned}$$

ϕ and R', having a semi-annual inequality, may be taken as constant for about a month, but must be recomputed for each month.

Now, suppose that we compute V_0 and V' at the epoch, that is, at the initial noon of the period during which we wish to predict the tides, and with these values put

$$\begin{aligned} \zeta_0 &= \kappa_0 - V_0 \text{ at epoch}, \\ \zeta' &= \kappa' - \phi - V' \text{ at epoch}, \end{aligned}$$

then the speed of V_0 is $\gamma - 2\sigma$, or 13°·94 per hour, or 360°—25°·37 per day; and the speed of V' is γ, or 15°·04 per hour, or 360°·986 per day. Hence, if t be the mean solar time in hours on the $(n+1)$th day since the epoch,

$$\begin{aligned} V_0 - \kappa_0 &= 360° n + 13°{\cdot}94 t - \zeta_0 - 25°{\cdot}37 n, \\ V' + \phi - \kappa' &= 360° n + 15°{\cdot}04 t - \zeta' + 0°{\cdot}986 n. \end{aligned}$$

Therefore the diurnal tide at the time t hours on the $(n+1)$th day is given approximately by

$$\begin{aligned} O &= R_0 \cos [14° t - \zeta_0 - 25\tfrac{1}{3}° \times n], \\ K_1 + P &= R' \cos [15° t - \zeta' + 1° \times n] \quad \ldots \ldots \quad (24) \end{aligned}$$

If we substitute for t the time of high or low water as computed simply from the semidiurnal tide, it is clear that the sum of these two expressions will give us the diurnal correction for height of tide at high or low water.

If we consider the maximum of a function,

$$A \cos 2n(t - \alpha) + B \cos n'(t - \beta),$$

where n is nearly equal to n', we see that the time of maximum is given approximately by $t = \alpha$, with a correction δt determined from

$$-2An \sin (2n \delta t) - n'B \sin n'(t - \beta) = 0,$$

or

$$\delta t = -\frac{180}{4\pi n} \frac{n'B}{nA} \sin n(t - \beta).$$

In this way we find the corrections to the time of high water from O and K_1+P; and since $n=\gamma-\sigma$, and $\frac{180}{4\pi n}=0^h{\cdot}988$, and $\frac{n'}{n}=1-\frac{\sigma}{\gamma-\sigma}$ for O, and $1+\frac{\sigma}{\gamma-\sigma}$ for K_1, we have

$$\delta t_0=-0^h{\cdot}988\left(1-\frac{\sigma}{\gamma-\sigma}\right)\frac{R_0}{H}\sin\left[14t-\zeta_0-25\tfrac{1}{3}^\circ\times n\right],$$

$$\delta t'=-0^h{\cdot}988\left(1+\frac{\sigma}{\gamma-\sigma}\right)\frac{R'}{H}\sin\left[15t-\zeta'+1^\circ\times n\right], \quad . \quad (25)$$

where H is the height of the semidiurnal high water.

With sufficient approximation we may write these corrections:

$$\delta t_0=-1^h\times\frac{R_0}{H}\sin\left[14^\circ t-\zeta_0-25\tfrac{1}{3}^\circ\times n\right],$$

$$\delta t'=-1^h\times\frac{R'}{H}\sin\left[15^\circ t-\zeta'+1^\circ\times n\right] \quad . \quad . \quad . \quad . \quad (26)$$

The computations are easily carried out, although the arithmetic is necessarily tedious. Since two places of decimals are generally sufficient for R_0 and R', the multiplications by the sines and cosines are very easily made with a Traverse Table.

The successive high and low waters follow one another on the average at $6^h\,12^m$; now, $14^\circ\times6{\cdot}2=87^\circ$, and $15^\circ\times6{\cdot}2=93^\circ$. Hence, if we compute $14^\circ t-\zeta_0-25\frac{1}{3}^\circ\times n$ for the first tide on any day, the remaining values are found with sufficient approximation by adding once, twice, thrice 87°; and similarly, in the case of $15^\circ t-\zeta'+1\times n$ we add once, twice, thrice 93°.

§ 6. *Certain Details in the Computation of the Tide-table.*

It will be well to give some explanatory details concerning the manner of carrying out the computations.

The angle Δ is given by $16^\circ{\cdot}51+3^\circ{\cdot}44\cos☊-0^\circ{\cdot}19\cos2☊$, where ☊ is the longitude of the moon's node. It is clear that Δ varies so slowly that it may be regarded as constant for many months, and the same is true of the factors f, f″, f′, f_o, and the small angles ν, ξ, ν', $2\nu''$. Approximate formulæ for these quantities in terms of ☊ were given in the Report of 1885, and are used in the article in the 'Manual.'

To find the cube of the ratio of the sun's parallax to his mean parallax, the following rule is given: Subtract the mean parallax from the parallax, multiply the difference by $19\frac{1}{3}$, read as degrees instead of seconds, look out the sine, and add 1. This rule is founded on the fact that a mean parallax $8''{\cdot}85$ multiplied by $19\frac{1}{3}$ gives $3\times57''$, and 57° is the unit angle or radian, whilst the sine of a small angle is equal to the angle in radians. Similarly, the cube of the ratio of the moon's parallax to her mean parallax is

$$1+3\sin\left[60(\text{parx}-\text{mean parx})\right].$$

That is to say, for the moon: Subtract the mean parallax from the parallax, read as degrees instead of minutes, look out the sine, multiply by 3, and add 1. This rule depends on the fact that the moon's mean parallax in radians is $\frac{1}{60}$.

For the purpose of applying the corrections $\delta_1 R_m$, $\delta_2 R_m$, $\delta_2 \kappa_m$, $\delta_2 i$, $\delta_2 \gamma$, it is most convenient to compute auxiliary tables for each degree of declination of the moon and minute of her parallax, and then the actual corrections are easily applied by interpolation.

These tables serve for the port as long as the longitude of the moon's node is nearly constant, or with rougher approximation for all time.

The declinational and parallactic corrections to high water depend on the moon's declination and parallax at a time anterior to high water by 'the age.' Hence, in order to find these corrections we have to know the time of high water in round numbers. Each high water follows a moon's transit at the port approximately by the interval i. The Greenwich time of the moon's transit at the port is the G.M.T of moon's transit at Greenwich, less 2 minutes for each hour of E. longitude, less the E. longitude in hours. Then, if we subtract from this 'the age' and add the interval i, we find the G.M.T's at which we want the moon's declination and parallax.

$$\left.\begin{array}{l}\text{Thus, at Port Blair}\\ \text{the G.M.T. at which}\\ \text{we want parx. and decl.}\end{array}\right\} = \left\{\begin{array}{l}\text{G.M.T of ☽'s}\\ \text{transit at Gr.}\end{array}\right\} - \text{long. corr. for transit } (0^{h}\cdot 2)$$

$$- \text{E. long. of port } (6^{h}\cdot 2) - \text{age of tide } (32^{h}\cdot 6)$$

$$+ \text{mean interval } (9^{h}\cdot 6)$$

$$= \text{G.M.T of ☽'s tr. at Gr.} - 29^{h}4.$$

Thus at Greenwich, on Feb. 1st, 1885, the moon's lower transit was at 2^{h}, and hence, corresponding to the lower transit at Port Blair of Feb. 1, we require the moon's parallax and declination at 21^{h} Jan. 30, G.M.T. The parallax at the nearest Greenwich noon or midnight is sufficiently near the truth, and therefore we take the parallax at 0^{h} Jan. 31, which is $60'\cdot 0$, and the excess above the mean is $3'\cdot 0$, and $1+3 \sin 3°$ is 1·157, which is the factor p'. Actually, however, we read off the correction $\delta_1 R_m$ and the other corrections $\delta_2 R_m$, $\delta_2 i$, $\delta_2 \gamma$ straight from the auxiliary tables.

§ 7. *On Tide-tables Computed by the above Method.*

A great deal of arithmetical work was necessary in making trial of the rules devised above and in various modifications of them, and I must record my thanks to Mr. Allnutt, who has been indefatigable in working out tide-tables for various ports, and in comparing them with official tables. The whole of the results, to which I now refer, are due to him. The following table exhibits the amount of agreement between a computed table and one obtained by the tide-predicting instrument. It must be borne in mind that the instrument is rigorous in principle, and makes use of far more ample data than are supposed to be available in our computations. The columns headed 'Indian tables' are taken from the official Indian tide-tables. The datum level, however, in those tables is 3·13 ft. below mean water mark, whereas 'Indian spring low-water mark' is 3·55 ft. below the mean. Thus, to convert the heights given in the Indian tables to our datum 0·42 ft. or 5 ins. have been added to all the heights in the official table.

TIDE-TABLE FOR PORT BLAIR, 1885.

	Calculated Times	Indian tables Times	Calcd. Heights	Indian tables Heights
	h. m.	h. m.	ft.	ft. in.
Feb. 1, H.W.	11 3 p.m.	11 4 p.m.	7·4	7 2
Feb. 2, L.W.	5 21 a.m.	5 18 a.m.	0·0	−0 2
H.W.	11 26 a.m.	11 31 a.m.	6·6	6 5
L.W.	5 28 p.m.	5 25 p.m.	0·4	0 0
H.W.	11 39 p.m.	11 43 p.m.	7·1	6 11
Feb. 3, L.W.	5 56 a.m.	5 56 a.m.	0·2	0 1
H.W.	0 3 p.m.	0 9 p.m.	6·4	6 3
L.W.	6 4 p.m.	6 5 p.m.	0·7	0 7
Feb. 4, H.W.	0 14 a.m.	0 20 a.m.	6·7	6 6
L.W.	6 31 a.m.	6 33 a.m.	0·5	0 5
H.W.	0 40 p.m.	0 48 p.m.	6·1	6 0
L.W.	6 42 p.m.	6 44 p.m.	1·2	1 0
Feb. 5, H.W.	0 48 a.m.	0 56 a m.	6·1	5 11
L.W.	7 5 a.m.	7 9 a.m.	1·0	0 10
H.W.	1 18 p.m.	1 28 p.m.	5·7	5 7
L.W.	7 20 p.m.	7 25 p.m.	1·7	1 7
Feb. 6, H.W.	1 24 a.m.	1 33 a.m.	5·5	5 4
L.W.	7 41 a.m.	7 45 a.m.	1·5	1 4
H.W.	2 1 p.m.	2 10 p.m.	5·3	5 2
L.W.	8 6 p.m.	8 12 p.m.	2·2	2 1
Feb. 7, H.W.	2 4 a.m.	2 13 a.m.	4·9	4 9
L.W.	8 23 a.m.	8 25 a.m.	1·9	1 10
H.W.	2 53 p.m.	2 57 p.m.	4·9	4 10
L.W.	9 7 p.m.	9 8 p.m.	2·7	2 6
Feb. 8, H.W.	2 58 a.m.	3 8 a.m.	4·4	4 3
L.W.	9 20 a.m.	9 24 a.m.	2·4	2 2
H.W.	4 10 p.m.	4 14 p.m.	4·7	4 7
L.W.	10 42 p.m.	10 40 p.m.	3·0	2 4
Feb. 9, H.W.	4 29 a.m.	4 40 a.m.	4·0	3 10
L.W.	10 46 a.m.	10 57 a.m.	2·6	2 6
H.W.	5 47 p.m.	5 48 p.m.	4·7	4 7

A tide-table was computed for Aden for a fortnight, and the results were found to be somewhat less satisfactory than those in the above table. It must be remarked, however, that the sum of the semi-ranges of the three diurnal tides K_1, O, P is 2·340 ft., and is actually greater than the sum of the semi-ranges of the tides M_2 and S_2, which is 2·265 ft. Thus, at some parts of some lunations the semidiurnal tide is obliterated by the diurnal tide, and there is only one high water and one low water in the day. In this case it is obvious that the approximation, by which we determine semidiurnal high and low water and apply a correction for the diurnal tides, becomes inapplicable. In the greater part of our computed table the concordance is fairly good; but the tide-predicting instrument shows that on each of the days, 7th and 8th February, 1885, there was only one high and low water, whereas our table, of course, gives a double tide as usual. Again, on the 9th February there is an error of 68 minutes in a high water. These discrepancies are to be expected, since the approximate method is here pushed beyond its due limits; and for such a port as Aden special methods of numerical approximation would have to be devised.

In a table computed for Amherst the agreement is not quite so good as was to be hoped; the error in heights amounts in two cases in fifteen days to nearly a foot, and in two other cases to three-quarters of an hour in time. It may be remarked, however, that the tides are large at Amherst, having a spring range of 20 ft. and a neap range of 6 ft., that the diurnal tide is considerable, and that the sum of the semi-ranges of the over-tides M_4, S_4 (which we neglect entirely) amounts to 6 inches. It appears also that the tidal constants are somewhat abnormal, for $H''=\frac{1}{2\cdot5}H_s$ instead of $H''=\frac{1}{3\cdot07}H_s$, and further $H_p=\frac{1}{3\cdot9}H'$ instead of $H_p=\frac{1}{3}H'$.

Under these circumstances it is perhaps not surprising that the discrepancies are as great as they are.

Tables were also computed for Liverpool and West Hartlepool, but no correction was here applied for the diurnal tides. The results were compared with the Admiralty tide-tables for Liverpool and Sunderland. In the case of Liverpool there were four tides in a fortnight in which there was a discrepancy in the times amounting to 12 minutes, and four other tides in which there was a discrepancy of a foot, and one with a discrepancy of 1 ft. 2 ins. It was obvious, however, that the agreement would have been better if the correction for the diurnal tides had been applied. The spring rise of tide at Liverpool is 26 ft.

In the case of Sunderland there were in a fortnight two discrepancies of 15 m., two of 14 m., two of 13 m., two of 12 m., &c. in the times, and in the heights one discrepancy of 3 ins., and four of 2 ins., &c. The spring rise at West Hartlepool is 14 ft.

These two tables are quite as satisfactory as could be expected considering the approximate nature of the methods employed.

Finally, in order to test the methods both of reduction and of prediction, Mr. Allnutt took the harmonic constants derived from our analysis of a fortnight of hourly observation at Port Blair, from April 19 to May 2, 1880, and computed therefrom a tide-table for that same fortnight. He then, by interpolation in the observed hourly heights, determined the actual high waters and low waters during that period.

The results of the comparison are exhibited in the table on next page.

If our method had been perfect, of course, the errors should be everywhere zero.

It must be admitted that the agreement is less perfect than might have been hoped. If, however, the calculated and observed tide curves are plotted down graphically side by side, it will be seen that the errors are inconsiderable fractions of the whole intervals of time and heights under consideration.

When we consider the extreme complication of tidal phenomena, together with meteorological perturbation, it is, perhaps, not reasonable to expect any better results from an admittedly approximate method, adapted for all ports, and making use of a very limited number of tidal constants. In devising these rules for reduction and prediction I could find no model to work from, and it seems probable that advantageous

COMPARISON OF A TIDE-TABLE COMPUTED FROM A FORTNIGHT'S OBSERVATION WITH ACTUALITY.

High Water							Low Water						
Astr. Date 1880	Observed Time	Calc. Time	C—O	Observed Height	Calc. Height	C—O	Astr. Date 1880	Observed Time	Calc. Time	C—O	Observed Height	Calc. Height	C—O
	h.	h.	h.	ft.	ft.	ft.		h.	h.	h.	ft.	ft.	ft.
April 19	4·76	4·76	·00	5·83	6·24	+·41	April 19	11·60	11·48	−·12	3·28	3·07	−·21
	18·29	17·86	−·43	5·59	5·94	+·35		23·92	23·78	−·14	3·71	3·62	−·09
„ 20	6·20	5·91	−·29	6·22	6·35	+·13	„ 20	12·58	12·41	−·17	2·84	2·76	−·08
	19·07	18·82	−·25	6·26	6·46	+·20	„ 21	1·13	·85	−·28	3·31	3·22	−·09
„ 21	7·16	6·88	−·28	6·60	6·61	+·01		13·40	13·20	−·20	2·33	2·38	+·05
	19·68	19·59	−·09	6·93	7·03	+·10	„ 22	1·82	1·72	−·10	2·74	2·74	·00
„ 22	7·80	7·72	−·08	6·97	6·90	−·07		14·12	13·91	−·21	1·76	2·01	+·25
	20·41	20·27	−·14	7·60	7·59	−·01	„ 23	2·73	2·47	−·26	2·27	2·28	+·01
„ 23	8·67	8·46	−·21	7·39	7·20	−·19		14·77	14·61	−·16	1·53	1·69	+·16
	21·06	20·97	−·09	8·22	8·06	−·16	„ 24	3·28	3·22	−·06	1·71	1·89	+·18
„ 24	9·30	9·22	−·08	7·50	7·40	−·10		15·26	15·32	+·06	1·25	1·46	+·21
	21·76	21·68	−·08	8·46	8·40	−·06	„ 25	3·90	3·98	+·08	1·50	1·62	+·12
„ 25	9·99	9·98	−·01	7·41	7·50	+·09		16·03	16·04	+·01	1·21	1·39	+·18
	22·37	22·41	+·04	8·40	8·57	+·17	„ 26	4·68	4·75	+·07	1·37	1·49	+·12
„ 26	10·80	10·76	−·04	7·31	7·44	+·13		16·78	16·80	+·02	1·36	1·49	+·13
	23·20	23·17	−·03	8·18	8·55	+·37	„ 27	5·30	5·57	+·27	1·48	1·55	+·07
„ 27	11·55	11·60	+·05	7·00	7·22	+·22		17·37	17·60	+·23	1·64	·80	+·16
	23·98	23·98	·00	7·89	8·29	+·40	„ 28	6·22	6·44	+·22	1·90	·78	−·12
„ 28	12·36	12·50	+·14	6·50	6·89	+·39		18·23	18·46	+·23	2·24	2·22	−·02
„ 29	0·70	·83	+·13	7·53	7·90	+·37	„ 29	7·20	7·38	+·18	2·43	2·08	−·35
	13·36	13·47	+·11	6·14	6·53	+·39		18·88	19·39	+·51	2·90	2·70	−·20
„ 30	1·64	1·76	+·12	7·29	7·42	+·13	„ 30	8·28	8·38	+·10	2·88	2·41	−·47
	14·17	14·53	+·36	5·86	6·22	+·36		20·00	20·43	+·43	3·52	3·14	−·38
May 1	2·46	2·78	+·32	6·74	6·98	+·24	May 1	9·43	9·49	+·06	3·15	2·65	−·50
	15 50	15·76	+·26	5·63	6·08	+·45		21·66	21·65	−·01	3·89	3·42	−·47
„ 2	3·81	3·92	+·11	6·36	6·65	+·29	„ 2	10·80	10·60	−·20	3·23	2·72	−·41
	17·24	16·98	−·26	5·84	6·17	+·33		23·20	22·94	−·26	3·95	3·45	−·50
„ 3	5·17	5·11	−·06	6·40	6·51	+·11							

modifications may be introduced. I spared, however, no pains to reduce the labour of computation. Nearly half the work in forming a short tide-table is preparatory, and would serve for a systematic computation of tables for all time.

III. AN ATTEMPT TO DETECT THE 19-YEARLY TIDE.

If M, E be the moon's and earth's masses; a the earth's mean radius; c the moon's mean distance; ω the obliquity of the ecliptic; i the inclination of the lunar orbit; e the eccentricity of the lunar orbit; ☊ the longitude of the moon's node; and λ the latitude of the port of observation; then the term in the equilibrium tidal theory which is independent of the moon's longitude (see Schedule B, iii., Report of 1883) is

$$\frac{3}{2}\frac{M}{E}\left(\frac{a}{c}\right)^3 a\left(\tfrac{1}{2}-\tfrac{3}{2}\sin^2\lambda\right)\left(1+\tfrac{3}{2}e^2\right)\sin i\cos i\sin\omega\cos\omega \left[-\cos☊+\tfrac{1}{4}\tan i\tan\omega\cos 2☊\right].$$

Since $\frac{1}{4}\tan i\tan\omega = \cdot 00975$, the second term is negligeable compared with the first.

If we take

$$\frac{M}{E}=\frac{1}{81\cdot 5},\ \frac{a}{c}=\frac{1}{60\cdot 27},\ a=21\times 10^6 \text{ feet},\ i=5^\circ\ 8',\ \omega=23^\circ\ 28',$$

the expression for this tide is, in British feet,

$$-0\cdot 0579\left(\tfrac{1}{2}-\tfrac{3}{2}\sin^2\lambda\right)\cos ☊.$$

Thus, at the poles this tide gives an oscillation of sea-level of 0·695 of an inch, or a total range of $1\frac{2}{5}$ of an inch, and at the equator it is half as great.

In the 'Mécanique Céleste' Laplace argues that all the tides of long period (such as the fortnightly tide) must conform nearly to the equilibrium law. I shall adduce arguments elsewhere[1] which seem to invalidate his conclusion, and to show that in these tides inertia still plays the principal part, so that the oscillations must take place nearly as though the sea were a frictionless fluid.

With a tide, however, of as long a period as nineteen years Laplace's argument must hold good, and hence the equilibrium tide of which the above is the expression must represent an actual oscillation of sea-level, provided that the earth is absolutely rigid. The actual observation of the 19-yearly tide would therefore be a result of the greatest interest for determining the elasticity of the earth's mass.

A reduction of the observed tides of long period at a number of ports was carried out in Thomson and Tait's 'Natural Philosophy,' Part II., 1883, in the belief in the soundness of Laplace's argument with regard to those tides, and the conclusion was drawn that the earth must have an effective rigidity about as great as that of steel. The failure of Laplace's argument, however, condemns this conclusion, and precludes us from making any numerical conclusions with regard to the rigidity of the earth's mass, excepting by means of the 19-yearly tide. The results

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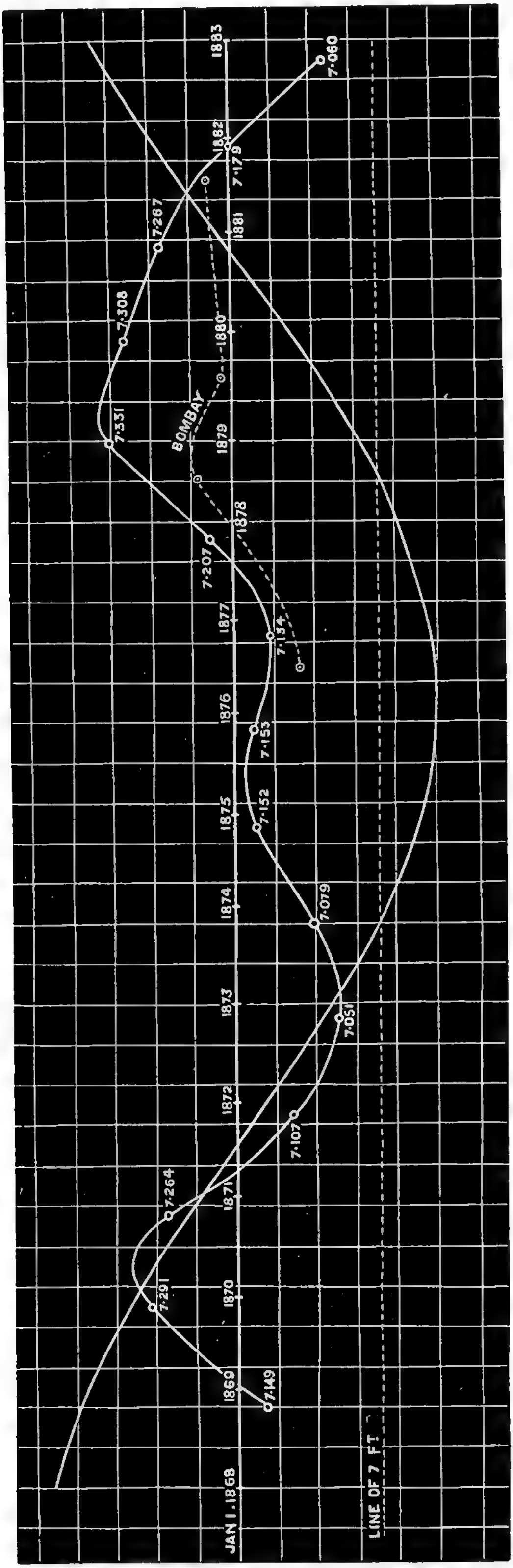
[1] In an article on the Tides in the *Encyclopædia Britannica*. The section of the article 'On the Tides of Long Period' will probably be communicated also to the Royal Society.



The ordinates of the curve of sines represent $-0{\cdot}25$ ft. $\cos \Omega$. The sinuous curve presents the variations of mean water at Karachi. The dotted line is the level of 7 ft. above the zero of the tide-gauge, and the numbers on the curve are the mean depths evaluated for each year. The side of each square represents horizontally, in time, 5 months, and vertically, in depth of sea, 0·05 ft., or $\frac{1}{5}$ of an inch.

given in the 'Natural Philosophy' merely remain, then, as generally confirmatory of Thomson's conclusion as to the great effective rigidity of the earth's mass.

There are but few ports for which a sufficient mass of accurate tidal observations are accumulated to make the detection of the 19-yearly tide a possibility.

Major Baird has, however, kindly supplied me with the values of the mean sea-level at Karachi for fifteen years. They are plotted out in the annexed figure. The horizontal line represents the mean sea-level for the period from 1869–1883, and the sinuous curve gives the variations of mean sea-level during that period. The dotted sinuous curve gives the annual variations for a portion of the same period for Bombay. The full-line sweeping curve has ordinates proportional to $-\cos ☊$, and shows the kind of curve which we ought to find if the alternations of sea-level were due to the 19-yearly tide.

It is obvious at a glance that the oscillations of sea-level are not due to astronomical causes.

At Karachi (lat. 24° 47′) the 19-yearly tide is

$$-0^{\mathrm{ft}}{\cdot}0138 \cos ☊ .$$

The figure shows that the actual change of sea-level between 1870 and 1873 was nearly 0·25 feet, and this is just about nine times the range of the 19-yearly tide, viz., 0·028 feet.

It is thus obvious that this tide must be entirely masked by changes of sea-level arising from meteorological causes.

It seems unlikely that what is true of Karachi and Bombay is untrue at other ports, and therefore we must regard it as extremely improbable that the 19-yearly tide will ever be detected.

G. H. D.

Report of the Committee, consisting of Professor CRUM BROWN (*Secretary*), Mr. MILNE HOME, Mr. JOHN MURRAY, *and* Mr. BUCHAN, *appointed for the purpose of co-operating with the Scottish Meteorological Society in making Meteorological Observations on Ben Nevis.*

DURING the past year the work of the Ben Nevis Observatory has been carried on by Mr. Omond and his assistants in a way that leaves nothing to be desired. The twenty-four daily eye-observations have been made uninterruptedly; and it deserves to be recorded that, as regards the outside observations, no hour has been omitted even on those occasions when the wind blew furiously at rates considerably above 100 miles an hour.

The eye-observations, taken five times daily at the sea-level station at Fort William, have also been made with the greatest regularity by Mr. Livingston; and with these are conjoined the continuous records of the barograph and thermograph, the results of which are so valuable in checking and discussing the observations.

For the twelve months ending May 1886 the mean temperatures and pressures at the Ben Nevis Observatory and Fort William were these:—

Observatory			Fort William		
	Temp. °	Pressure, Inches		Temp. °	Pressure, Inches
Summer . .	39·3	25·502	Summer . . .	55·5	30·027
Autumn . . .	29·9	·185	Autumn . . .	45·2	29·736
Winter . . .	22·5	·244	Winter . . .	36·8	·880
Spring . . .	26·4	·276	Spring . . .	43·7	·873
Year	29·5	25·302	Year	45·3	29·879

These twelve months were thus characterised by an unusually low mean temperature, the annual mean at the sea-level station, 45·3°, being 1·9° below its normal mean temperature.

The *maximum* temperature at the observatory for the period was 60·0° at 3 P.M. of July 31, which nearly approaches the *maximum* of previous years, viz. 60·1° at 2 P.M. on August 9, 1884. The lowest temperature was 8·4° at noon, December 29, 1885, which is the lowest temperature yet recorded on Ben Nevis. The lowest temperatures for the three winters have been respectively 9·9°, 11·1°, and 8·4°.

But the most remarkable features in the climate of Ben Nevis during the year were the frequent occurrence of excessive droughts, comparatively large amount of sunshine, and occasional unusually heavy falls of rain and snow. The following observations were made on July 30, 1885:—

	Dry	Wet	Diff.
	°	°	°
1 A.M. . .	48·8	46·9	1·9
2 „ . .	48·3	45·3	3·0
3 „ . .	50·3	36·2	14·1
4 „ . .	49·7	36·2	13·5

Such low humidities, sharply marked off from high humidities, are among the most valuable observations of the observatory, particularly when viewed in connection with the irregular geographical distribution of frosts and other low night temperatures which occur over the country on subsequent evenings.

But the most remarkable drought yet recorded at the observatory occurred in March last, commencing at 1 A.M. of the 11th, and ending at midnight of the 12th, thus extending over a period of forty-eight hours. The mean humidity of the first twenty-four hours was only 19, and of the second twenty-four hours 15, the lowest being 6 at 8 P.M. of the 12th. From noon of the 12th to 11 P.M. the mean was only 11. The three consecutive hours of greatest dryness were the following :—

	Dry	Wet	Dewpoint	Calculated Humidity
	°		°	
March 12, 1886, 7 P.M. . .	21·8	14·8	−32·1	7
„ 8 „	21·0	14·0	−34·3	6
„ 9 „	19·2	13·0	−32·3	8

During these two days the sky was absolutely cloudless, and the wind south-easterly, blowing at first with force 5, then falling gradually to 3 at 9 A.M. of the 11th, about which it remained till 4 P.M. of the 12th, when it fell either to a calm or the lightest airs from the north-east, when the greatest dryness took place. On these two days the extremes of temperature were 24·3° and 13·3°; and at 8 A.M. of the 12th, while the temperature at the observatory was 23·9°, in Fort William it was 19·2°, or 4·7° lower than on the top of Ben Nevis.

During the twelve months the Sunshine Recorder registered 777 hours of sunshine, which is about 19 per cent. of the possible sunshine. In the previous year the hours of sunshine only amounted to 464. The extreme months were July, with 162 hours, and January, with only 15 hours of sunshine. The observations of the two years show that the annual period of daily *maximum* sunshine is the four hours from 9 A.M. to 1 P.M., the means being 61, 67, 67, and 65 hours respectively. For the six months from April to September the hour of most sunshine is from 8 to 9 A.M., the mean being 39 hours. From this time it slowly but steadily diminishes to 36 hours for the hour ending 1 P.M., and from 4 to 5 P.M. the number has fallen to 26 hours. The numbers for the five hours preceding, and the five hours succeeding noon, are respectively 38 and 32 hours. The total number of hours for the six months, from January to June, is 294, and for the second half of the year 326 hours, the difference being wholly due to the exceptionally large amount of sunshine in July and August 1885. In truth the distribution of the sunshine through the year cannot be said to be dependent on the great annual rise and fall of temperature, but on those causes which bring anticyclones over Ben Nevis.

The rainfall for the year ending May 1886 amounted to 128·34 inches, the largest monthly fall being 24·33 inches in December 1885 and the smallest 2·85 inches in February following. The heaviest precipitation on any day was 5·34 inches on December 12, and 4·45 inches on January 1—these being heavier than any previously recorded daily falls. On the two days December 12 and 13 the precipitation amounted to 8·86 inches. For five-day periods the following heavy falls are recorded:—for the five days ending December 15, 10·25 inches; October 5, 10·02 inches; January 3, 9·25 inches; and September 16, 6·13 inches.

On the other hand, the year was marked by the large number of days on which either no rain fell or on which the amount was less than 0·01 inch. The number of these days amounted to 126, being thus in the proportion of two rainy days for each fair day. The largest number of fair days in any month was twenty in August, and the least, two, in September. In the previous year there were only seventy-nine days without rain, being thus forty-seven fewer than last year.

In the meantime, the whole of the hourly observations of the observatory, and the observations of the station at Fort William down to date are in the press. The publication will appear as an extra volume of the 'Transactions of the Royal Society of Edinburgh,' and by this handsome act on the part of the Royal Society these observations will shortly be in the hands of scientific men in all parts of the world.

In connection with the Ben Nevis observations the investigation of the important question of the bearing of the results on the weather of these islands steadily advances. The position of the observatory on an elevated isolated peak, and that of the low-level station at Fort William, being close to the sea and on a bank sloping down to it, renders this pair of stations second to none anywhere yet established for the investigation of some of the fundamental data of meteorology. Among the more important of these is the rate of decrease of temperature with height, and the rate of diminution of pressure with height, for different atmospheric temperatures and sea-level pressures.

In these aspects the double set of observations for the past two-and-a-half years have now been discussed. The decrease of the temperature with height is at the rate of one degree Fahrenheit for every 270 feet of ascent, the lowest rate being one degree for every 284 feet in winter, and the most rapid rate 247 in spring. This rate closely agrees with the results of the most carefully conducted balloon ascents, and of those other pairs of stations over the world which are so situated as to give trustworthy results for the inquiry. Ben Nevis Observatory and Fort William Station are among the very few pairs of stations yet established from which the requisite data can be obtained, the required conditions being great difference in height combined with close proximity, and the position of the thermometers in situations where the effects of solar and terrestrial radiation are minimised.

The next point, and as regards weather phenomena the most important point, to be determined was the normal differences between atmospheric pressure at the top of the Ben and at Fort William for the different air temperatures and sea-level pressures that occur. These differences, or, as they are technically called, corrections for height, were empirically calculated from the observations, and thereafter the departures from these normals were ascertained for each of the five daily observations since the observatory was opened. The results showed a diminution of pressure from the normals on almost every occasion during the occurrence of high winds at the observatory. In other words, in all cases when high winds (30 miles an hour and upwards) prevailed at the observatory the observations reduced to sea-level showed a less pressure than that actually observed at Fort William. The differences increase with the strength of the wind, and amount not unfrequently to the tenth of an inch, and one day when the winds continued to blow at the rate of 120 miles an hour, the five consecutive readings showed differences exceeding a tenth and a half. This diminution is doubtless occasioned by the winds as they brush past the buildings, partially sucking out the air from the interior, thus lowering the pressure. It was therefore necessary to recalculate the table of corrections to sea-level, using in the new calculation only those observations which were made when the wind blew at lower rates than 30 miles an hour. This recalculation has been recently completed, and the inquiry as to the bearing of the Ben Nevis observations on the weather is being pushed forward.

So far as the investigation has been carried, it is evident that rapid and considerable changes from the normals, but particularly a more rapid decrease of temperature with height than the normal decrease, as shown by the thermometric observations, are frequently a precursor and concomitant of storms of wind. This is only what might be expected considering that such observations indicate a disturbance of the equilibrium of the atmosphere. But when with this is conjoined a lower sea-level pressure, as calculated from the Ben Nevis Observatory barometric readings, than what is actually observed at Fort William; in other words, when the barometric observations indicate a more rapid decrease of temperature with height *somewhere in the aërial stratum between sea-level and the top of the Ben* than the thermometric observations alone indicate, then the indications of a coming storm become more decided. Conversely the absence of any abnormally rapid decrease of temperature with height as revealed by all the observations is seldom followed by storms of wind.

For a number of years past the Scottish Meteorological Society has, through the courtesy of the Commissioners of the Northern Lighthouses, been favoured with meteorological observations from all the lighthouses, the keepers being regular observers of the Society; and an important part of their duty as such is to record the hour of beginning and ending of all strong winds, gales, and storms which occur. The observations, made since the establishing of the observatory in December 1883, have been plotted on monthly sheets, which show graphically when storms have occurred at the lighthouses; and on the same sheets have been entered for the respective districts all cases when storm-signals have been hoisted under direction of the Meteorological Office. This investigation is still in progress, but the following results may be provisionally stated.

Leaving out of view those cases in which the barometer at the observatory was lowered by high winds, as above explained, by far the larger number of the remaining cases, when the calculated sea-level pressure was less than what was actually observed at Fort William, preceded or accompanied storms, and when the differences were unusually great the storms were severe and widespread.

Again, neglecting the occasions during 1884 when the wind at the observatory exceeded 30 miles an hour, there remain nine instances which in the west and north of Scotland were not followed by a storm. On eight of these occasions the observations did not indicate the existence of a disturbance in the lower stratum of the atmosphere between Fort William and the observatory.

The Ben Nevis Observatory may be regarded as contributing, towards the forecasting of the weather of the British Islands, a body of facts differing wholly in kind from what is contributed by any other meteorological observatory or station in the country. To the bearing of these observations on weather the directors propose to direct attention next year; and thereafter to use the results that may be arrived at in an examination of the observations of the high-level stations of Europe in their relations to the paths pursued by storms over the Continent.

Mr. Omond, superintendent of the observatory, has compared the results obtained from the registrations of Professor Chrystal's anemometer with the estimations of wind-force made by him and the assistants on scale 0 to 12, and thereby determined the velocity in miles per hour for each figure of the scale 1, 2, 3, &c. The highest figure for which the double observations were sufficiently numerous, so as to give a good average, was 8, which was found to be equivalent to a rate of 73 miles an hour. This wind-force is of frequent occurrence, and as regards the higher estimations Mr. Omond estimates force 11, which occasionally occurs, as equivalent to a rate of 120 miles an hour. This paper has been published by the Royal Society of Edinburgh.

Mr. Omond has written another paper on the rainfall of Ben Nevis in 1885 in relation to the winds. The investigation shows that, as regards the rainfall, the winds arranged in their order of greatest frequency are N., S.W., W., S.E., S., N.E., N.W., and E., the N.W. and E. winds being remarkably few in number. As regards the total fall the order of the winds for wetness is W., N.W., S.W., N., S., N.E., S.E., and E. Thus the direction of wind with which most rain came during 1885 was a little north of west, and the quantity diminishes as we go round the compass in both directions, until the driest point is reached a little south of east, the east again having a very low value. The dryness of S.E. winds is remarkable. They seem mostly to occur when an area of high pressure is moving off and a cyclonic storm approaches from the west; and this dry character indicates that the wind shifts when the storm actually reaches the observatory and the rain begins to fall.

For the past two years much attention has been given by Mr. A. Rankin, the first assistant, in making rainband observations, and he has discussed them in an interesting paper, recently read before the Scottish Meteorological Society, which, along with Mr. Omond's paper on the Rainfall and Winds, will shortly appear in the Society's journal.

A series of elaborate hygrometric observations was made at the observatory during August, September, and October 1885 by Mr. H. N. Dickson, under the direction of Professor Tait and Mr. Buchan. The observations have been discussed by Mr. Dickson in a paper recently read before the Royal Society of Edinburgh. The results are of considerable value in determining how far Glaisher's factors, so largely used by meteorologists in hygrometric inquiries, can be safely used. As regards the remarkably dry states of the air, which form so prominent a feature in the climate of Ben Nevis, Glaisher's factors are found to be altogether inapplicable, and the hygrometric observations will therefore require a specially constructed set of tables. Copies of this and the other papers referred to above will, when published, be forwarded to the Association.

Third Report of the Committee, consisting of Professor BALFOUR STEWART (*Secretary*), Professor STOKES, Professor SCHUSTER, Mr. G. JOHNSTONE STONEY, Professor Sir H. E. ROSCOE, Captain ABNEY, and Mr. G. J. SYMONS, *appointed for the purpose of considering the best methods of recording the direct Intensity of Solar Radiation.*

THE Committee, in conformity with their last report, have had constructed by Mr. Casella an instrument of the following description:—

It consists of a cubic copper enclosure, $3\frac{1}{2}$ inches square outside, the faces of which are $\frac{5}{8}$ of an inch thick. This cube is packed round with felt, $\frac{9}{16}$ of an inch thick, and the whole is faced outside with thin polished brass plates, $\frac{1}{16}$ of an inch in thickness.

In that vertical face of the cube which is intended to face the sun two holes are bored into the copper from above. These holes are equally distant from the centre on each side, and are intended to receive the cylindrical bulbs of two delicate thermometers wrapped round with tin foil so as to be in metallic contact with the copper. Let us call these thermometers A and B. In the opposite face of the cube there is one such hole bored centrally into the copper, also intended to receive the bulb of a thermometer, which we shall call C. Finally, in the very centre of the enclosure there is placed the bulb of a thermometer similar to the above, which we shall call D.

This last thermometer occupies the position that will ultimately be occupied by the interior flat bulb thermometer upon which the sun is to play through a hole, as mentioned in our last report, only this hole has not yet been constructed. The thermometers A, B, C, and D have been carefully verified at the Kew Observatory.

It is proposed to place these thermometers in their respective holes, to expose the instrument to the sun as it will be ultimately exposed, and then to read the thermometers from time to time. If it shall be found that the central thermometer D has a temperature which bears a nearly constant relation to the temperatures of the front face as represented by A and B, and of the back face as represented by C, the Committee will proceed finally with the construction of the instrument. If, however, the temperature of D be not related to those of the other thermometers in a sufficiently definite manner, the Committee may require to reconsider the construction of the instrument.

The Committee have expended 9*l.* 10*s.* 6*d.* and returned to the Association a balance of 10*l.* 9*s.* 6*d.*

They suggest that they be reappointed, and that the sum of 20*l.* be again placed at their disposal.

Second Report of the Committee, consisting of Professor BALFOUR STEWART (*Secretary*), Professor W. G. ADAMS, Mr. W. LANT CARPENTER, Mr. C. H. CARPMAEL, Mr. W. H. M. CHRISTIE (*Astronomer Royal*), Professor G. CHRYSTAL, Staff Commander CREAK, Professor G. H. DARWIN, Mr. WILLIAM ELLIS, Sir J. H. LEFROY, Professor S. J. PERRY, Professor SCHUSTER, Sir W. THOMSON, *and* Mr. G. M. WHIPPLE, *appointed for the purpose of considering the best means of Comparing and Reducing Magnetic Observations. Drawn up by* Professor BALFOUR STEWART.

[PLATES I., II., and III.]

IT is with deep regret that the Committee record the death of one of their number—Captain Sir Frederick Evans, so well known for the valuable contributions which he has made to terrestrial magnetism. His eminent scientific qualities combined to make him a greatly esteemed member of this Committee, who now deplore his loss.

The Committee have added to their number the following gentlemen: The Astronomer Royal, Mr. William Ellis, Professor W. G. Adams, and Mr. W. Lant Carpenter. They could hardly consider their list complete without the addition of the first two names, and they are glad that, although not members of the British Association, these gentlemen were not unwilling to serve on one of its committees.

Since the last meeting of the Association Mr. G. M. Whipple has made a comparison between the method of obtaining the solar-diurnal variation of declination adopted by Sir E. Sabine, and that of Mr. Wild. These methods were applied to three years' observations at the Kew Observatory, and the results were compared with those deduced by the Astronomer Royal from the same three years at Greenwich. The comparison will be found in Appendix IV. to this report.

The Committee think that this comparison deserves careful study, but they do not feel themselves able to pronounce as yet upon the comparative merits of these various methods. Nevertheless, they are of opinion that it is highly desirable to record the daily mean values (undisturbed) of the three magnetic elements side by side with their solar-diurnal variations.

It will be seen by Appendix III. that Sir J. Henry Lefroy has continued his comparison of the Toronto and Greenwich observations. He has obtained from the smooth curves—that is to say, taking Mr. Wild's method—results which appear to him to show that the turning-point of the declination is decidedly later in local time at Toronto than at Greenwich. Sir J. H. Lefroy attributes this to the fact that these two stations are on different sides of the Atlantic.[1]

Appendix II. exhibits, by aid of a diagram, an interesting comparison of Senhor Capello between the diurnal variation of the inclination and that of the tension of aqueous vapour. It is remarkable to notice the great similarity between these variations; a similarity which holds separately for each month of the year. Senhor Capello hopes that these results may be confirmed by a more extended series of observations.

The researches to which allusion has now been made refer to the solar-diurnal variation, excluding disturbed observations. With respect to disturbances Sir J. Henry Lefroy has continued his comparison of Toronto and Greenwich, and his results are indicated in Appendix III.

Professor W. G. Adams has, it is well known, made extensive comparisons between the simultaneous traces of magnetographs in various places. He is at present engaged on such an undertaking, and the Committee are in hopes that when this is completed he will give them the benefit of his experience.

Captain Creak and other members of the Committee feel disposed to consider the continuous observation of earth currents an important part of magnetic work.

The Rev. S. J. Perry and Professor Stewart (Appendix V.) have completed their preliminary comparison of certain simultaneous fluctuations of the declination at Kew and at Stonyhurst in a paper which has been published in the Proceedings of the Royal Society, No. 241, 1885. The results are virtually those which were stated in the last report of the Committee. The comparison is being continued and extended.

Professor Stewart and Mr. W. Lant Carpenter (Appendix VI.) have given the results of other four years' reduction of Kew declination disturbances classified according to the age of the moon. These are very similar to the results of the first four years given in our last report. The same observers give a comparison, extending over four years, between declination disturbances and wind values, which appears to them to show that there is some relation between these two phenomena. They are anxious to continue and extend both these inquiries.

Professor Stewart has pointed out certain general considerations which appear to him to indicate that the solar-diurnal variation may perhaps be caused by electric currents in the upper atmospheric regions. Dr. Schuster has likewise made a preliminary application of the Gaussian analysis, tending, in his opinion, to confirm the hypothesis that currents in the upper regions are the cause of these variations.[2]

By this analysis Dr. Schuster obtains certain relations between the

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[1] See Appendix by Sir G. B. Airy to the Greenwich Observations, 1884.

[2] An account of these researches will be found in the *Phil. Mag.*, April and May 1886.

solar-diurnal variations of the three magnetic elements which ought, in his opinion, to hold on the hypothesis that these variations are caused by currents in the upper atmospheric regions. One of these is that the horizontal force component of the daily variation ought to have a maximum or minimum at the time when the declination component vanishes—that is to say, attains its mean position. Another is that the horizontal force ought to be a maximum in the morning and a minimum in the afternoon in the equatorial regions, while in latitudes above 45° the minimum ought to take place in the morning. A third is that in the equatorial regions the maximum of horizontal force ought to be coincident with the minimum of vertical force, and *vice versâ.*

These conclusions are considered by Dr. Schuster to be sufficiently well confirmed by observations, and thus to render hopeful the first attempt to apply the Gaussian analysis to the solar-diurnal variation.

The appendices of Captain Creak (I.) and of Dr. Schuster (VII.) have reference to this subject, and maintain the importance of some action being taken by the Committee to prepare for a thorough application of the Gaussian analysis to the magnetic variations. It will be seen from the remarks of Dr. Schuster that some time must elapse before observations are obtained sufficiently good and complete to justify a systematic application to them of mathematical analysis. This circumstance has induced the Secretary to lay before this Committee in Appendix VIII. a provisional working hypothesis regarding the cause of the periodic variations of terrestrial magnetism which has gradually grown up by contributions from various quarters.

While this Committee do not hold themselves responsible for the various statements contained in this hypothesis, they would point out the desirability of ascertaining to what extent well-known magneto-electric laws may succeed in accounting for the phenomena of terrestrial magnetism, and likewise the desirability of ascertaining to what extent the magnetic earth appears to be subject to the laws of ordinary magnets.

A preliminary working hypothesis of this nature might serve to elicit facts while the material for the Gaussian analysis is being completed, and it would add to the interest of the final result if we should obtain reason to think that electric currents in the upper atmospheric regions are at once the *immediate causes* of magnetic variations and the *effects* of atmospheric motions in these regions, so that a knowledge of the one set of currents might possibly enable us to determine the other.

In Appendix IX. we have a practical example by Mr. C. Chambers of the method of reduction which he suggested in Appendix XII. of the last report of this Committee. Finally, in Appendix X. there are some remarks by Captain Creak on the advantages to the science of terrestrial magnetism to be obtained from an expedition to the region within the Antarctic Circle.

The Committee have drawn 10*l.* 10*s.*, and returned to the Association a balance of 29*l.* 10*s.* They would desire their reappointment, and would request that the sum of 50*l.* should be placed at their disposal, to be spent as they may think best on the researches mentioned in this report.

APPENDIX.

I. *Letter from Captain Creak to Professor Stewart.*

Richmond Lodge, Kidbrooke Park Road,
Blackheath: *April* 26, 1886.

Dear Professor Stewart,—In the appendix accompanying the last Report of the Committee on Reducing and Comparing Magnetic Observations, so many valuable suggestions are made by various well-known magneticians that I feel there is little left for me to add.

I have long noticed the difficulties attending Sabine's method of separating the disturbances from the normal values of the solar diurnal variation of the declination. It has done good work in the past, but now the question has arisen, Has a better been proposed? I think that adopted at the Greenwich Royal Observatory is better, and that the whole of the Greenwich methods of reduction, as set forth in the published volume of 'Magnetic Reductions' of 1883, invite the attentive consideration of the Committee, with a view to their adoption as a whole or in part.

I am, however, disposed to think that the method proposed by M. H. Wild, of ascertaining 'the normal daily path of the magnetic elements,' has much to commend it, and is rather less open to the possibility of individual bias than that of Greenwich.

In recalling to the notice of the Committee Gauss's valuable memoir 'On the General Theory of Magnetism,' I consider Dr. Schuster has done excellent service. Possibly the prospect of formidable computations has prevented Gauss's treatment of magnetic observations from being hitherto adopted, but if, as Dr. Schuster proposes, by selecting stations the computations may be reduced within comparatively easy limits, I would suggest some such course as follows:—

(1) That the selected stations be fixed observatories provided with the usual magnetographs of like pattern.

(2) That the several Superintendents be invited to make a series of observations for a year or more of the solar diurnal variation of the three magnetic elements, according to a method to be decided by the Committee, with a view to their being treated after the method of Gauss.

(3) That Earth currents be made, as far as possible, a subject of observation at each observatory.

In thus advocating the application of Gauss's method of calculation to the variations of the magnetic elements, I apprehend that the most important immediate result will be the settlement of the question whether the causes are situated above or below the surface of the Earth, and consequently we shall thereafter be better instructed as to the path we should follow in future observations.

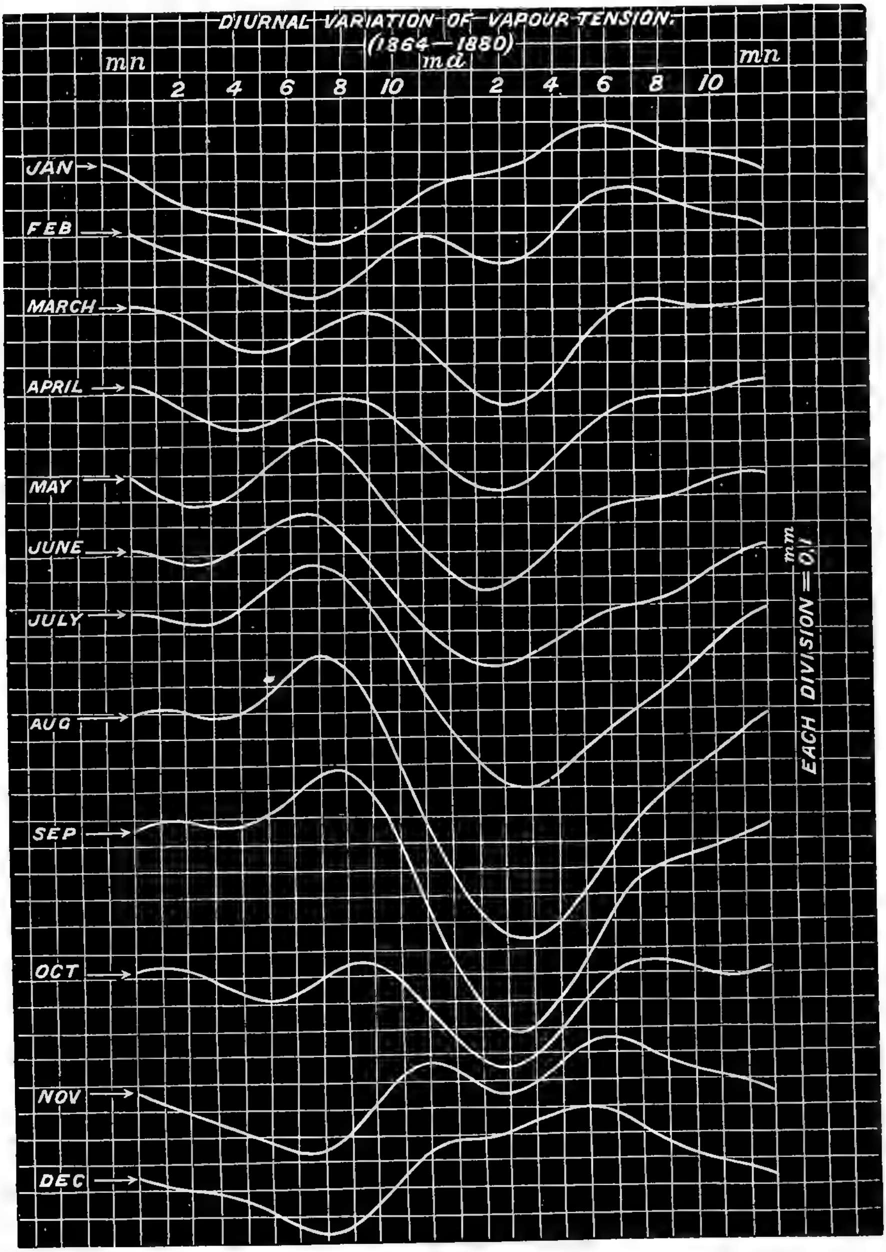
Although in these suggestions only future observations have been considered, it is not in forgetfulness of the large and valuable series already obtained, which all must wish to see made generally available by being rendered in a common form.

I remain, yours truly,
Ettrick W. Creak.

II. *Letter from Senhor Capello, Lisbon, to Professor Stewart.*

Lately in studying the diurnal variation of the tension of vapour at Lisbon, I have been struck with the great similarity of the course of this meteorological element, and that of the magnetic inclination, as shown in the following curves.

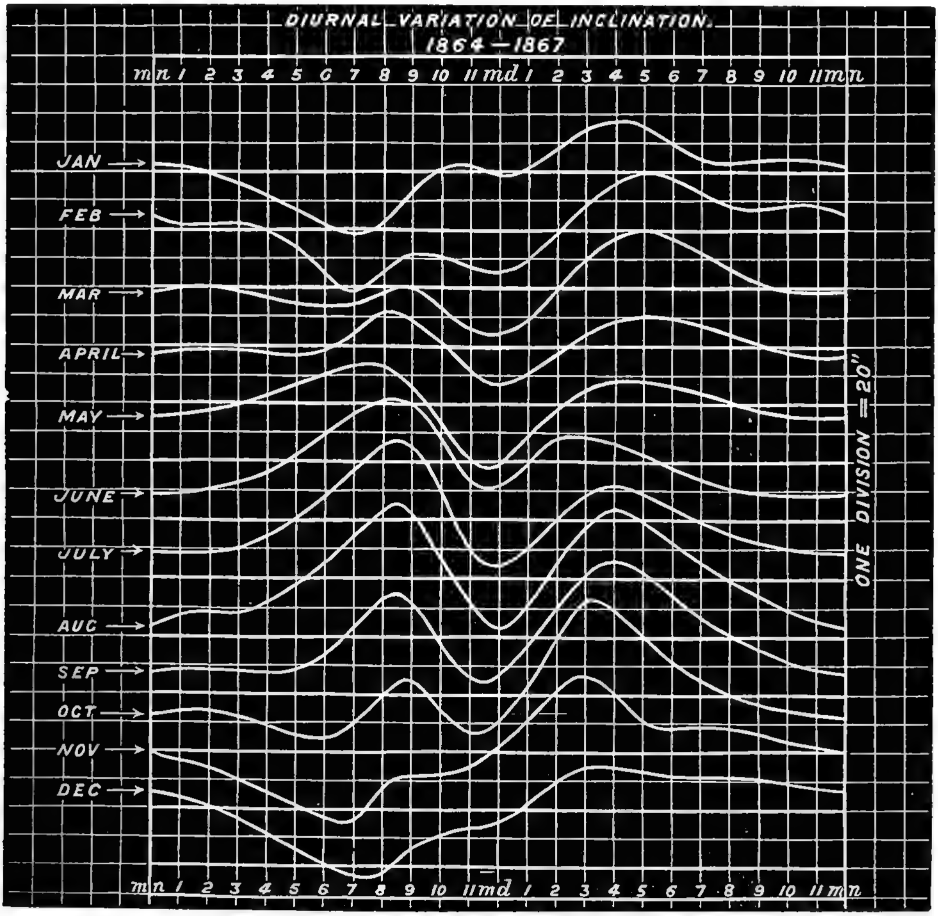
It will be very difficult to say what direct connection there can be between the tension of vapour and the magnetic inclination, but the great similarity of the curves (month by month), and also in the different



seasons (although the phases of the inclination are nearly two hours earlier) make one think that at least the causes of the variations of these heterogeneous elements are the same.

One would therefore attribute to the currents of the atmosphere the magnetic variations: can it be that the vertical currents which are supposed to be the cause of the variations of the tension of vapour can also produce the movements of the inclination needle?

It will be necessary to carefully verify this connection for different places. I send you the diurnal curves for these two elements.



III. *Extract of letter from Sir J. Henry Lefroy to Professor Stewart.*

I have virtually finished the comparison of Photographic Records of Declination at Greenwich and Toronto for 1850, and have made up mean curves for each month from the undisturbed days alone, generally 7 or 8 in number (the total number for Greenwich is 99). On plotting the means they give, notwithstanding the small number of days in some of them, very regular curves are obtained, and they present a feature which is new to me. Sabine never compared Greenwich with his colonial stations, and has not, that I remember, remarked it. It is that the N. end of the magnet reaches the most westerly position of the 24 hours from 1 to 1½ hour earlier at Greenwich than it does at Toronto. This appears in every month compared; there are only seven of them, as the whole apparatus caught fire and was destroyed in June, and did not get to work again before November; but seven months are good for something.

The detailed comparison of disturbed movements has not suggested much beyond the fact that there is rarely any marked correspondence, and that the movements are usually in contrary directions. I have transferred all the Greenwich movements of any magnitude to my sheets, and this is apparent too frequently to leave any doubt that it is the law; it could only be demonstrated by lithographing examples. I enclose a tracing of mean curves from the tracings of undisturbed days, together with an abstract of the numerical values. The Greenwich turning points agree very closely with those at Dublin. That they are so much earlier than they are at Toronto seems to me likely to be traceable to some influence of the Atlantic on the mean direction of the currents. I should add to my explanation that, to obtain three months for the winter solstice, January from the beginning of the year was grouped with November and December at the end, as I had not the next following month of January.

Senhor Capello has sent me his curves showing the general correspondence of character between the diurnal changes of magnetic inclination and those of the tension of vapour in the atmosphere. Lloyd in 1849[1] showed that the area of the diurnal curves of declination gave an annual progression closely resembling the corresponding progression given by the area of the daily curves of temperature, with which the tension of vapour is so intimately connected; so that it would seem that there is a closer connection between meteorologic and magnetic phenomena than has been supposed.

Abstract of mean Solar-diurnal Curves of Declination by measurement from photographic records at Greenwich and Toronto, 1850. *Undisturbed days only*, grouped in astronomical seasons.

Note.—The mean date of each group only corresponds approximately to the equinox or solstice, the days being irregularly distributed.

− = E of mean. + = W of mean of the 24h.

M T	Greenwich.				Toronto.	
	Vernal E	Summer S	Autumn E	Winter S	Vernal E	Winter S
Midnight	−1′·12	−0′·91	−1′·31	−0′·84	−0′·71	−0′·20
13	−0·89	−1·43	−1·45	−0·63	−0·76	−0·25
14	−0·85	−1·15	−1·54	−0·23	−0·82	+0·04
15	−0·78	−1·64	−1·84	−0·42	−0·82	−0·46
16	−0·72	−2·11	−1·65	−0·55	−1·41	−0·57
17	−0·97	−3·68	−2·54	−0·76	−1·19	−1·11
18	−2·05	−4·50	−3·56	−0·96	−2·35	−1·02
19	−3·30	−4·89	−4·53	−1·05	−4·22	−2·08
20	−4·15	−4·25	−4·26	−1·02	−5·91	−3·08
21	−3·31	−2·02	−1·68	−0·88	−6·34	−4·13
22	−0·38	+1·89	+2·20	+0·66	−4·11	−2·85
23	+3·44	+5·44	+5·75	+2·58	−1·60	−0·47
Noon	+5·83	+7·10	+6·67	+3·34	+2·05	+1·72
1	+6·51	+7·24	+6·79	+2·99	+5·58	+3·05
2	+5·69	+5·93	+5·52	+2·13	+6·23	+3·61
3	+3·55	+3·86	+3·31	+0·73	+5·50	+3·55
4	+1·23	+1·85	+1·32	+0·48	+4·20	+2·94
5	−0·18	+0·28	−0·39	−0·05	+2·95	+2·22
6	−0·95	−1·05	−0·92	−0·43	+1·93	+0·87
7	−1·26	−1·36	−1·07	−0·66	−1·05	−0·01
8	−1·67	−1·52	−1·15	−1·06	+0·57	−0·44
9	−1·19	−1·17	−1·13	−1·20	+0·18	−0·60
10	−1·25	−1·26	−1·02	−1·41	−0·08	−0·30
11	−1·43	−0·95	−1·25	−1·14	−0·28	−0·53

The Greenwich observations were 20m. after the hours named; the Toronto observations $2\frac{1}{2}$m. before the hours named.

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[1] *Trans. R. Irish Academy*, vol. xxii. Pt. I.

The days accepted as undisturbed are the following :—

	Greenwich.		*Toronto.*
Jan.	14, 15, 16, 17, 21, 22.	Jan.	14, 15, 16,[1] 17, 21,[1] 22.
Feb.	7, 11, 14, 17, 25.	Feb.	7, 10, 14, 17, 25, 27, 28.
Mar.	2, 8, 14, 18, 20, 28, 29.	Mar.	2, 8, 14, 18, 20, 28, 29.
Apr.	3, 5, 16, 17, 23, 25, 26, 30.	Apr.	3, 5, 23, 26, 30.
May	5, 6, 10, 15, 21, 25, 30, 31.	May	5, 6, 10, 21, 22, 25, 29, 30, 31.
June	11, 12, 15, 20, 23, 24, 25, 29, 30.	June	12[2].
July	3, 4, 14, 17, 26, 31.	July	—
Aug.	6, 7, 14, 25, 26, 28, 31.	Aug.	—
Sept.	1, 9, 11, 17, 20, 25, 26.	Sept.	—
Oct.	4, 10, 11, 21, 22, 24.	Oct.	—
Nov.	4, 5, 8, 15, 17, 22, 23, 24, 28.	Nov.	16[3], 23, 27 28.
Dec.	5, 7, 9, 10, 13, 14, 19, 20, 21, 30.	Dec.	5, 9, 12, 13, 14, 19, 20, 21.

July 1, 1886.

J. H. LEFROY.

IV. *Report by G. M. Whipple.*

In the Report of the Committee presented to last year's meeting, Dr. Wild, of St. Petersburg, submitted a Table showing the different values of the solar-diurnal variation of the declination in Pawlowski for October 1882 and March 1883, as derived from the photographic records of that observatory, after treatment by the two methods of Sabine and Wild.

He found that the difference in the value of the declination at any hour of the day for the two months in question varied from +0·8 to −0·9 in a range of 8·1, or 21 per cent., of the whole.

At the request of the Committee I have prepared tables showing the mean daily variation of declination at the Kew Observatory for the three years (1870–1872) and have contrasted the values obtained there, by Sabine's and Wild's methods, both for the whole year, as well as for the summer and winter semi-annual periods. I have, in addition, compared both sets of values with those published by the Royal Observatory, Greenwich, for the same periods.

The results given in Table III. would show that the differences in the values of the diurnal range of the declination magnet at the Kew Observatory, as determined by Sabine's or Wild's methods, vary to an extent of 0·7′ in a total range of 12′, or may equal 6 per cent. of the whole; whilst in the summer half-year (Table I.) the extreme difference amounts to 1·1 in a range of 15′, or 7 per cent., and in winter to an extreme difference of 0·8 in a range of 8·7, equal to 9 per cent.

The greater diurnal range is afforded in every instance by Sabine's method of treatment of the observations, although the difference is but small.

Contrasting the Kew results with those of Greenwich, we may fairly consider the difference to be due in some measure to instrumental causes, the construction of the magnetographs being dissimilar at the two observatories. The slight difference in position of the two observatories may likewise have some influence.

Accordingly, Table III. shows that the normal daily range at Greenwich differs from that at Kew, as deduced by Sabine's method, by 1·4′, or from that derived by Wild's method by 1·8′, in a range of 11·6′, the percentages being 12 and 15 respectively.

In the summer half-year (Table I.) we get differences of 1·4′, or 10 per cent., by Sabine's, and the same percentage by Wild's method, in a range of 14·7′; whilst in the winter we similarly obtain differences of 1·3′ by Sabine's, and 2·0′ by Wild's method in a range of 8·4′, or percentages of 16 and 25 respectively.

G. M. WHIPPLE.

KEW OBSERVATORY, *July* 1886.

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[1] Owing to imperfections of the record only these two days were eventually used.

[2] Apparatus destroyed by fire.

[3] Record begins Nov. 12.

TABLE I.—*Semi-Annual Solar-Diurnal*

—		Noon											
		0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h
1870.													
SUMMER.													
April to September	Greenwich . .	+7·2	+8·9	+8·6	+6·5	+4·2	+2·1	+0·5	−0·1	−0·2	−0·6	−0·8	−1·5
	Kew (1) . . .	+7·0	+8·8	+8·8	+6·4	+4·4	+2·2	+0·4	+0·4	0·0	−0·4	−0·2	−0·9
	Kew (2) . . .	+7·5	+8·6	+8·1	+5·9	+3·7	+1·5	+0·2	−0·4	−0·2	−0·4	0·0	−0·4
WINTER.													
Jan. to Mar. and Oct. to Dec.	Greenwich . .	+4·8	+6·2	+6·0	+4·9	+3·3	+2·2	+1·4	+0·5	−0·5	−1·5	−2·5	−2·8
	Kew (1) . . .	+4·4	+5·7	+5·7	+4·4	+2·6	+1·5	+0·7	0·0	−0·7	−1·3	−2·2	−2·2
	Kew (2) . . .	+4·4	+5·3	+5·7	+4·4	+2·4	+1·5	+1·1	+0·7	−0·2	−1·1	−2·0	−1·8
1871.													
SUMMER.													
April to September	Greenwich . .	+7·1	+8·8	+8·5	+6·9	+4·6	+2·5	+0·9	+0·1	−0·4	−0·7	−0·9	−1·3
	Kew (1) . . .	+7·0	+8·8	+8·6	+6·6	+4·6	+2·2	+0·6	0·0	−0·2	−0·4	−0·4	−0·9
	Kew (2) . . .	+6·6	+8·4	+8·1	+6·2	+4·2	+2·2	+1·1	+0·2	−0·2	−0·4	−0·4	−0·7
WINTER.													
Jan. to Mar. and Oct. to Dec.	Greenwich . .	+4·9	+6·2	+6·1	+4·8	+3·2	+1·8	+1·1	+0·2	−0·8	−2·0	−2·8	−3·0
	Kew (1) . . .	+4·4	+5·9	+5·7	+4·4	+2·9	+1·5	+1·1	0·0	−0·7	−1·5	−2·0	−2·2
	Kew (2) . . .	+4·4	+5·7	+5·3	+4·2	+2·6	+1·5	+0·9	+0·2	−0·4	−1·1	−1·8	−1·5
1872.													
SUMMER.													
April to September	Greenwich . .	+6·7	+8·2	+8·0	+6·3	+4·5	+2·4	+0·7	−0·2	−0·6	−0·9	−1·2	−1·5
	Kew (1) . . .	+6·4	+7·9	+7·7	+6·4	+4·4	+2·2	+0·9	−0·2	−0·4	−0·4	−0·7	−0·9
	Kew (2) . . .	+6·2	+7·7	+7·5	+5·7	+4·0	+1·8	+0·4	−0·2	−0·2	−0·2	−0·9	−0·7
WINTER.													
Jan. to Mar. and Oct. to Dec.	Greenwich . .	+4·9	+5·9	+5·9	+4·5	+2·8	+1·6	+0·9	−0·1	−1·2	−2·3	−2·9	−3·3
	Kew (1) . . .	+4·4	+5·5	+5·5	+4·0	+2·6	+1·5	+0·9	+0·4	−0·7	−1·5	−2·2	−2·2
	Kew (2) . . .	+4·4	+5·1	+5·1	+3·5	+2·2	+1·3	+0·9	+0·2	−0·2	−1·3	−1·5	−2·0
													MEANS OF
SUMMER.													
April to September	Greenwich . .	+7·0	+8·6	+8·4	+6·6	+4·4	+2·3	+0·7	−0·1	−0·4	−0·7	−1·0	−1·4
	Kew (1) . . .	+6·8	+8·5	+8·4	+6·5	+4·5	+2·2	+0·6	+0·1	−0·2	−0·4	−0·4	−0·9
	Kew (2) . . .	+6·8	+8·2	+7·9	+5·9	+4·0	+1·8	+0·6	−0·1	−0·2	−0·3	−0·4	−0·6
WINTER.													
Jan. to Mar. and Oct. to Dec.	Greenwich . .	+4·9	+6·1	+6·0	+4·7	+3·1	+1·9	+1·1	+0·2	−0·8	−1·9	−2·7	−3·0
	Kew (1) . . .	+4·4	+5·7	+5·6	+4·3	+2·7	+1·5	+0·9	+0·1	−0·7	−1·4	−2·1	−2·2
	Kew (2) . .	+4·4	+5·4	+5·4	+4·0	+2·4	+1·4	+1·0	+0·4	−0·3	−1·2	−1·8	−1·8
Differences of 3 years' Semi-annual Means		0·0	+0·3	+0·5	+0·6	+0·5	+0·4	0·0	+0·2	0·0	−0·1	0·0	−0·3
		0·0	+0·3	+0·2	+0·3	+0·3	+0·1	−0·1	−0·3	+0·4	+0·2	+0·3	+0·4
Differences of 3 years' Semi-annual Means		+0·2	+0·1	0·0	+0·1	+0·1	+0·1	+0·1	−0·2	−0·2	−0·3	−0·6	−0·5
		+0·5	+0·4	+0·4	+0·4	+0·4	+0·4	+0·2	+0·1	−0·1	−0·5	−0·6	−0·8
Differences of 3 years' Semi-annual Means		+0·2	+0·4	+0·5	+0·7	+0·4	+0·5	+0·1	0·0	−0·2	−0·4	−0·6	−0·8
		+0·5	+0·7	+0·6	+0·7	+0·7	+0·5	+0·1	−0·2	−0·5	−0·7	−0·9	−1·2

Variation. Greenwich and Kew.

12^h	13^h	14^h	15^h	16^h	17^h	18^h	19^h	20^h	21^h	22^h	23^h	—
−1·9	−2·1	−2·3	−2·6	−3·0	−4·0	−5·2	−6·1	−6·1	−4·2	−0·7	+3·7	—
−1·1	−1·3	−1·8	−2·2	−3·3	−4·6	−5·9	−6·6	−6·8	−4·8	−1·5	+3·7	Normal according to Sabine.
−0·9	−1·3	−1·3	−2·0	−2·6	−4·2	−5·3	−6·8	−6·8	−5·1	−1·1	+3·3	„ Wild.
−2·6	−2·6	−2·4	−2·3	−2·1	−1·9	−1·8	−2·1	−2·8	−2·6	−0·7	+2·2	—
−2·0	−2·0	−2·0	−2·0	−2·4	−2·2	−2·2	−2·6	−3·3	−3·1	−1·1	+2·0	Normal according to Sabine.
−1·8	−2·0	−2·0	−1·8	−2·0	−2·0	−2·0	−2·6	−3·1	−3·1	−1·3	+1·8	„ Wild.
−1·5	−2·0	−2·3	−2·7	−3·3	−4·3	−5·1	−5·9	−6·0	−4·4	−1·1	+3·2	—
−1·3	−1·1	−1·8	−2·2	−3·1	−4·6	−5·7	−6·6	−6·6	−4·8	−1·8	+3·1	Normal according to Sabine.
−1·1	−1·3	−1·8	−2·2	−2·9	−4·2	−5·5	−6·6	−6·4	−4·8	−1·5	+3·3	„ Wild.
−2·9	−2·6	−2·4	−2·0	−1·8	−1·5	−1·4	−1·8	−2·5	−2·6	−0·5	+2·4	—
−2·2	−1·8	−1·5	−1·5	−1·5	−1·8	−2·0	−2·4	−3·3	−3·1	−0·9	+2·0	Normal according to Sabine.
−1·5	−1·5	−1·5	−1·3	−1·5	−2·0	−2·4	−3·1	−3·7	−3·3	−1·8	+2·0	„ Wild.
−1·9	−1·9	−2·0	−2·6	−3·0	−3·8	−4·7	−5·4	−5·6	−4·1	−0·8	+3·1	—
−1·5	−1·5	−1·1	−2·4	−2·9	−4·0	−5·1	−5·7	−6·2	−4·8	−1·5	+2·9	Normal according to Sabine.
−1·1	−1·1	−1·5	−2·0	−2·2	−3·5	−4·8	−5·9	−6·4	−4·8	−1·5	+2·6	„ Wild.
−2·7	−2·5	−2·4	−2·3	−1·6	−1·3	−1·3	−1·5	−2·0	−1·9	−0·1	+2·6	—
−2·4	−2·2	−2·0	−1·8	−1·5	−1·8	−2·0	−2·2	−2·4	−2·4	−0·9	+2·4	Normal according to Sabine.
−2·0	−1·5	−1·8	−1·5	−1·3	−1·5	−2·0	−2·2	−2·6	−2·6	−1·5	+1·8	„ Wild.

THREE YEARS

−1·8	−2·0	−2·2	−2·6	−3·1	−4·0	−5·0	−5·8	−5·9	−4·2	−0·9	+3·3	Greenwich, Summer, three years' Means.
−1·3	−1·3	−1·6	−2·3	−3·1	−4·4	−5·6	−6·3	−6·5	−4·8	−1·6	+3·2	Kew, Summer, three years' (Sabine).
−1·0	−1·2	−1·5	−2·1	−2·6	−4·0	−5·2	−6·4	−6·5	−4·9	−1·4	+3·1	Kew, Summer, three years' (Wild).
−2·7	−2·6	−2·4	−2·2	−1·8	−1·6	−1·5	−1·8	−2·3	−2·4	−0·4	+2·4	Greenwich, Winter, three years' Means.
−2·2	−2·0	−1·8	−1·8	−1·8	−1·9	−2·1	−2·4	−3·0	−2·9	−1·0	+2·1	Kew, Winter, three years' (Sabine).
−1·8	−1·7	−1·8	−1·5	−1·6	−1·8	−2·1	−2·6	−3·1	−3·0	−1·5	+1·9	Kew, Winter, three years' (Wild).
−0·3	−0·1	−0·1	−0·2	−0·5	−0·4	−0·4	+0·1	0·0	+0·1	−0·2	+0·1	(Sum.), Sabine *minus* Wild.
+0·4	+0·3	0·0	+0·3	+0·2	+0·1	0·0	+0·2	+0·1	+0·1	+0·5	+0·2	(Win.), Sabine *minus* Wild.
−0·5	−0·7	−0·6	−0·3	0·0	+0·4	+0·6	+0·5	+0·6	+0·6	+0·7	+0·1	Greenwich *minus* Sabine (Summer).
−0·5	−0·6	−0·6	−0·4	0·0	+0·3	+0·6	+0·6	+0·7	+0·5	+0·6	+0·3	Greenwich *minus* Sabine (Winter).
−0·8	−0·8	−0·7	−0·5	−0·5	0·0	+0·2	+0·6	+0·6	+0·7	+0·5	+0·2	Greenwich *minus* Wild (Summer).
−0·9	−0·9	−0·6	−0·7	−0·2	+0·2	+0·6	+0·8	+0·8	+0·6	+1·1	+0·5	„ „ (Winter).

TABLE II.—*Annual Solar-Diurnal Variation. Greenwich and Kew.*

—	Noon 0	1^h	2^h	3^h	4^h	5^h	6^h	7^h	8^h	9^h	10^h	11^h	12^h	13^h	14^h	15^h	16^h	17^h	18^h	19^h	20^h	21^h	22^h	23^h	—
YEAR. **1870.**																									
Greenwich . .	+6·0	+7·5	+7·3	+5·7	+3·7	+2·1	+0·9	+0·2	−0·3	−1·1	−1·7	−2·2	−2·3	−2·4	−2·3	−2·5	−2·6	−2·9	−3·5	−4·1	−4·4	−3·4	−0·7	+3·0	Greenwich.
Kew (1) . . .	+5·7	+7·3	+7·3	+5·3	+3·5	+1·8	+0·7	+0·2	−0·2	−0·9	−1·1	−1·5	−1·5	−1·8	−1·8	−2·0	−2·6	−3·3	−4·0	−4·6	−5·1	−4·0	−1·3	+2·0	Kew. Normal according to Sabine.
Kew (2) . . .	+5·9	+7·0	+6·8	+5·3	+3·1	+1·5	+0·7	+0·2	−0·2	−0·7	−0·9	−1·1	−1·3	−1·5	−1·5	−1·8	−2·4	−3·1	−3·7	−4·6	−4·8	−4·0	−1·3	+2·6	Kew. Normal according to Wild.
1871.																									
Greenwich . .	+6·0	+7·5	+7·3	+5·8	+3·9	+2·1	+1·0	+0·1	−0·6	−1·3	−1·8	−2·2	−2·2	−2·3	−2·4	−2·4	−2·6	−2·9	−3·3	−3·9	−4·3	−3·5	−0·8	+2·8	Greenwich.
Kew (1) . . .	+5·7	+7·0	+7·0	+5·5	+3·7	+2·0	+0·9	0·0	−0·4	−0·9	−1·1	−1·5	−1·5	−1·5	−1·5	−1·8	−2·2	−3·1	−3·7	−4·6	−5·0	−4·0	−1·1	+2·4	Kew. Normal according to Sabine.
Kew (2) . . .	+5·5	+7·0	+6·6	+5·0	+3·3	+1·8	+0·9	+0·2	−0·4	−0·4	−1·1	−1·1	−1·3	−1·5	−1·8	−1·8	−2·2	−3·1	−4·0	−4·8	−5·0	−4·2	−1·5	+2·6	Kew. Normal according to Wild.
1872.																									
Greenwich . .	+5·8	+7·1	+7·0	+5·4	+3·6	+2·0	+0·8	−0·1	−0·9	−1·6	−2·0	−2·4	−2·3	−2·2	−2·2	−2·4	−2·3	−2·5	−3·0	−3·5	−3·8	−2·9	−0·5	+2·8	Greenwich.
Kew (1) . . .	+5·5	+6·8	+6·6	+5·1	+3·5	+1·8	+0·9	0·0	−0·7	−0·9	−1·5	−1·5	−2·0	−1·8	−1·8	−2·0	−2·2	−2·6	−3·5	−4·0	−4·4	−3·5	−1·1	+2·6	Kew. Normal according to Sabine.
Kew (2) . . .	+5·3	+6·4	+6·4	+4·6	+3·1	+1·5	+0·7	0·0	−0·2	−0·9	−1·1	−1·3	−1·5	−1·3	−1·5	−1·8	−1·8	−2·4	−3·3	−4·0	−4·6	−3·7	−1·5	+2·2	Kew. Normal according to Wild.

TABLE III.—*Mean of Three Years*

—	Noon 0	1^h	2^h	3^h	4^h	5^h	6^h	7^h	8^h	9^h	10^h	11^h	12^h	13^h	14^h	15^h	16^h	17^h	18^h	19^h	20^h	21^h	22^h	23^h	—
Greenwich .	+5·9	+7·4	+7·2	+5·6	+3·7	+2·1	+0·9	+0·1	−0·6	−1·3	−1·8	−2·3	−2·3	−2·3	−2·3	−2·4	−2·5	−2·8	−3·3	−3·8	−4·2	−3·3	−0·7	+2·9	Greenwich three years' Means.
Kew (1) . . .	+5·6	+7·0	+7·0	+5·3	+3·6	+1·9	+0·8	+0·1	−0·4	−0·9	−1·2	−1·5	−1·7	−1·7	−1·7	−1·9	−2·3	−3·0	−3·7	−4·3	−4·8	−3·8	−1·2	+2·6	Kew, three years' (Sabine).
Kew (2) . . .	+5·6	+6·8	+6·6	+5·0	+3·2	+1·6	+0·8	0·0	−0·3	−0·7	−1·0	−1·2	−1·4	−1·4	−1·6	−1·8	−2·1	−2·9	−3·7	−4·5	−4·8	−4·0	−1·4	+2·5	Kew, three years' (Wild).
Differences.	0·0	+0·2	+0·4	+0·3	+0·4	+0·3	0·0	0·0	−0·1	−0·2	−0·2	−0·3	−0·3	−0·3	−0·1	−0·1	−0·2	−0·1	0·0	+0·2	0·0	+0·2	+0·2	+0·1	Sabine *minus* Wild.
	+0·3	+0·4	+0·2	+0·3	+0·1	+0·2	+0·1	0·0	−0·2	−0·4	−0·6	−0·8	−0·6	−0·6	−0·6	−0·5	−0·2	+0·2	+0·4	+0·5	+0·6	+0·5	+0·5	+0·3	Greenwich *minus* Sabine.
	+0·3	+0·6	+0·6	+0·6	+0·5	+0·5	+0·1	0·0	−0·3	−0·6	−0·8	−1·1	−0·9	−0·9	−0·7	−0·6	−0·4	+0·1	+0·4	+0·7	+0·6	+0·7	+0·7	+0·4	Greenwich *minus* Wild.

V. *Note by the Rev. Professor Perry and Professor Stewart. Comparison of Magnetograms of Kew and Stonyhurst.*

The existence of two magnetic observatories not very far apart, and supplied with similar sets of self-recording instruments, affords a very favourable opportunity for discussing the lesser variations that may be detected in the simultaneous movements of the magnetic needle. A first comparison was therefore made in 1868 between the declination magnetograms of Kew and Stonyhurst, and it was found that the ratio between the changes at the two stations was a variable one. A further discussion of the curves of 1883 and 1884 has lately been made by the Rev. S. J. Perry and Dr. Balfour Stewart, and the results communicated to the Royal Society in a paper read on December 10, 1885. The observed differences in the declination ordinates between the turning-points of certain marked fluctuations in the curves have led to the conclusion that the fluctuations at both observatories follow the same general law as to direction, but that there is apparently a slight difference of duration at the two stations in the case of some short period movements. In discussing the tabulated measurements it was assumed as a working hypothesis that the disturbances are due partly to true magnetic changes and partly to secondary currents arising therefrom. The ratios of the simultaneous changes at Kew and Stonyhurst show that the angular values of the declination disturbances are in excess at the latter observatory, especially when the movement is of short duration; but these ratios appear to be independent of the extent of the oscillation.

The Rev. S. J. Perry and Dr. Stewart are continuing this research.

VI. *Note by Professor Stewart and W. L. Carpenter, Esq.*

We have reduced other four years of Kew declination disturbances after the method described in the last report of this Committee, and have obtained the following result from the two series of four years each :—

Supposed connection between disturbances and the Moon's age.

(0) = new (4) = full moon.

	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1866–69 .	88	91	78	64	52	69	74	75
1870–73 .	111	114	104	95	83	94	107	101

From this it will be seen that the results obtained from both series agree together in exhibiting the same sort of fluctuation.

We have likewise reduced the four years of Kew declination disturbance, 1870–73, with the view of determining whether there is any apparent connection between wind values and magnetic disturbances. In doing this we have adopted the following procedure :—

1. We have obtained, by the kindness of the Kew Committee, the total amount in miles gone over by the wind at Kew for each day of the years 1870–73, and have then converted these into daily averages of three days. Let us call this table A.

2. We have next obtained a table B, where each day's value is the average of 25 days of table A, all being properly placed with respect of dates.
3. Taking the difference between the entries of tables A and B, we obtain a series representing departures from the mean—*plus* when in excess, and *minus* when in deficiency—which may be taken to represent *wind weather*.
4. The declination aggregate daily disturbance numbers have been treated in exactly the same way as the wind numbers, and the differences obtained may be taken to represent *disturbance weather*.
5. The values representing wind weather have then been formed into series of twelve terms each, so chosen that *maximum* wind values come together at the middle of each series. The series are then added up. The result is given in (α).
6. The declination disturbance weather values have then been arranged into series of twelve each, so that each entry is two days previous in date to the corresponding entry in (α). Call this (β) when added up.
7. The values representing wind weather have next been formed into series of twelve terms each, so chosen that *minimum* wind values come together at the middle of each series. Let this be added up and called (γ).
8. The declination disturbance weather values have then been arranged into series of twelve each, so that each entry is two days previous in date to the corresponding entry in (γ). This is added up and called (δ).

The results of these tables are given below:—

(α) Wind weather arranged so that *max.* values represent middle of series.

$$-2384-1655-101+2205+5935+7431+7022$$
$$+4157+2401-360-1667-2196.$$

(β) Dec. disturbance values so arranged that each entry of (β) is two days previous to each entry of (α).

$$-2220-652+245+1110+919+693+1007+466$$
$$+1067+588+33-186.$$

(γ) Wind values arranged so that *min.* values represent middle of series.

$$+2535+1114-1017-3393-4872-5312-5177$$
$$-4740-3322-1680+1074+3196.$$

(δ) Dec. disturbance values so arranged that each entry of (δ) is two days previous to each entry of (γ).

$$+679+177-474-1022-1227-587-260-367$$
$$-1041-980-535+116.$$

From this it would appear that high disturbance values correspond with and slightly precede high wind values. It is our intention to reduce all the available Kew observations in this way, and ultimately to present the result to the Royal Society.

VII. *Report to the Secretary of the Committee of the British Association appointed for the purpose of considering the best means of comparing and reducing magnetic observations.*

In the suggestions which I submitted to the Committee last year I proposed that the method of spherical harmonics employed by Gauss should be applied to the periodic variations of terrestrial magnetism. I have in the course of the past year examined by this method the principal term of the solar diurnal variation; and I hope that the results obtained will induce the Committee to continue the examination in greater detail of the same variation, and also the other periodic changes. Assuming that the Committee is willing to adopt a course of action which must necessarily lead to results of primary importance, I venture to submit to them more definite proposals.

If we had eight magnetic stations separated as far as possible we should be able to obtain a fairly complete expression of the general distribution of magnetic potential on the surface of the earth. For the expansion in spherical harmonics, including terms of the third order, involves fifteen constants, while the horizontal components of magnetic force at each of the eight stations would give us sixteen quantities to determine them. As far as I can judge at present, periodic variations are not much affected by local circumstances, and therefore harmonics of the first three orders will in all probability be sufficient, as a first approximation at any rate. After obtaining the expression for the variable part of the potential, we can easily, with the help of the vertical component of magnetic force, determine the question whether the cause of the disturbance has its seat inside or outside the surface of the earth. I think, therefore, that we should endeavour to obtain a complete record during a period of about ten years of the elements of terrestrial magnetism at eight stations, and that these should be reduced in exactly the same manner, under the superintendence of the Committee.

As it is important to proceed without delay, we must choose stations at which self-registering instruments are at present in existence. I think the following will be the most suitable: Lisbon, Greenwich or Kew, St. Petersburg, Bombay, Mauritius, Melbourne, Zi Ka Wei (China), Toronto, or Washington. It is a matter of regret that South America is not represented, but I do not think the deficiency is sufficiently great to justify delay.

I should propose, then—

(1) To write to the chief observers at these stations at once, asking them for such information as will enable us to judge whether the instruments are in good condition, whether sufficient precautions are taken to eliminate temperature variations, and whether they are willing to pay particular attention to the magnetic instruments for a period of ten years.

(2) To ask these observers how far they are willing to undertake the reduction of their observations according to a scheme submitted to them by the Committee, and, in case they cannot undertake this, whether they are willing to forward to the Committee the necessary records.

(3) To obtain an estimate of the cost of the reductions, which will have to be undertaken by the Committee.

I cannot help thinking that on inquiry a good many difficulties which have been raised will be found to disappear, and that in view of the great importance of the subject the necessary funds will be forthcoming whenever a definite scheme is proposed which will lead to certain results.

The secular variation of terrestrial magnetism will probably require a different treatment. Captain Creak has informed the Committee that a large number of observations of declination, inclination, and total force distributed over the world have been collected by the late Sir Frederick Evans and himself, and that he has already exhibited on a globe at a recent soirée of the Royal Society some leading results of the distribution of the secular change for the epoch 1880. The Committee should, in my opinion, collect and tabulate all available records of the secular variations of the three components of the magnetic force. We cannot decide on the best method of reduction until the material has been collected.

ARTHUR SCHUSTER.

VIII. *Remarks on a Provisional Working Hypothesis.*

By Professor BALFOUR STEWART.

1. From various quarters there have been brought together the elements of what may be termed a provisional working hypothesis with respect to the main causes of the periodical variations of terrestrial magnetism.

In this hypothesis it is supposed that electric currents in the upper regions of the atmosphere may be the main immediate causes of the periodical non-disturbance variations of the magnet, while small but abrupt changes in the magnetism of the earth along with secondary or induced currents in the earth's moist conducting strata and also (occasionally at least) in the upper atmospheric regions, in times of auroras, called forth by these changes may account for the disturbance variations of the magnetic needle. It will thus at once be seen that the regular variations are supposed to be mainly due to a cause above the needle, while the irregular variations are supposed to be mainly due to a cause beneath the needle.

2. The electric currents in the upper atmospheric regions which cause the regular variations are supposed to originate in the motion of a conductor (rarefied air) across lines of magnetic force, and it is supposed that such electric currents will vary *in the first place* according to the power of the sun as exercised in producing these atmospheric motions, and *in the second place* according to the temperature of the moving strata, it having been remarked by Professor Stokes that such strata will become better conductors as their temperature increases. This increase in the temperature of such strata may either be due to an increase in the sun's radiation of such rays as are absorbed by these strata, or to a change in their constitution with respect to aqueous vapour, a substance which may be presumed to possess strong absorptive power for certain rays.

3. With regard to the solar diurnal variation, the most prominent feature is the very simple character of this variation as far as the element of declination is concerned. For the average of a year, and for all but high latitudes, this variation may be represented as if due to positive electric currents in the upper atmospheric regions flowing during those hours when the sun has most power from the equator to the poles; that is to say, from

south to north in the northern, and from north to south in the southern hemisphere, and producing about 2 P.M. a maximum westerly deflection of the north-seeking pole of the magnet in the northern hemisphere, while that in the southern hemisphere for the same pole is of an opposite character, being easterly.

4. Again we know that the air in the upper atmospheric regions travels from the equator to the poles, forming (in those regions) a south-west current in the northern hemisphere, and a north-west current in the southern hemisphere, these being, in fact, the well-known anti-trades. If, then, owing to their passage across the earth's lines of force, these moving conductors are animated by electric currents, these currents must, according to the well-known law, be in such a direction as to stop the atmospheric motions.[1]

5. For the purpose of the following argument we may without sensible error imagine the magnetic earth to be really similar to the model that is sometimes used to represent it; that is to say, we may regard it as a globe wrapped round continuously with insulated wires all in the same direction, and conveying a current, the circles of these wires being small near the poles, and, of course, large at the equator. If we should take a bird's-eye view of this system from above the point which represents the north pole (which corresponds approximately to the south pole of a magnet), we should find that the positive current in the wires would circulate in the direction of the hands of a watch, ascending on the east and descending on the west side. Such hypothetical currents may, therefore, be imagined to move along the earth's surface from east to west.

6. Let us now take the upper systems of atmospheric currents and consider that element of their motion which is from *west to east.* This motion is common to both systems. If in the northern hemisphere these upper winds be animated by a positive electric current going north, this current will be attracted by the hypothetical magnetic current on the west side and repelled on the east; that is to say, there will be a tendency to stop the easterly motion of the atmospheric current. In the same way it may be shown that if in the southern hemisphere the upper winds be animated by a positive current going south, this will tend to stop the easterly motion of the atmospheric current.

7. It thus appears that the electric currents with which, according to this argument, the upper trade-winds in the two hemispheres ought to be animated are precisely such as will account for the solar-diurnal variation of declination, this being alike the most prominent and the most simple feature of the solar-diurnal variations.

8. While it is advocated that the provisional working hypothesis thus accounts, as far as direction is concerned, for the positive currents going north and south—which are presumed to be the main causes of the diurnal variation of declination—it is also necessary to remark that such currents will naturally present a decided diurnal fluctuation. Indeed, if this were not the case, they could not properly account for a variation one marked feature of which is its prominence during the day as distinguished from the night hours. Now we may conceive that the upper atmospheric currents *may* be stronger, and *will* at any rate be better

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[1] Sir J. Henry Lefroy has long been of opinion that the key to the magnetic movements in both hemispheres is to be found by studying the simultaneous effects in both produced by the action of the sun on the equator (see p. 182 of his 'Survey,' 1851).

conductors when heated by the sun, and hence, through a diminution of resistance, the electric current will be increased. The curious similarity detected by Senhor Capello between the diurnal variation of the magnetic dip and that of the tension of aqueous vapour (see Appendix II. to this report) might perhaps seem to point to a variation of absorptive power, and hence of electric conductivity brought about in certain atmospheric strata by the carriage of aqueous vapour.

Again, Sir G. B. Airy (see appendix to the Greenwich observations, 1884) has expressed his opinion that the diurnal magnetic inequality is due mainly, if not entirely, to the radiant heat of the sun, and he is also led to imagine that the magnetic effect of the sun's heat upon the sea is considerably greater than the effect on land; while again Sir J. Henry Lefroy (see Appendix III. to this report) having observed a difference in the time of turning between the solar-diurnal variation of declination at Toronto and at Greenwich, has expressed his belief that this difference is due to the fact that these two places are differently situated with regard to the Atlantic.

9. The fact that the solar-diurnal variation is greater at times of maximum than at times of minimum sun-spot frequency is explained by the advocates of this hypothesis on the assumption that not only is the sun most powerful on the former occasions, but that the solar radiation then contains probably a larger proportion of such rays as are absorbed by the upper strata of the atmosphere, while the composition of these strata with respect to aqueous vapour may likewise be such as to cause an increased absorption. This increased absorption means an increased temperature, and hence an increased conductivity.

10. It has moreover been adduced in favour of this hypothesis that the tendency seems to be, as pointed out by Mr. William Ellis and by Professor Stewart, that changes in the range of the daily variation of magnetic declination lag behind corresponding solar changes in point of time. This kind of behaviour is apparently inconsistent with direct magnetic action of the sun operating as the chief cause, and points rather to some indirect influence, probably caused by the radiant energy of the sun, inasmuch as the changes and turning-points of such indirect influences due to radiation are well known to lag, in respect of time, behind the corresponding changes and turning-points in their cause. This subject demands further attention.

11. Hitherto we have been considering that portion of the motion of the upper atmospheric currents which is from west to east in both hemispheres. Let us now consider that portion of such motion which is from *south to north* in the northern, and from *north to south* in the southern, hemisphere.[1]

Now, here it may be well to remark that it seems quite possible to conceive a set of currents to exist in the earth's atmosphere without exhibiting a considerable diurnal variation. Let us take, for instance, an ordinary electric current, say of a circular shape and horizontal, and heat it by causing some source of heat, such as a lamp, to travel slowly round it with a definite rate of progress. It will be evident that we shall have (assuming the current to be otherwise constant) no variation in flow due to this heating effect. In like manner, if there be electric currents in

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[1] The discussion of this point is almost identical in wording with a similar discussion brought by Professor Stewart before the Physical Society.

the atmosphere which circulate round the earth in the direction of parallels of latitude, such currents will not be subject to any considerable solar-diurnal variation. For, while the conductivity of a given region would vary according to the position of the sun with regard to it, yet the whole circuit round the earth, which would always embrace a region affected by the sun, would not have its total resistance altered, or at least not greatly altered; and, as there would be no cause for much alteration of the total electromotive force, there would be no great reason for inconstancy of current—in other words, no great solar-diurnal variation.

12. For the purpose of the following argument, we may consider the earth to be at rest (*i.e.*, devoid of rotation), and imagine that the sun circulates round the equator in twenty-four hours. As a consequence of solar influence we shall have convection currents in the upper regions of the atmosphere flowing from the equator northwards and southwards toward the poles. Whether these currents reach the poles or come down in some intermediate region may be left an open question. Now, such currents will not only be conductors, but they will form a movable system of conductors, which we may suppose to be created at the equator when they rise into the upper regions, and destroyed at the poles or those intermediate regions where they descend.

13. Again, for the purpose of this argument we may, without sensible error, regard the magnetic globe in the way already mentioned; that is to say, as represented by a small globe, wrapped round with wires, conveying currents that go round it from east to west. Now, if an external insulated circuit of wire a trifle larger than the diameter of this globe be supposed to travel from the equator to either of the poles, it will leave behind it more convolutions of the primary globe current than it approaches, and will therefore be traversed by an induced current in the same direction as that of the primary; and the continuous travelling of such an external system might be supposed to increase the magnetic power of the globe. Applying the same sort of reasoning to the earth and to the convection currents under consideration, these may be imagined to be traversed by equatorial electric currents, the tendency of which in both electric hemispheres would be to increase the general magnetism of the globe. For the reason already given such currents would have little solar-diurnal variation, but yet they would be dependent upon the state of the sun, and would vary with it. For imagine a change to take place in the radiation of our luminary, producing an excess of such rays as are greedily absorbed by the upper atmospheric regions, there would be (as already remarked) a sensible increase in the conductivity of these regions, even if the electromotive force remained unaltered; and hence there would be an increase in the supposed equatorial current. In other words, such currents, while presenting no great diurnal variation due to the carriage of a constant sun round the earth, would yet be eminently susceptible to any inconstancy in the sun itself.

14. Now here it will be asked, Have we any such phenomenon connected with terrestrial magnetism? The reply to this question will be an affirmative one. The late John Allan Broun has shown that we have changes in the mean daily value of the horizontal force, which are simultaneous and in the same direction at places on the earth's surface very far removed from each other; and the author of these remarks has endeavoured to show that the changes of this nature as recorded by Mr. Broun depend, as far as we can judge from somewhat imperfect records,

upon the state of the sun's surface, an increased area of spotted surface coinciding apparently with increased values of the daily means of horizontal force all over the earth.

While such currents might be supposed to possess, as a whole, no distinct daily variation, yet at the time when the sun heats a tropical region it might be supposed to increase the relative conductivity of that region with respect to that of the atmosphere nearer the pole. It would thus divert to the heated region an unusual proportion of the whole current, so that we should have a maximum of horizontal force near noon in the equatorial, and a minimum at the same time in the polar regions. This is probably the case.

15. One chief object in giving prominence to this part of the subject is with the view of advocating that the Gaussian method of analysis should not be applied merely to the solar-diurnal variation of the three magnetic elements, but should likewise embrace a consideration of the simultaneous variations in the mean daily values of the elements at various stations. We must, in fine, consider the possibility at least of there being in the upper atmospheric regions, not merely currents which present a marked solar-diurnal variation, but others that have no marked solar-diurnal variation, while yet they may be highly susceptible to changes in the sun. The double method of treating mathematically not merely the solar-diurnal variation, but likewise the simultaneous changes in the mean daily values of the elements, would thus appear to be necessary and sufficient for giving us the required information.

16. If we turn from the solar-diurnal variations to those caused by the moon, we find in this region likewise an attempt to explain the phenomena by the same working hypothesis. It has been remarked by Dr. Schuster that we live at the bottom of the atmospheric ocean, where lunar tides will necessarily be small, and he imagines that in the upper regions of the atmosphere the motions caused by lunar tides may be very considerable. Such motions would be subject to the same magneto-electric laws as those caused by the sun, and we might therefore expect a lunar semi-diurnal magnetic variation, such as, in fact, we have. The late John Allan Broun has shown that the moon's magnetic effect varies approximately as the inverse cube of the moon's distance from the earth, a conclusion that would seem to point to some sort of tidal influence as the cause of this effect.

17. Again, if this tidal influence be seated in the upper atmospheric regions, it should be greater during the day (when these regions are heated, and so become good conductors) than during the night. Now, Broun was the first to point out that the semi-diurnal lunar variation at Trevandrum, in India, is subject to this law, and his results have lately been confirmed, in an independently conceived investigation, by Mr. C. Chambers, of Bombay. We might likewise expect that the lunar variation, like the solar one, should be greatest at times of maximum sun-spot frequency, and there is some reason to think that this is the case, although the fact is not yet definitely established.

18. There seems, therefore, reason to believe that the diurnal variation of any one magnetic element—the declination, for instance—may be due to the joint action of several causes, which we may, perhaps, represent as follows:—

In the first place, the sun may act in producing atmospheric motions in the upper regions; this would cause a solar diurnal magnetic effect.

Secondly, the moon would produce tides in those regions, which would be the cause of a lunar semi-diurnal magnetic effect.

Thirdly, the sun, acting as the moon does, would likewise produce tides which would be the cause of a solar semi-diurnal magnetic effect.

Fourthly, these various effects would be increased during those hours when the sun is powerful, inasmuch as the upper atmospheric regions become better conductors at high temperatures.

19. If we now leave the regular variations, and turn to magnetic disturbances, there seems reason to suppose that the earth, like any other magnet, may be subject to small and abrupt changes of magnetism, and it is quite conceivable that such changes may produce secondary currents in the moist conducting strata of the earth, and likewise in the upper atmospheric regions. We know, as a matter of fact, that there are such earth-currents, and the observations made at Greenwich show that they are intimately associated with the disturbances registered by the self-recording magnetographs.

20. The late Dr. Lloyd was the first to remark that 'the rapid changes of the earth currents are much greater in proportion to the regular daily changes than the corresponding movements of the magnetometers.' We may perhaps interpret this to mean that a small but abrupt magnetic change is associated with a larger earth-current manifestation than another change of the same size, but of a more gradual nature. This would appear to be in favour of the view that such earth currents are secondary currents due to small but abrupt changes which take place in the magnetism of the earth. In conformity, too, with this hypothesis, cases may be pointed out where the magnetic disturbance, while rapidly varying, is yet altogether on one side of the normal, and where the corresponding earth currents pass alternately from strong positive to strong negative.

21. Quite recently (see Appendix V. to this report) the Rev. Professor Perry and Professor Stewart have brought before the Royal Society the results of a preliminary comparison between the fluctuations of the declination at Kew and at Stonyhurst (neighbouring stations), and have derived the following conclusions:—

(1) In the very great majority of cases the angular value of the declination disturbance is greater for Stonyhurst than for Kew.

(2) The ratio $\frac{\text{Stonyhurst}}{\text{Kew}}$ is certainly greater for disturbances of short than for those of long duration.

If we add to these conclusions the fact noticed by these observers that all the disturbances occur in couplets, we may be disposed to agree with them that in the case of disturbance as exhibited by a suspended magnet there are probably two causes at work, the first of these being a change in the magnetism of the earth, and the second an induced current due to this change.

22. It would thus appear that in this provisional working hypothesis the principle of current induction is brought forward with the object of explaining both the regular and the irregular magnetic fluctuations. It is sought to explain the former by the hypothesis that in the upper atmospheric regions we have conductors moving across lines of magnetic force, and hence animated by a current. It is sought to explain the latter on the supposition that small but abrupt changes of the magnetism of the earth by a method similar to that in a Ruhmkorff's coil cause secondary

currents in the moist conducting strata of the earth's surface and in the upper atmospheric regions, which currents, as well as the magnetic change which causes them, will, of course, influence a suspended magnet.

23. There is still left the question, Why should there be small and rapid changes of the earth's magnetism? In reply to this it is argued that we must regard the earth as we would any other magnet, the only difference being one of size. Now, there are at least two known causes which may operate upon a magnet to change its magnetic state. These are *first*, mechanical disturbance; and *secondly*, a change in the electric currents in whose field the magnet is placed: and it is asserted that the changes which take place in the magnetism of the earth should be studied from these two points of view. It is the second of these causes that has hitherto been chiefly investigated, and magneticians have succeeded in showing that disturbances vary with the state of the sun's surface, with the time of the year, and with the hour of the day. Possibly, however, considerations connected with the first of these causes might seem best to explain the second portion of the preliminary results obtained by Messrs. Stewart and Carpenter (see Appendix VI. to this report).

24. In conclusion, perhaps the strongest objection to this hypothesis is that which questions the possibility of electric currents being produced in the upper atmospheric regions. It may be said that while undoubtedly rarefied air is a conductor of electricity, yet it is not a good conductor; and where can we look for sufficient potential to drive such currents through these regions? To this it may be replied that *as a matter of fact* we know that there are visible electric currents in the upper atmospheric regions which occur occasionally at ordinary latitudes, and which are very frequent if not continuous in certain regions of the earth. These are known as the Aurora which, both with respect to the time of its occurrence and to the disposition of its beams, manifests a close connection with the phenomena of terrestrial magnetism, occurring at ordinary latitudes only when there are great magnetic disturbances, and the disposition of its beams having a distinct reference to lines of magnetic force. Besides. considerations of a mathematical nature induce us, as we have already seen, to suppose that the solar-diurnal variation is due to electric currents in the upper atmospheric regions. We are, therefore, justified in asserting that there is no impossibility in conceiving a set of electrical currents intimately associated with certain phenomena of terrestrial magnetism to exist in the upper regions of the earth's atmosphere.

IX. *Examples of the Application of a Modified Form of Sabine's Method of Reduction of Hourly Observations of Magnetic Declination and Horizontal Force to a Single Quarter's Registrations of the Magnetographs at the Colaba Observatory, Bombay.* *By* CHARLES CHAMBERS, *F.R.S.*

On the invitation of Dr. Balfour Stewart, the Secretary of the Committee appointed by the British Association to consider the best means of comparing and reducing magnetic observations, I submitted last year, for the Committee's consideration, some remarks which had the honour to find a place in their Report to the Association. Amongst the suggestions which I then made was one for a trial application of a somewhat elaborate process of reduction, the results of which it was anticipated would, in some respects, be as definite and informing when derived from a comparatively short series of observations as those of Sabine's rougher method when derived from a much longer series of observations. Such a trial I have since been able to make upon the hourly tabulations from the registers of the Colaba declination and horizontal force magnetographs for the quarter November 1875 to January 1876; and the results are of so highly satisfactory a character, and bear so directly on the inquiry upon which the Committee are engaged, that I deem it my duty to place an account of them before the Committee.

The process may be described as follows :—

1. Tabulations of hourly ordinates are entered upon monthly abstract forms (Form A), which have the hours of the day marked at the head of the columns, and the days of the month at the left-hand side of the lines,[1] and upon these ruled forms the daily mean is taken and entered in a column at the right-hand side of the twenty-four hourly entries of each day, and the mean for the month of the entries in each hour column is taken and entered at the foot of the column. Let us suppose this to have been done for a given month, and for the two preceding and two following months.

2. Take the mean of the daily means for the first fifteen days of the same month and the last fifteen days of the preceding month as the mean ordinate for the beginning of the former month, and, for the present, let the excess of the mean ordinate for the beginning of the next month over this mean ordinate be taken to represent the progressive increase of the ordinate for the given month, whether arising from instrumental change or from secular or annual variation, and in allowing for such increase treat it as growth at a uniform rate.

3. On a blank strip of ruled paper cut out from one of the columns enter the proportional corrections for progressive increase, to reduce the tabulations to the standard of the middle of the month; these corrections will be *zero* for the middle of the month, and equal positive and negative numbers at equal intervals before and after the middle of the month, and the sum of these for the whole column will be *zero*. The strip is to be placed close up to each column in succession for reference in the operation of separating disturbed observations.

4. Apply Sabine's method of separating disturbances to each hour column in succession, taking account of the corrections for progressive increase entered on the loose slip, and calculate final normals. The separating values adopted are for declination ·048 inch of tabulation or ·00150 of force, and for horizontal force ·078 inch of tabulation or ·00334 of force.

5. Substitute for each disturbed tabulation the higher or lower limit for that hour and day of an undisturbed tabulation according as the disturbance is positive or negative. The deviations of the disturbed tabulations above the higher or below the lower limits respectively are to be called positive or negative 'disturbances without the limits,' and the laws of their variations are to be determined by the method that Sabine applied to his 'larger disturbances.' In what follows we are to confine our attention to the original numbers entered upon Table A, except where these have been replaced, in the case of disturbed tabulations, by the higher or lower limits.

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[1] If the continuity of the record has been interrupted during the month, either by accident or by instrumental adjustments, due allowances must be made to render the whole month's tabulations comparable before proceeding further.

6. Construct now a new table (B), each entry in which is the 29-day mean of the numbers for the same hour in Table A, viz., of the numbers for the day of the entry and of the fourteen preceding and fourteen following days. The numbers of Table B for all the hours of a given day we may take to represent very approximately the mean solar-diurnal variation—*plus* a constant—for that day, the average extending over the lunation of which that day is the middle day. They will be affected by progressive change of the values of the tabulations and by disturbance within the limits.

7. The excesses of the numbers of Table A over the corresponding numbers in Table B, *plus* a constant round number, are now entered on a third table (C). The numbers in this table will be affected only by that part of the solar-diurnal variation which goes through a cycle of change in a lunation, and by disturbance within the limits. On the left-hand margin of table C mark the days of the moon's age, the number 1 being placed opposite the first day of which at least a full half follows the time of new moon, and the other numbers, in order, up to 29 or 30. If table C were calculated for each month of a long series of years it would be practicable to re-arrange the days in tables, of which there would be one for each day of the moon's age in each month, with a probability of obtaining characteristic diurnal variations from the numbers of each table; but as the trial calculations extend over three months only, these (November to January) were grouped together, and the days of the moon's age were arranged in eight groups as follows:—

Group	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Days of the Moon's age	29	3	6	10	14	18	21	25
	30		7	11	15		22	26
	1	4	8	12	16	19	23	27
	2	5	9	13	17	20	24	28

Thus eight tables were formed corresponding to the times of the four quarters of the moon, and to the four intermediate phases, and the numbers of Table C were duly distributed amongst them.[1] The hourly means were taken of all the numbers on each of these tables, and then the excesses of those means above the general mean for the twenty-four hours of the same table, and finally these excesses were converted from inches (of tabulations) into m.g.s. units of force. In this way were obtained the excess solar-diurnal variations for each of the eight phases of the moon. From these were calculated the luni-solar-diurnal variations

$$f_{c\cdot 2}(h) \text{ and } f_{s\cdot 2}(h)$$

of the formula

$$f_{c\cdot 2}(h)\cos 2\left(\frac{2\pi}{\mathrm{P}}\right)+f_{s\cdot 2}(h)\sin 2\left(\frac{2\pi}{\mathrm{P}}t\right),$$

---

[1] By inadvertence the last three days of January, which formed part of a fourth lunation, were left undistributed; so that the results will be for the three lunar periods from November 1, 1875, to January 28, 1876.

where h is the solar hour, P is the mean period of a lunation, and t is the age of the moon.

Designating the variations for the eight different phases by (0), (1), (2) . . . . (7), we have

$$f_{c\cdot2}(h)=\frac{(0)-(2)+(4)-(6)}{4}$$

$$f_{s\cdot2}(h)=\frac{(1)-(3)+(5)-(7)}{4}$$

And the results for the quarter November 1875 to January 1876 are—

	Solar hours	Midnight	1	2	3	4	5	6	7	8	9	10	11
Declination—East	$f_{c\cdot2}(h)$	·000+ −03	·000+ −04	·000+ −03	·000+ −03	·000+ 00	·000+ +04	·000+ +02	·000+ +05	·000+ +16	·000+ +20	·000+ +11	·000+ −05
	$f_{s\cdot2}(h)$	+07	+06	+09	+04	−04	−02	−01	00	−05	−10	−06	+07
Horizontal Force	$f_{c\cdot2}$ (	+03	−04	+01	+02	−01	−01	−06	+11	+37	+46	+25	+13
	$f_{s\cdot2}(h)$	−16	−16	+05	+05	−08	−16	−15	−24	00	+05	+56	+55

	Solar hours	Noon	13	14	15	16	17	18	19	20	21	22	23
Declination—East	$f_{c\cdot2}(h)$	·000+ −14	·000+ −20	·000+ −14	·000+ − 4	·000+ +05	·000+ +05	·000+ +02	·000+ +01	·000+ +02	·000+ −01	·000+ −02	·000+ 00
	$f_{s\cdot2}(h)$	+12	+13	−08	−17	−13	−05	+03	+03	+01	+01	+04	+08
Horizontal Force	$f_{c\cdot2}(h)$	−04	−13	−25	−21	−12	−04	−15	−14	−09	−10	+03	00
	$f_{s\cdot2}(h)$	+47	+35	+21	−02	−09	−15	−05	−17	−31	−19	−28	−10

These numbers are curved (in black) in figs. 1 to 4, and on the same forms are curved (in dotted lines), for comparison, the results of a similar treatment, but by Sabine's rougher method, of the long series of eye observations made in the winter quarters of the period 1846·0 to 1871·0 in the case of the declination, and of the period 1846·5 to 1873·0 in the case of the horizontal force.[1]

We see at a glance that the black curves have the same general characteristics as the respective dotted curves, with only such deviations in form and range as might well be expected to be found in the real features of the variations of individual quarters. They thus confirm the evidence afforded by the longer series of observations that there is *in nature* a magnetic periodicity of the kind that we have called the luni-solar-diurnal variation; but their special significance, and that to which we would at present particularly direct attention, lies in the indication which they afford that it is possible, by applying a suitable process of reduction, to utilise short series of observations for purposes requiring a degree of nicety that is quite beyond the powers of the older method.

It may be worth while to mention here that each quarter's reduction, carried out in the manner described above, occupies an Indian computer of very ordinary capabilities about 360 hours. This includes the calculation of the luni-solar variations both for declination and horizontal force. The computer of a temperate climate, with his greater natural energy and better surroundings, would, of course, accomplish the work in much less time.

Examples are appended hereto of the construction and computations of Tables A, B, and C, and of the combination of days belonging to the (4th) phase of a lunation; also of the calculation of the luni-solar-diurnal variations.

In the last calculation the variations are taken after instead of before the combination of the numbers for the several phases; this is to avoid the inconvenience of having to deal with positive and negative numbers.

The curves of fig. 5, exhibiting the regular solar-diurnal variation of horizontal force for each day of the month, are constructed from the 29-day means of Table B.

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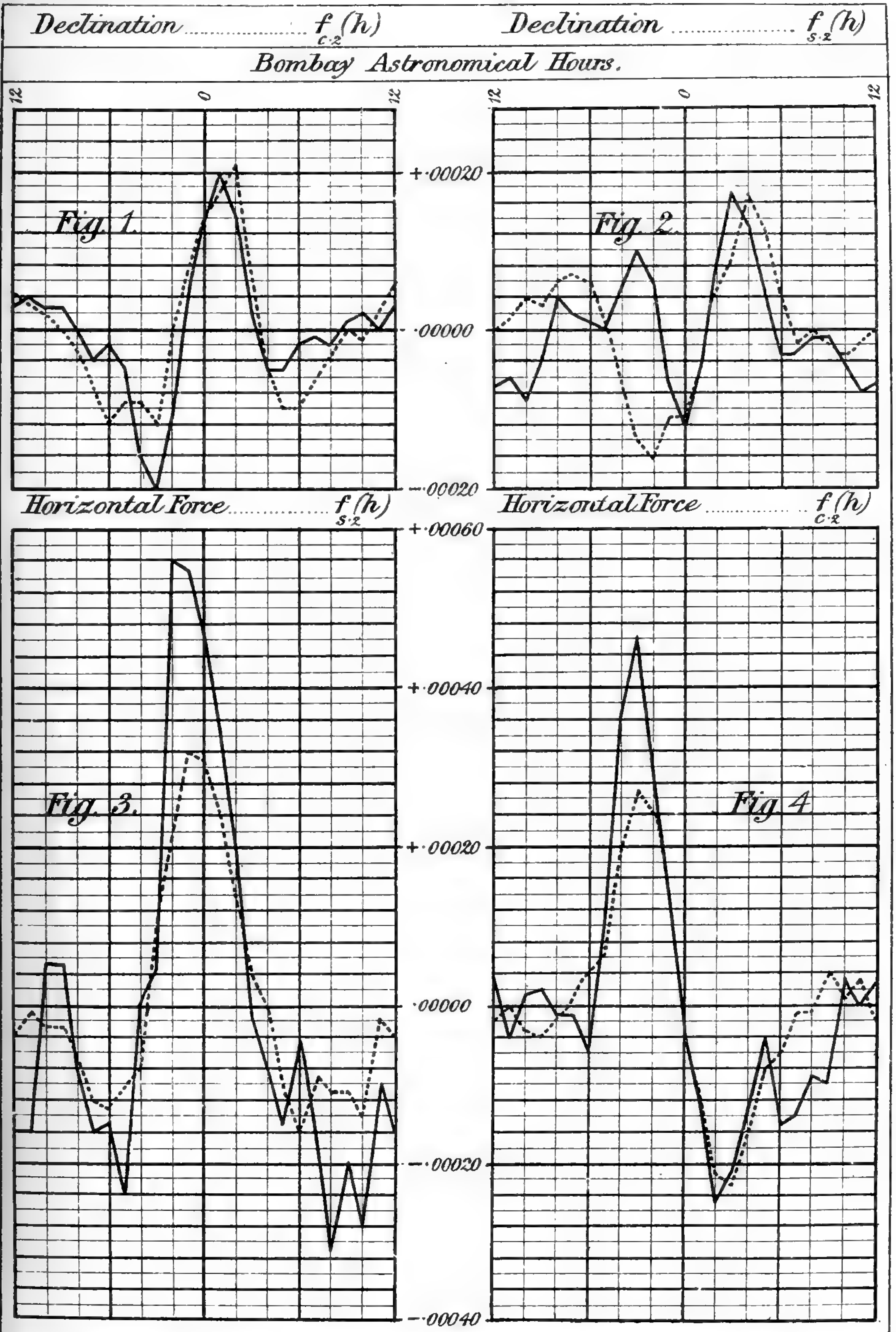
[1] In the curves for declination as sent by Mr. Chambers, the signs as given above are reversed.



Declination .... $f_{c.2}(h)$ Declination .... $f_{s.2}(h)$

Bombay Astronomical Hours.

Horizontal Force .... $f_{s.2}(h)$ Horizontal Force .... $f_{c.2}(h)$

Black Curves Novr. 1875 to Jany. 1876. – Dotted Curves of Declination 1846·0 to 1871·0. Dotted Curves of Horizontal Force 1846·5 to 1873·0. – The scale is in m.-g.-s. units of force.

Spottiswoode & Co. Lith. London

Illustrating Report on the best means of Comparing & Reducing Magnetic Observations.

Solar diurnal variation of Horizontal Force for each day of November 1885.

Bombay Astronomical Hours.

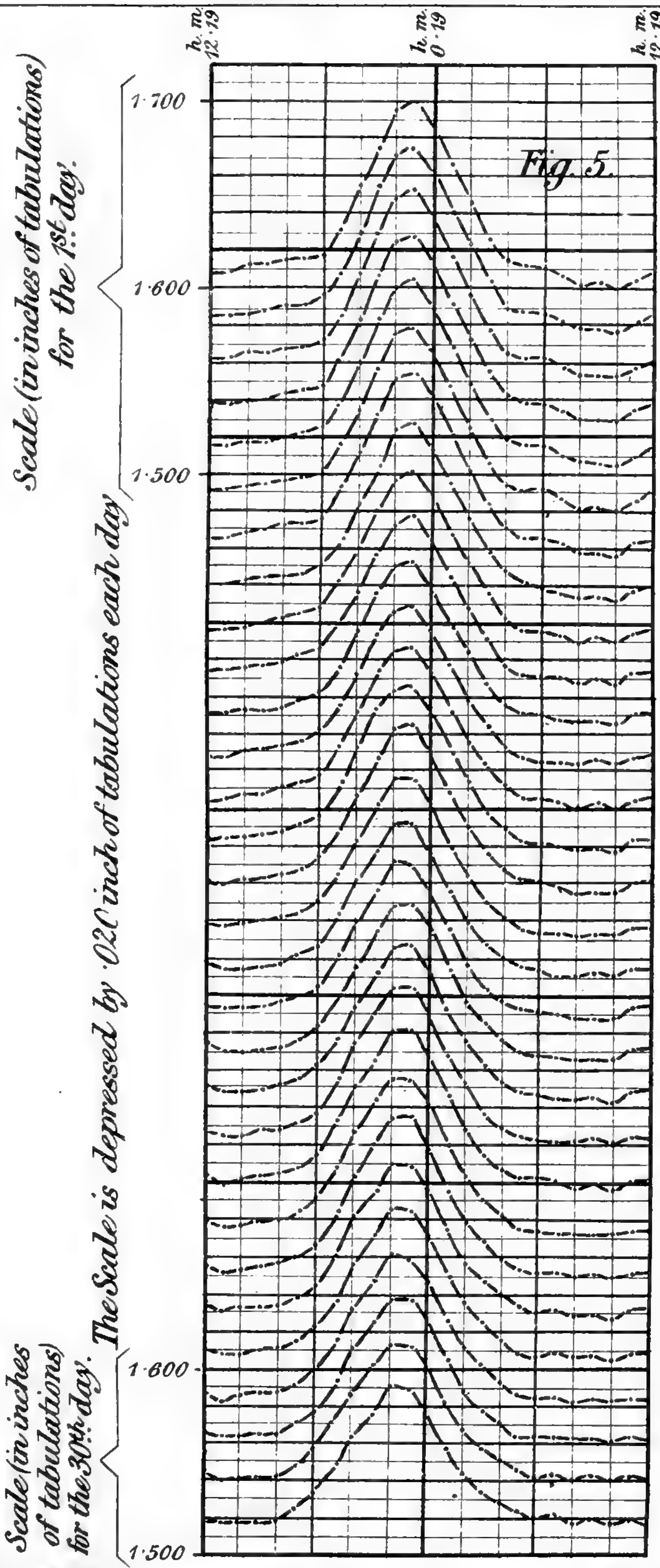


Fig. 5.

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lustrating Report on the best means of Comparing & Reducing Magnetic Observations.

TABLE A (*continued backwards*).—*Government Observatory, Bombay, Month of October*, 1875. *Hourly Abstract of Tabulations (in Inches) of Horizontal Force Magnetograph.*

Colaba Civil Hour	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	8	9	Sum	Mean
Date 18	1·766	1·775	1·759	1·725	1·703	1·688	1·688	1·682	1·675	1·671	1·668	1·665	1·668	1·670	1·660	1·676	1·669	1·665	1·659	1·676	1·672	1·681	1·690	1·710	—	—
19	·716	·741	·743	·717	·694	·677	·692	·700	·691	·690	·686	·678	·678	·675	·674	·673	·670	·677	·677	·676	·684	·702	·731	·760	—	—
20	·776	·788	·772	·747	·728	·707	·690	·694	·685	·681	·673	·676	·672	·672	·673	·673	·676	·672	·674	·678	·679	·691	·736	·774	—	—
21	·799	·807	·781	·754	·733	·716	·703	·693	·685	·681	·680	·675	·672	·676	·674	·667	·662	·658	·661	·663	·664	·676	·712	·750	—	—
22	·765	·767	·748	·723	·700	·684	·670	·668	·668	·667	·665	·663	·659	·656	·661	·663	·663	·663	·665	·669	·674	·693	·727	·753	—	—
23	·760	·761	·741	·713	·701	·683	·679	·673	·666	·668	·667	·656	·664	·668	·667	·667	·667	·668	·670	·671	·669	·678	·711	·740	—	—
24	·750	·760	·741	·725	·707	·690	·675	·678	·682	·674	·660	·659	·660	·661	·660	·661	·662	·659	·670	·674	·670	·691	·707	·733	—	—
25	·737	·747	·737	·720	·680	·629	·634	·639	·630	·636	·632	·599	·579	·613	·629	·631	·629	·629	·639	·623	·641	·656	·687	·726	—	—
26	·724	·706	·703	·685	·650	·644	·650	·652	·644	·584	[·550 ·529]	·568	·593	·603	·609	·604	·602	·609	·610	·612	·622	·625	·658	·661	—	—
27	·698	·703	·693	·670	·659	·634	·589	·554	·561	·596	·585	·640	·604	·615	·620	·610	·632	·631	·629	·622	·625	·640	·662	·691	—	—
28	·708	·719	·712	·691	·667	·646	·623	·622	·620	·606	·618	·617	·619	·607	·615	·620	.619	·622	·624	·627	·631	·641	·653	·668	—	—
29	·692	·704	·693	·677	·660	·627	·604	·611	·611	·614	·616	·615	·614	·614	·618	·623	·622	·622	·620	·619	·616	·624	·640	·650	—	—
30	·669	·678	·665	·654	·643	·638	·628	·618	·618	·616	·612	·612	·614	·618	·617	·623	·622	·621	·617	·617	·614	·620	.629	·641	—	—
31	·659	·669	·664	·652	·649	·641	·629	·624	·625	·628	·621	·622	·621	·624	·627	·624	·628	·634	·634	·642	·648	·665	·687	·708	—	—

TABLE A.—*Government Observatory, Bombay, Month of November*, 1875.

Corrections for progressive increase in the month of November, 1875	Colaba Civil Hour	10	11	12	13	14	15	16	17	18	19	20	21
	Date												
−·046	1	1·740	1·747	1·729	1·703	1·684	1·663	1·639	1·640	1·636	1·618	1·600	1·594
−·043	2	·712	·721	·700	·656	·612	·566	[·528 ·503]	[·524 ·493]	[·522 ·521]	·580	[·519 ·510]	[·520 ·500]
−·040	3	·614	·617	·607	·570	·567	·547	·531	[·521]	·558	·524	·553	·586
−·037	4	·644	·626	·615	·590	·561	·568	·569	·577	·577	·576	·565	·571
−·034	5	·654	·662	·644	·622	·614	·606	·600	·592	·595	·591	·584	·581
−·030	6	·665	·672	·682	·661	·642	·618	·615	·612	·610	·603	·598	·591
−·027	7	·669	·672	·670	·656	·642	·628	·620	·622	·610	·596	·596	·584
−·024	8	·699	·706	·694	·667	·659	·640	·651	·649	·633	·630	·620	·621
−·021	9	·634	·651	·641	·634	·619	·585	·570	·582	·583	·573	·572	·575
−·018	10	·655	·648	·628	·597	·577	·547	[·503 ·442]	·537	·551	·531	·552	·542
−·014	11	·634	·638	·627	·611	·584	·581	·575	·571	·568	·564	·563	·572
−·011	12	·661	·660	·636	·618	·595	·574	·563	·555	·544	·550	·550	·544
−·008	13	·610	612	·607	·591	·583	·572	·549	·548	·534	·528	·533	·529
−·005	14	·686	·676	·651	·620	·581	·565	·570	·519	·550	·542	·541	·538
−·002	15	·650	·664	·640	·623	·607	·590	·570	·567	·562	·545	·565	·552
+·002	16	·662	·651	·622	·606	·592	·578	·571	·567	·563	·559	·560	·559
+·005	17	·660	·667	·654	·626	·598	·576	·560	·561	·566	·563	·564	·566
+·008	18	·670	·672	·653	·623	·600	·589	·580	·581	·578	·576	·574	·572
+·011	19	·651	·648	·638	·626	·609	·600	·597	·590	·578	·565	·548	·548
+·014	20	·650	·644	·626	·604	·586	·575	·576	·566	·560	·559	·556	·554
+·018	21	·599	·607	·595	·591	·608	·610	·576	·528	·533	·554	·555	·558
+·021	22	·544	·551	[·526 ·522]	[·503 ·485]	·525	·537	·528	·511	·482	·502	·510	·516
+·024	23	·567	·565	·560	·551	·549	·533	·526	·515	·510	·514	·515	·529
+·027	24	·591	·597	·588	·564	·539	·539	·535	·531	·528	·532	·534	·533
+·030	25	·593	·582	·569	·551	·531	·521	·516	·518	·524	·539	·542	·547
+·034	26	·617	·615	·602	·576	·550	·548	·551	·548	·545	·540	·541	·540
+·037	27	·646	·630	·611	·583	·548	·529	·533	·528	·530	·521	·526	·530
+·040	28	·625	·620	·604	·575	·564	·557	·563	·556	·543	·547	·544	·542
+·043	29	·656	·654	·626	·594	·571	·560	·550	·549	·559	·559	·548	·539
+·046	30	·563	[·516 ·515]	[·501 ·490]	·483	·486	·487	·489	·494	·490	·485	·481	·510
—	31	—	—	—	—	—	—	—	—	—	—	—	—
—	Sum *minus* 30·000	19·221	19·190	18·731	18·057	17·583	17·189	16·818	16·728	16·721	16·666	16·600	16·623
—	Mean	1·641	1·640	1·624	1·602	1·586	1·573	1·561	1·558	1·557	1·556	1·553	1·554
—	Final Normal	1·641	1·640	1·625	1·602	1·586	1·573	1·563	1·559	1·557	1·556	1·554	1·555
—	Variation	—	—	—	—	—	—	—	—	—	—	—	—

Increasing ordinates indicate increasing horizontal force.

Hourly Abstract of Tabulations (in Inches) of Horizontal Force Magnetograph.

22	23	0	1	2	3	4	5	6	7	8	9	Sum *minus* 24·000	Mean	Means for beginning and end of the month
1·570	1·583	1·575	1·583	1·593	1·593	1·604	1·606	1·622	1·647	1·673	1·690	15·332	1·639	1·631
[·518 ·502]	·536	·544	·560	·600	·572	·573	·568	·572	·585	·592	·610	13·888	·579	
·573	·566	·583	·584	·580	·582	·586	·588	·579	·575	·595	·628	13·814	·576	
·580	·588	·581	·588	·589	·581	·581	·590	·589	·600	·619	·636	14·161	·590	
·582	·578	·587	·589	·594	·598	·601	·597	·600	·605	·623	·648	14·547	·606	
·592	·597	·600	·597	·597	·598	·601	·605	·611	·622	·631	·660	14·880	·620	
·590	·597	·602	·602	·602	·598	·595	·602	·610	·622	·644	·663	14·892	·620	
·613	·620	·614	·599	·598	·594	·615	·609	·602	·606	·610	·618	15·167	·632	
·577	·582	·586	·587	·586	·595	·596	·623	·638	·647	·616	·650	14·502	·604	
·543	·553	·538	·439	·548	·564	·568	·560	·575	·597	·617	·624	13·633	·568	
·565	·569	·565	·564	·561	·560	·562	·563	·571	·596	·624	·643	14·031	·585	
·559	·572	·573	·593	·587	·586	·612	·620	·574	·588	·631	·646	14·191	·591	
·527	·522	·575	·536	·548	·550	·540	·534	·544	·576	·612	·662	13·522	·563	
·550	·555	·557	·546	·546	·553	·554	·551	·555	·576	·603	·625	13·810	·575	
·550	·551	·556	·563	·564	·563	·564	·566	·570	·588	·620	·647	14·037	·585	
·560	·563	·569	·570	·570	·572	·571	·571	·572	·589	·610	·639	14·046	·585	
·562	·564	·567	·569	·567	·567	·566	·569	·576	·602	·629	·652	14·151	·590	
·574	·571	·570	·571	·567	·564	·569	·574	·576	·591	·624	·646	14·265	·594	
·555	·564	·563	·566	·572	·563	·575	·565	·584	·598	·618	·632	14·153	·590	
·546	·557	·577	·570	·558	·573	·564	·565	·585	·591	·600	·612	13·954	·581	
·537	·599	·501	·504	·511	·522	·524	·538	·553	·575	·578	·573	13·429	·560	
·511	·510	·513	·513	·522	·518	·511	·511	·520	·526	·541	·565	12·474	·520	
·521	·520	·532	·522	·518	·517	·521	·534	·542	·551	·554	·571	12·837	·535	
·539	·533	·531	·524	·523	·521	·526	·533	·541	·555	·588	·601	13·126	·547	
·541	·533	·541	·533	·525	·525	·534	·530	·549	·568	·579	·598	13·089	·545	
·540	·537	·539	·539	·543	·557	·558	·563	·576	·597	·617	·634	13·573	·566	
·538	·536	·532	·534	·535	·539	·535	·541	·555	·571	·582	·605	13·318	·555	
·542	·543	·546	·546	·546	·551	·556	·560	·580	·605	·637	·648	13·700	·571	
·530	·536	·547	·530	·542	·543	·516	·536	·520	·528	·561	·550	13·404	·558	
·505	·500	·506	·507	·509	·512	·519	·526	·532	·541	·552	·562	12·244	·510	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	1·535
16·574	16·735	16·770	16·728	16·801	16·831	16·897	16·998	17·173	17·618	18·180	18·738	416·170	—	—·096= progressive increase in the month
1·552	1·558	1·559	1·558	1·560	1·561	1·563	1·567	1·572	1·587	1·606	1·625	13·873	1·578	
1·553	1·558	1·559	1·558	1·560	1·561	1·563	1·567	1·572	1·587	1·606	1·625	—	—	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table A (*continued forwards*).—*Government Observatory, Bombay, Month Horizontal*

Colaba Civil Hour	10	11	12	13	14	15	16	17	18	19	20	21
Date												
1	1·565	1·568	1·555	1·533	1·518	1·514	1·500	1·486	1·485	1·502	1·499	1·498
2	·586	·596	·567	·539	·526	·500	·497	·491	·486	·493	·477	·488
3	·581	·592	·624	·605	·553	·496	·470	·485	·510	·511	·516	·518
4	·589	·595	·593	·567	·547	·533	·527	·522	·515	·514	·510	·514
5	·573	·583	·564	·541	·520	·513	·516	·518	·520	·520	·518	·519
6	·602	·604	·599	·579	·562	·553	·573	·568	·576	·550	·509	·504
7	·569	·560	·525	·501	·474	·496	·480	·450	·460	·480	·473	·457
8	·570	·568	·551	·526	·521	·509	·494	·489	·489	·486	·480	·480
9	·515	·517	·516	·527	·526	·521	·511	·505	·488	·487	·496	·497
10	·523	·514	·514	·499	·497	·497	·501	·500	·501	·512	·505	·503
11	·515	·515	·522	·500	·497	·481	·489	·494	·489	·481	·485	·488
12	·542	·540	·530	·526	·513	·504	·503	·502	·495	·487	·485	·479
13	·564	·560	·551	·541	·530	·529	·513	·520	·508	·501	·495	·488
14	·540	·537	·512	·483	·473	·470	·460	·457	·469	·462	·456	·463

Table B.—*Government Observatory, Bombay, Month of November, Horizontal Force*

There are in the forms two columns for each hour; in the second are entered the 29-day sum (above), and the 29-day mean (below) for a given day; the first are checked by actual summation at the beginning and middle of each month, and these figures are entered in ink; the rest are entered in pencil only. In the first column are entered the number to be added to the 29-day sum of the preceding day and the number to be subtracted from it to obtain the 29-day sum of the day of the entries, and also the excess of the first entry over the second with its proper sign.

Bombay Civil Hour	10	11	12	13	14	15	16	17	18	19	20	21
Date												
1	·695	·700	·687	·665	·645	·626	·614	·611	·610	·606	·602	·602
2	·691	·696	·682	·660	·641	·622	·610	·607	·606	·602	·598	·598
3	·689	·693	·679	·657	·638	·619	·605	·602	·602	·597	·594	·594
4	·686	·689	·675	·653	·633	·615	·602	·599	·598	·594	·590	·590
5	·680	·684	·670	·649	·629	·611	·598	·595	·595	·590	·586	·586
6	·676	·679	·666	·645	·625	·607	·595	·591	·591	·586	·582	·582
7	·671	·674	·661	·640	·622	·604	·591	·586	·586	·582	·578	·579
8	·664	·667	·654	·633	·616	·599	·586	·581	·579	·576	·573	·574
9	·658	·661	·647	·627	·611	·596	·582	·576	·575	·572	·569	·572
10	·653	·657	·643	·623	·607	·592	·578	·572	·571	·570	·568	·570
11	·650	·653	·639	·619	·603	·588	·576	·571	·570	·568	·567	·567
12	·647	·649	·635	·615	·599	·585	·573	·568	·567	·566	·564	·565
13	·645	·646	·633	·611	·595	·582	·571	·566	·565	·563	·561	·562
14	·643	·644	·630	·609	·592	·579	·569	·563	·562	·560	·559	·559
15	·643	·644	·629	·607	·590	·576	·566	·561	·560	·558	·556	·556
16	·637	·636	·621	·599	·583	·570	·561	·556	·555	·553	·552	·553
17	·632	·631	·616	·595	·579	·568	·560	·555	·553	·551	·551	·553
18	·631	·630	·615	·594	·578	·566	·559	·553	·551	·550	·549	·549
19	·629	·629	·615	·594	·578	·564	·555	·550	·549	·547	·547	·547
20	·627	·627	·613	·592	·575	·561	·553	·548	·546	·545	·544	·545

of December, 1875. *Hourly Abstract of Tabulations (in Inches) of Force Magnetograph.*

22	23	0	1	2	3	4	5	6	7	8	9	Sum	Mean
1·503	1·507	1·512	1·512	1·502	1·499	1·504	1·508	1·517	1·536	1·554	1·525	—	—
·490	·500	·501	·501	·503	·504	·503	·507	·521	·532	·533	·579	—	—
·515	·517	·539	·522	·509	·513	·510	·515	·521	·529	·547	·566	—	—
·511	·514	·510	·508	·507	·508	·509	·513	·518	·527	·543	·555	—	—
·518	·516	·515	·516	·518	·522	·525	·532	·541	·563	·589	·592	—	—
·467	·451	·444	·444	·490	·479	·474	·486	·499	·530	·546	·561	—	—
·484	·477	·469	·478	·481	·485	·490	·494	·498	·516	·540	·559	—	—
·483	·486	·489	·483	·483	·480	·506	·503	·505	·508	·510	·518	—	—
·497	·504	·504	·503	·496	·493	·487	·501	·509	·504	·521	·519	—	—
·493	·498	·489	·487	·479	·479	·486	·494	·509	·520	·520	·514	—	—
·477	·479	·480	·483	·487	·492	·489	·493	·500	·515	·533	·544	—	—
·487	·492	·491	·491	·492	·492	·492	·498	·506	·532	·553	·557	—	—
·495	·490	·480	·493	·479	·470	·468	·476	·486	·500	·520	·540	—	—
·463	·463	·469	·465	·466	·464	·471	·481	·500	·520	·540	·556	—	—

1875. *Hourly Determinations of* 29-*day Means of each Hour. Magnetograph.*

The actual operation is to add this excess to the 29-day sum of the preceding day, and enter the result as the 29-day sum of the day of the entries. The 29-day sums are divided by 29 by means of a table of products of 29 into all the integers from 1 to 999, and the quotients are entered below as the 29-day means. The integer 1 in each number of Table A is thrown out of account in the construction of Table B, and this is kept in mind in taking the differences of Table C.

Bombay Civil Hour	22	23	0	1	2	3	4	5	6	7	8	9
Date												
1	·600	·605	·608	·608	·611	·611	·614	·616	·618	·631	·653	·676
2	·596	·601	·605	·605	·607	·608	·611	·612	·615	·628	·650	·674
3	·592	·597	·601	·601	·604	·604	·607	·608	·611	·625	·647	·670
4	·589	·594	·598	·598	·600	·600	·603	·605	·607	·621	·643	·666
5	·585	·590	·594	·594	·597	·597	·600	·601	·604	·619	·640	·662
6	·581	·587	·591	·591	·593	·594	·597	·598	·601	·615	·635	·657
7	·577	·584	·585	·585	·588	·589	·592	·593	·597	·612	·631	·651
8	·572	·579	·580	·580	·583	·584	·586	·587	·592	·606	·625	·645
9	·570	·576	·577	·577	·579	·580	·582	·584	·589	·602	·620	·640
10	·568	·573	·574	·574	·577	·577	·579	·582	·586	·600	·618	·638
11	·566	·571	·572	·571	·573	·573	·576	·579	·583	·597	·615	·635
12	·563	·568	·569	·568	·570	·571	·574	·576	.582	·596	·614	·634
13	·560	·565	·566	·565	·567	·568	·571	·574	·579	·594	·612	·632
14	·558	·563	·564	·563	·565	·566	·569	·572	·578	·594	·612	·632
15	·555	·560	·561	·559	·562	·563	·565	·568	·574	·589	·608	·627
16	·552	·557	·558	·557	·559	·560	·562	·565	·571	·585	·604	·622
17	·552	·556	·557	·555	·556	·557	·559	·563	·569	·584	·602	·619
18	·549	·554	·555	·552	·553	·555	·557	·560	·567	·582	·600	·618
19	·547	·551	·553	·550	·550	·552	·554	·558	·564	·580	·598	·615
20	·544	·549	·550	·547	·547	·549	·551	·555	·562	·577	·595	·612

TABLE B (*continued*).—*Government Observatory, Bombay, Month of Horizontal Force*

Bombay Civil Hour	10	11	12	13	14	15	16	17	18	19	20	21
Date												
21	·624	·623	·609	·588	·571	·558	·549	·545	·543	·542	·542	·543
22	·621	·621	·607	·586	·569	·555	·548	·543	·542	·540	·539	·540
23	·617	·616	·601	·580	·562	·550	·542	·536	·536	·535	·534	·534
24	·615	·613	·598	·576	·559	·548	·539	·533	·532	·532	·530	·531
25	·610	·609	·594	·574	·557	·547	·540	·532	·530	·531	·529	·529
26	·606	·604	·590	·570	·554	·544	·537	·529	·528	·529	·527	·527
27	·601	·599	·586	·566	·551	·541	·534	·527	·526	·526	·524	·525
28	·599	·597	·584	·564	·548	·538	·533	·525	·525	·525	·523	·523
29	·594	·593	·580	·561	·546	·537	·531	·526	·523	·524	·521	·522
30	·591	·589	·576	·556	·542	·533	·527	·522	·520	·521	·517	·519

TABLE C.—*Government Observatory, Bombay, Month of November*, 1875. *Magnetograph*

Days after New Moon	Bombay Civil Hour	10	11	12	13	14	15	1	17	18	19	20	21
	Date												
4	1	·145	·147	·142	·138	·139	·137	·125	·129	·126	·112	·098	·092
5	2	·121	·125	·118	·096	·071	·044	·018	·017	·016	·078	·021	·022
6	3	·025	·024	·028	·013	·029	·028	·026	·019	·056	·027	·059	·092
7	4	·058	·037	·040	·037	·028	·053	·067	·078	·079	·082	·075	·081
8	5	·074	·078	·074	·073	·085	·095	·102	·097	·100	·101	·098	·095
9	6	·089	·093	·116	·116	·117	·111	·120	·121	·119	·117	·116	·109
10	7	·098	·098	·109	·116	·120	·124	·129	·136	·124	·114	·118	·105
11	8	·135	·139	·140	·134	·143	·141	·165	·168	·154	·154	·147	·147
12	9	·076	·090	·094	·107	·108	·089	·088	·106	·108	·101	·103	·103
13	10	·102	·091	·085	·074	·070	·055	·025	·065	·080	·061	·084	·072
14	11	·084	·085	·088	·092	·081	·093	·099	·100	·098	·096	096	·105
15	12	·114	·111	·101	·103	·096	·089	·090	·087	·077	·084	·086	·079
16	13	·065	·066	·074	·080	·088	·090	·078	·082	·069	·065	·072	·067
17	14	·143	·132	·121	·111	·089	·086	·101	·056	·088	·082	·082	·079
18	15	·107	·120	·111	·116	·117	·114	·104	·106	·102	·087	·109	·096
19	16	·125	·115	·101	·107	·109	·108	·110	·111	·108	·106	·108	·106
20	17	·128	·136	·138	·131	·119	·108	·100	·106	·113	·112	·113	·113
21	18	·139	·142	·138	·129	·122	·123	·121	·128	·127	·126	·125	·123
22	19	·122	·119	·123	·132	·131	·136	·142	·140	·129	·118	·101	·101
23	20	·123	·117	·113	·112	·111	·114	·123	·118	·114	·114	·112	·109
24	21	·075	·084	·086	·103	·137	·152	·127	·083	·090	·112	·113	·115
25	22	·023	·030	·019	·017	·056	·082	·080	·068	·040	·062	·071	·076
26	23	·050	·049	·059	·071	·087	·083	·084	·079	·074	·079	·081	·095
27	24	·076	·084	·090	·088	·080	·091	·096	·098	·096	·100	·104	·102
28	25	·083	·073	·075	·077	·074	·074	·076	·086	·094	·108	·113	·118
29	26	·111	·111	·112	·106	·096	·104	·114	·119	·117	·111	·114	·113
30	27	·145	·131	·125	·117	·097	·088	·099	·101	·104	·095	·102	·105
1	28	·126	·123	·120	·111	·116	·119	·130	·131	·118	·122	·121	·119
2	29	·162	·161	·146	·133	·125	·123	·119	·123	·136	·135	·127	·117
3	30	·072	·027	·025	·027	·044	·054	·062	·072	·070	·064	·064	·091

November 1875. *Hourly Determinations of* 29-*day Means of each Hour. Magnetograph.*

Bombay Civil Hour	22	23	0	1	2	3	4	5	6	7	8	9
Date												
21	·542	·546	·547	·544	·544	·547	·548	·552	·559	·575	·594	·610
22	·538	·541	·542	·539	·541	·543	·544	·548	·555	·572	·590	·606
23	·533	·536	·537	·535	·536	·539	·540	·544	·552	·569	·588	·604
24	·530	·533	·534	·531	·533	·535	·537	·540	·547	·564	·584	·600
25	·528	·531	·533	·530	·531	·532	·534	·538	·545	·561	·581	·596
26	·526	·529	·530	·527	·528	·530	·531	·536	·543	·558	·577	·592
27	·523	·526	·527	·523	·525	·526	·527	·531	·540	·555	·574	·588
28	·522	·525	·524	·522	·523	·524	·525	·530	·539	·554	·572	·584
29	·520	·522	·521	·520	·521	·521	·522	·528	·537	·551	·569	·582
30	·517	·519	·518	·517	·517	·518	·519	·525	·534	·549	·566	·578

Hourly Abstract of Differences from 29-*day Means of Horizontal Force* A − B + ·100 *Inch.*

22	23	0	1	2	3	4	5	6	7	8	9
·070	·078	·067	·075	·082	·082	·090	·090	·104	·116	·120	·114
·022	·035	·039	·055	·093	·064	·062	·056	·057	·057	·042	·036
·081	·069	·082	·083	·076	·078	·079	·080	·068	·050	·048	·058
·091	·094	·083	·090	·089	·081	·078	·085	·082	·079	·076	·070
·097	·088	·093	·095	·097	·101	·101	·096	·096	·086	·083	·086
·111	·110	·109	·106	·104	·104	·104	·107	·110	·107	·096	·103
·113	·113	·117	·117	·114	·109	·103	·109	·113	·110	·113	·112
·141	·141	·134	·119	·115	·110	·129	·122	·110	·100	·085	·073
·107	·106	·109	·110	·107	·115	·114	·139	·149	·145	·096	·110
·075	·080	·064	·065	·071	·087	·089	·078	·089	·097	·099	·086
·099	·098	·093	·093	·088	·087	·086	·084	·088	·099	·109	·108
·096	·104	·104	·125	·117	·115	·138	·144	·092	·092	·117	·112
·067	·057	·109	·071	·081	·082	·069	·060	·065	·082	·100	·130
·092	·092	·093	·083	·081	·087	·085	·079	·077	·082	·091	·093
·095	·091	·095	·104	·102	·100	·099	·098	·096	·099	·112	·120
·108	·106	·111	·113	·111	·112	·109	·106	·101	·104	·106	·117
·110	·108	·110	·114	·111	·110	·107	·106	·107	·118	·127	·133
·125	·117	·115	·119	·114	·109	·112	·114	·109	·109	·124	·128
·108	·113	·110	·116	·122	·111	·121	·107	·120	·118	·120	·117
·102	·108	·127	·123	·111	·124	·113	·110	·123	·114	·105	·100
·095	·153	·054	·060	·067	·075	·076	·086	·094	·100	·084	·063
·073	·069	·071	·074	·081	·075	·067	·063	·065	·054	·051	·059
·088	·084	·095	·087	·082	·078	·081	·090	·090	·082	·066	·067
·109	·100	·097	·093	·090	·086	·089	·093	·094	·091	·104	·101
·113	·102	·108	·103	·094	·093	·100	·092	·104	·107	·098	·102
·114	·108	·109	·112	·115	·127	·127	·127	·133	·139	·140	·142
·115	·110	·105	·111	·110	·113	·108	·110	·115	·116	·108	·117
·120	·118	·122	·124	·123	·127	·131	·130	·141	·151	·165	·164
·110	·114	·126	·110	·121	·122	·094	·108	·083	·077	·092	·068
·088	·081	·088	·090	·092	·094	·100	·101	·098	·092	·086	·084

Horizontal Force-Calculation of the Excess Solar-Diurnal Variation for

Days after New Moon		10	11	12	13	14	15	16	17	18	19	20
Phase (4)	14	·0850	·0893	·0960	·0960	·0967	·1020	·1113	·1143	·1087	·1027	·1000
	15	·1140	·1127	·1090	·1043	·1010	·1010	·1050	·1060	·1017	·1017	·1040
	16	·1037	·1023	·1013	·1003	·1003	·1033	·1033	·1127	·1050	·1053	·1090
	17	·1380	·1330	·1217	·1117	·1043	·1030	·1050	·0893	·1020	·0967	·0987
	Sum	·4407	·4373	·4280	·4123	·4023	·4093	·4246	·4223	·4174	·4064	·4117
	Mean	·1104	·1093	·1070	·1031	·1006	·1023	·1061	·1056	·1043	·1016	·1029

Horizontal Force-Calculation of the Luni-Solar

Phase (*o*) . .	·1104	·1059	·1052	·1006	·0911	·0920	·0961	·0978	·0990	·1007	·1009
Phase (4) . .	·1104	·1093	·1070	·1031	·1006	·1023	·1061	·1056	·1043	·1016	·1029
Sum = a . . .	·2208	·2152	·2122	·2037	·1917	·1943	·2022	·2034	·2033	·2023	·2038
Phase (2) . .	·0920	·0972	·1057	·1012	·0988	·0963	·0957	·0962	·1021	·0961	·0959
Phase (6) . .	·0937	·0940	·0977	·1031	·1047	·1055	·1054	·0990	·1033	·1076	·1041
Sum = (b) . .	·1857	·1912	·2034	·2043	·2035	·2018	·2011	·1952	·2054	·2037	·2000
$a-b$	+ ·0351	+ ·0240	+ ·0088	− ·0006	− ·0118	− ·0075	+ ·0011	+ ·0082	− ·0021	− ·0014	+ ·0038
$\frac{a-b}{4}$	+ ·0088	+ ·0060	+ ·0022	− ·0001	− ·0029	− ·0019	+ ·0003	+ ·0020	− ·0005	− ·0003	+ ·0009
[1] $\frac{a-b}{4} \times$ ·0427 .	+·00038	+·00026	+·00009	·00000	−·00012	−·00008	+·00001	+·00009	−·00002	−·00001	+·00004
Variatn. = $f_{c\cdot 2}(h)$	+·00025	+·00013	−·00004	−·00013	−·00025	−·00021	−·00012	−·00004	−·00015	−·00014	−·00009
Phase (1) . .	·1121	·1128	·1074	·1009	·1036	·0986	·0922	·0922	·0911	·0964	·0889
Phase (5) . .	·1138	·1112	·1057	·1090	·1061	·0981	·0973	·0979	·0983	·0883	·0889
Sum = a' . .	·2259	·2240	·2131	·2099	·2097	·1967	·1895	·1901	·1894	·1847	·1778
Phase (3) . .	·0906	·0899	·0916	·0939	·0968	·1019	·1028	·1068	·1031	·1026	·1060
Phase (7) . .	·0788	·0783	·0736	·0791	·0896	·0927	·0915	·0937	·0875	·0941	·0974
Sum = b' . . .	·1694	·1682	·1652	·1730	·1864	·1946	·1943	·2005	·1906	·1967	·2034
$a'-b'$ . . .	+ ·0565	+ ·0558	+ ·0479	+ ·0369	+ ·0233	+ ·0021	− ·0048	− ·0104	− ·0012	− ·0120	− ·0256
$\frac{a'-b'}{4}$ . . .	+ ·0141	+ ·0139	+ ·0120	+ ·0092	+ ·0058	+ ·0005	− ·0012	− ·0026	− ·0003	− ·0030	− ·0064
[1] $\frac{a'-b'}{4} \times$ ·0427 .	+·00060	+·00059	+·00051	+·00039	+·00025	+·00002	−·00005	−·00011	−·00001	−·00013	−·00027
Variatn. = $f_{s.2}(h)$	+·00056	+·00055	+·00047	+00035	+·00021	−·00002	−·00009	−·00015	−·00005	−·00017	−·00031

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[1] An ordinate of 1 inch corresponds to ·0427 m.g.s. unit of force.

the (*4th*) *Phase of a Lunation*, i.e., *for Full Moon*. *Nov.* 1875 *to Jan.* 1876.

21	22	23	0	1	2	3	4	5	6	7	8	9
·0993	·0930	·0947	·0940	·0940	·0957	·0977	·0987	·0983	·1017	·1037	·1100	·1117
·1017	·1050	·1093	·1090	·1133	·1130	·1133	·1220	·1233	·1057	·1107	·1190	·1150
·1063	·1060	·1007	·1140	·1030	·1023	·0983	·0930	·0907	·0947	·1033	·1137	·1343
·0997	·1023	·1043	·1110	·1050	·1033	·1033	·1100	·1080	·1110	·1220	·1237	·1277
·4070	·4063	·4090	·4280	·4153	·4143	·4126	·4237	·4203	·4131	·4397	·4664	·4887
·1017	·1016	·1022	·1070	·1038	·1036	·1031	·1059	·1051	·1033	·1099	·1166	·1222

Diurnal Variations $f_{c\cdot2}(h)$ *and* $f'_{s\cdot2}(h)$. *Nov.* 1875 *to Jan.* 1876.

·1008	·1067	·1059	·1041	·1011	·1074	·1072	·1042	·1058	·1037	·1089	·1157	·1161
·1017	·1016	·1022	·1070	·1038	·1036	·1031	·1059	·1051	·1033	·1099	·1166	·1222
·2025	·2083	·2081	·2111	·2049	·2110	·2103	·2101	·2109	·2070	·2188	·2323	·2383
·0977	·0941	·0903	·0946	·0947	·0991	·0980	·0988	·1011	·0986	·0961	·0915	·0918
·1020	·0990	·1059	·1015	·1013	·0986	·0984	·1002	·0990	·1020	·1002	·0945	·0912
·1997	·1931	·1962	·1961	·1960	·1977	·1964	·1990	·2001	·2006	·1963	·1860	·1830
+ ·0028	+ ·0152	+ ·0119	+ ·0150	+ ·0089	+ ·0133	+ ·0139	+ ·0111	+ ·0108	+ ·0064	+ ·0225	+ ·0463	+ ·0553
+ ·0007	+ ·0038	+ ·0030	+ ·0037	+ ·0022	+ ·0033	+ ·0035	+ ·0028	+ ·0027	+ ·0016	+ ·0056	+ ·0116	+ ·0138
+·00003	+·00016	+·00013	+·00016	+·00009	+·00014	+·00015	+·00012	+·00012	+·00007	+·00024	+·00050	+·00059
−·00010	+·00003	·00000	+·00003	−·00004	+·00001	+·00002	−·00001	+·00001	−·00006	+·00011	+·00037	+·00046
·0894	·0887	·0902	·0951	·0973	·0999	·0953	·0952	·0975	·0978	·0977	·0950	·0937
·0951	·0937	·1011	·0885	·0909	·0960	·1004	·0930	·0862	·0887	·0800	·0929	·0970
·1845	·1824	·1913	·1836	·1882	·1959	·1957	·1882	·1837	·1865	·1777	·1879	·1907
·1034	·1058	·1068	·1049	·1028	·1001	·0996	·1017	·1037	·1041	·1014	·0917	·0890
·0947	·0993	·0896	·0904	·0963	·0878	·0879	·0902	·0911	·0929	·0952	·0927	·0927
·1981	·2051	·1964	·1953	·1991	·1879	·1875	·1919	·1948	·1970	·1966	·1844	·1817
− ·0136	− ·0227	− ·0051	− ·0117	− ·0109	+ ·0080	+ ·0082	− ·0037	− ·0111	− ·0105	− ·0189	+ ·0035	+ ·0090
− ·0034	− ·0057	− ·0013	− ·0029	− ·0027	+ ·0020	+ ·0020	− ·0009	− ·0028	− ·0026	− ·0047	+ ·0009	+ ·0022
−·00015	−·00024	−·00006	−·00012	−·00012	+·00009	+·00009	−·00004	−·00012	−·00011	−·00020	+·00004	+·00009
−·00019	−·00028	−·00010	−·00016	−·00016	+·00005	+·00005	−·00008	−·00016	−·00015	−·00024	·00000	+·00005

X. *The Advantages to the Science of Terrestrial Magnetism to be obtained from an expedition to the region within the Antarctic Circle.* *By* Staff Commander ETTRICK W. CREAK, *R.N., F.R.S.*

In Gauss's paper on the general theory of magnetism, published in England in 1839, will be found the following conclusions:—

(1) 'It is clear that the knowledge of Y (or the component of the horizontal magnetic force directed towards the west) on the whole earth, combined with the knowledge of X (or the component of the horizontal force towards the north) at all points of a line running from one pole of the earth to the other, is sufficient for the foundation of the *complete* theory of the magnetism of the earth.'

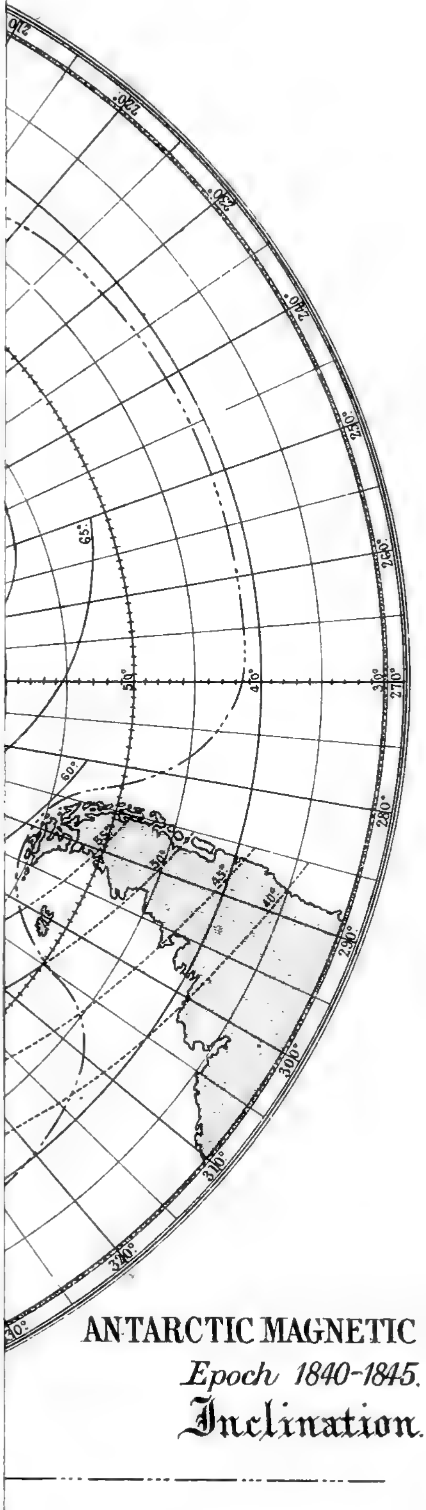
(2) 'Finally it is clear that the complete theory is also deducible from the simple knowledge of the value of Z (or the component of the magnetic force directed towards the centre of the earth) on the whole surface of the earth.'

Accepting these conclusions as thoroughly sound, and in no measure altered since they were written by other investigators, let us now inquire into the question how far are we prepared by observation of the earth's magnetism for a calculation of this kind. Thanks to the activity of observers in many lands and over many seas during the years 1865–85, we have been supplied with the necessary observations, which have been utilised for compiling charts on a large scale of the normal values of the declination, horizontal force, and vertical force for the epoch 1880 from which the values of X, Y, Z may readily be obtained for a large portion of the earth's surface.

These elements for the zone contained between the parallels of 60° N. and 50° S. are (except for some portions of Northern Asia and Central Africa) accurate; from 60° to 70° north latitude and 50° to 60° south latitude they are less accurate. North of the parallel of 70° N. and south of 60° S. are two portions of the earth of which our knowledge is far more limited; but whilst we have had comparatively recent observations in Arctic regions, nearly the whole of the Antarctic regions have remained unvisited for magnetic purposes since the memorable survey conducted by the late Sir James Ross in 1840–43, so that the charts are correspondingly weak in those latitudes.

A reference to the accompanying map shows that the *Challenger*, whilst on her voyage from the Cape of Good Hope to Melbourne, crossed the Antarctic circle about the meridian of 79° E. The magnetic observations during that period combined with those made at Sandy Point, Magellan Strait, since 1868, and some declination observations recently made in the South Pacific between New Zealand and Cape Horn in latitudes between 50° and 60° S. give ample evidence that considerable change of the magnetic elements has occurred since Ross's voyage. Of the extent of these changes our information is so limited that the old survey is of but little use in enabling us to complete the charts of 1880 with the requisite amount of accuracy, and therefore the X, Y, Z required for Gauss's method of theoretical investigation are still wanting.

Although it is true that Gauss has shown the method by which mathematicians may, from an accurate knowledge of the magnetic elements over an extended area in both hemispheres, calculate, nearly, those of the remaining portions, yet supposing this to have been done—and it



ANTARCTIC MAGNETIC SURVEY,
Epoch 1840-1845.
Inclination.

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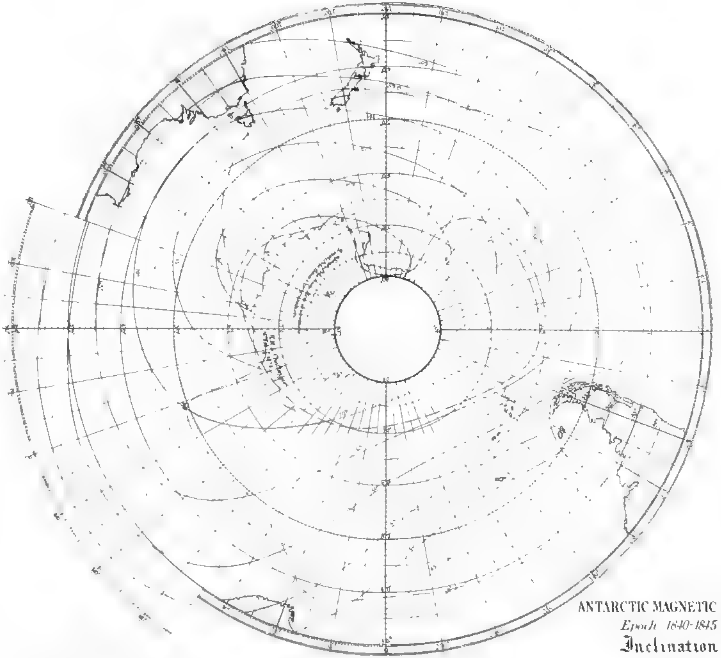

ANTARCTIC MAGNETIC SURVEY.

Epoch 1840-1845

Inclination

Southerly limit of observations since Ross's Voyage, and Antarctic Survey, 1840-45.

Southerly limit of Ross's Voyage, and Antarctic Survey, 1840-45.

Illustrating Report on the best means of Comparing & Reducing Magnetic Observations is a work of considerable labour—the results would hardly be accepted as final until observation had done its work in every navigable sea and on every shore open to the explorer, in proof of the theoretical results.

It has already been remarked that we know far more of the earth's magnetism from observation in Arctic regions, where the approximate position of the north magnetic pole has been determined, than in the Antarctic regions where the position of the south magnetic pole is yet indeterminate. Thus it appears that great advantage to the science of terrestrial magnetism would be derived from a new magnetic survey of the southern hemisphere extending from the parallel of 40° S. as far towards the geographical pole as possible.

For carrying out such a survey we have many advantages over our predecessors in the *Erebus* and *Terror*, besides the benefit of their experience. At Melbourne there is a magnetic observatory equipped with all the most modern apparatus which would form an admirable base station, whilst subsidiary base stations might be formed at the Cape Observatory, and Sandy Point, Magellan Strait, for the use of the portable absolute instruments. The survey, too, must in a great measure again be carried out on board ship at sea, and here we have a powerful aid in steam which would enable an observer in calms and moderate weather to obtain excellent results by the process of swinging the ship. The observations at sea might be accompanied with considerable advantage by observations made with the portable absolute instruments on ice as frequently as possible. Ice is specially mentioned as being free from the local magnetic disturbance which is common in islands and on rocky shores of igneous formation.

But the valuable aid of steam, which enables the seaman and observer to handle his vessel with ease and precision, involves a large increase of iron in the ship in the form of engines, boilers, &c., and a corresponding increase of trouble to the magnetician. Those who have read Sabine's detailed account of the errors of the compass, due to iron in the ships *Erebus* and *Terror*, will have found that the deviation of 3° or 4° in the compass at Hobart Town became 50° in the high southern latitudes, which must have all but annihilated the earth's directive force on certain courses and rendered the compass useless.

Experience derived from the magnetic results of H.M.S. *Challenger* and other ships of the Royal Navy points to a means of avoiding much of this difficulty, as well as to the selection of a suitable vessel, and above all to a proper position on board—considered magnetically—for the instruments. The importance of this latter point will be appreciated when it is remembered that the errors of the observed magnetic elements due to the direction of the ship's head can generally be eliminated by swinging the ship, whilst those proceeding from vertical magnetic forces are constant for every direction of the ship's head when upright—variable when she is inclined at different angles of heel, and requiring frequent references to a base station to ascertain their amount.

On all accounts, therefore, it is necessary that directly a vessel is selected for a magnetic survey, positions for the compasses and relative magnetic instruments used at sea should be determined after careful experiment, and all iron within 30 feet of them removed if possible.

Subject to these precautions, a magnetic survey of the Antarctic seas might be made with satisfactory precision and great advantage to the science of terrestrial magnetism.

First Report on our Experimental Knowledge of the Properties of Matter with respect to Volume, Pressure, Temperature, and Specific Heat. *By* P. T. MAIN, *M.A.*

Relation of Pressure to Volume; Gases—Regnault's Investigations, and General Results.

BEFORE Regnault published his 'Mémoires' attempts had been made without success to detect deviations from the relation of pressure to volume required by Boyle's law. In his sixth mémoire[1] of tome xxi. Regnault describes in detail his arrangement for testing the accuracy of Boyle's law for atmospheric air, and for the gases nitrogen, carbon dioxide, and hydrogen. At a large number of pressures ranging from that of a single atmosphere to that of about thirty atmospheres experiments were made of the following kind: a manometer, at the middle of which was etched a mark which divided it into (almost) exactly equal volumes, as known by the weights of its contents of mercury, was filled at a given exactly known temperature and pressure with atmospheric air, or the gas to be examined; the pressure was then increased until the mercury was forced up to the manometer tube, so that the top of the meniscus was seen, by the cathetometer, to be just touched by the mark on the middle of the manometer tube, the length of which was about 3 metres; the pressure was then again recorded, and the ratio of the former to the latter pressure calculated. If in all cases Boyle's law applied with accuracy the ratio would always be 2 to 1. But it was found for the gases mentioned that this was never accurately the case, and that the deviation from this ratio was greater the greater the original pressure, and that air and nitrogen under these conditions up to 30 atmospheres were always *more* compressible than Boyle's law required, but that for hydrogen the compressibility was always *less* than Boyle's law required, and that the deviations from Boyle's law were always greater the greater the original pressure up to 30 atmos.

For example, in the case of *nitrogen* the ratio of vp for the original and for the doubled pressure (which should be 1, if Boyle's law applied exactly) was

	1·001012 for original pressure	753·96 mm.
and	1·006784 „ „	10978·20 „

the temperature being constant (4° to 5°) in each case.

Again, for *carbon dioxide* the ratio was

at 3·08°	1·007597 for original pressure	764·03 mm.
and, at 2·7°	1·153681 „ „	9612·39 „

But for hydrogen the ratio was

at 4·4°	0·998584 for original pressure,	969·19 mm.
and, at 8·95°	0·994460 „ „	1183·06 „

In all three cases we notice that the deviation from Boyle's law is greater the greater the pressure; the deviation is much greater for carbon dioxide than for the other two gases; for hydrogen the compressibility is less, for the others greater, than if Boyle's law were accurate. These

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[1] *Mémoires de l'Académie*, t. xxi.

results of Regnault's work have been confirmed by his successors within the same range of pressure.

In tome xxvi. of the Mémoires, Regnault, in the third part of the first mémoire of the volume, determines the variations of vp for pressures from about one atmo up to not more than eight atmos for atmospheric air and for carbon dioxide again; and for oxygen, nitrous oxide, nitric oxide, carbon monoxide, marsh-gas, cyanogen, ammonia, hydrochloric acid, hydrogen sulphide, sulphur dioxide. The variations of vp for atmospheric air and for carbon dioxide agreed very well with the values obtained up to 8 atmos in the former set of experiments; and this agreement is a guarantee of the general accuracy of the results for the other gases, the gas in each case being tested and found pure and experimented on at some fixed temperature lower than 10°.

The deviations from Boyle's law were in all these cases found to be in direction of greater compressibility. It should be mentioned that the dates of publication of these two sets of mémoires of Regnault were 1847 and 1862.

The volumes, in each case, occupied by the gas at different pressures were known by the weight of mercury corresponding to the part of the manometer-tube occupied by the gas, and the pressure by the vertical height of mercury supported by the gas, this height being corrected for standard pressure and density of mercury: for Regnault found by special experiments that mercury is compressible, and the density which at 0° is 13·596 is at higher temperatures less, according to the rate of absolute expansion of mercury. The results of these investigations are given in the fifth and seventh mémoires of tome xxi.; at p. 328 there is a list of absolute dilatations of mercury between 0° and T°, where T is 10°, 20°, or any multiple of 10° up to 350°; the total dilatation for

0° to 10° being ·001792 for 1 volume at 0°
0° „ 350° „ ·065743 „ „

and the compressibility of mercury *per atmosphere* was investigated and found (p. 462) to be ·00000352, and for this corrections have to be applied throughout the height of the column of mercury. It will be noticed however that for pressures of not more than 30 atmospheres the correction due to this is inappreciable, and will in fact be drowned in inevitable or unavoided sources of error. The constant temperature of the gas in the manometer was always secured by surrounding it with a jacket through which a current of water of constant temperature was passing constantly.

Regnault, as Debray pointed out (see Ditte's 'Propriétés générales des corps,' p. 17), omitted from his calculations the weight of the compressed gas in the manometer, which being added increases the apparent pressure of the gas, the increase in Regnault's tables being due to the weight of a column of about 2 metres of the gas: a small correction is due to Regnault's numbers on this account.

Among the data required for the determination of the values of pv mention must not be omitted of the atmospheric pressure which must be reckoned and added to the pressure of the column of mercury.

This outline must suffice to give some notion of the precautions taken to avoid error, and the pains taken to secure an accurate determination of all the data required in these investigations, in which Regnault obtained for many gases up to eight atmospheres, and for a few up to thirty, the actual relations of pressure and volume, and the extent to which in each gas Boyle's law is found to be, though approximately true for small variations of pressure, deviated from more and more as the pressure is increased ('Mémoires de l'Académie,' t. xxvi.).

Some of the gases which Regnault selected were liquefied at the temperature of the experiment by pressure alone, and in these cases it was noticed that drops of liquid condensed on the mercury and on the glass, and that while this was taking place quite a considerable diminution of volume was brought about by a small and gradual increase of pressure (p. 261). The liquefaction of these gases—viz., H_2S, SO_2, C_2N_2, NH_3, CO_2, and of chlorine and hydrogen chloride—was known, having been effected by Faraday many years before.[1]

Andrews has shown[2] that a body in the gaseous state may be brought to the liquid state by a continuous process, in which it is impossible to notice any precise point at which the gas becomes liquid, the deviations from Boyle's law, which are hardly noticeable at first, being gradually increased till the relation between pressure and volume is not even approximately represented by this law, the gas becoming on still continued pressure less and less compressible, so as to finally be undistinguishable in this respect from a liquid. It was thus shown incidentally in the course of Andrews' experiments that for high pressures the gases examined became less compressible the greater the pressure, a phenomenon which was observed by Regnault for hydrogen only, but not for the other gases at the pressures to which he subjected them, *i.e.* up to 30 atmospheres.

Before Andrews, Natterer had made experiments extending over a long time—his published papers dating from 1844 to 1856—with the object of liquefying and solidifying gases by great pressures, and he found that up to 2790 atmospheres the gases hydrogen, oxygen, nitrogen, nitric oxide, as well as atmospheric air, beyond 100 atmospheres, were all notably less compressible than Boyle's law required.[3-5] The general result of the effect of pressure on volume in the case of gases at ordinary temperatures as given by Regnault and by Natterer made it desirable to investigate this relation with all the accuracy attainable for a range of pressures much greater than Regnault had been able to measure with sufficient accuracy.

Amagat's Investigations on Relation of Pressure to Volume in Gases.

Amagat in the year 1880 published a paper, the first of a series, in which he examined air, hydrogen, oxygen, carbon monoxide, marsh-gas, and ethylene as to their behaviour at given temperature at various pressures up to 400 atmospheres or beyond.[6]

In these investigations Amagat obtained his greatest pressures by the height of a column of mercury in narrow flexible steel tubes attached to the side of a shaft of a mine of some hundreds of metres in depth.

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[1] *Phil. Trans.* 1823, pp. 160, 189.

[2] *Phil. Trans.* 1869, Part II. p. 575.

[3] Poggendorff's *Annalen*, lxii. 1844, p. 132, and Liebig's *Ann.* liv. 1845 p. 254.

[4] *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften zu Wien*, v. 1850, p. 351; vii. 1851, p. 557; xii. 1854, p. 199.

[5] Poggendorff's *Annalen*, xciv. 1855, p. 436.

[6] *Annales de Chimie et de Physique*, 1880 (5), xix. p. 345; 1881 (5), xxii. p. 353; 1883 (5), xxviii. pp. 456, 480, 501.

The principle of the measurement of pressures was the same, therefore, as that used by Regnault.

Various devices have been used by Cailletet for applying and measuring increased pressures; and Amagat suggests a plan which might be adopted, and by which the experiments might be extended to vastly increased pressures—namely, having, *e.g.*, determined the law of compressibility by a vertical height of 76 metres of mercury up to 100 atmos pressure, we may extend it up to 200 atmos by exerting on the top of the column pressures up to 100 atmos. But Amagat prefers the direct method, and applies it up to 430 atmos; though for the purpose of extending the results to still higher pressures he has[1] all the apparatus necessary.

One most striking fact which results from Amagat's observations—and it is so uniformly true for the gases which he used and for all the temperatures at which he experimented, and whether the gas was or was not liquefied in the course of compression, that it has the appearance of being a natural law—is that for each gas beyond a certain pressure the law of compressibility is more and more nearly represented by the equation—

$$p\ (v-a)=b,$$

where a and b are constant for a given substance at a given temperature; and a varies but slightly for the same substances at different temperatures.

The curves by which the results are represented[2] have for abscissæ the values of p in metres, and for ordinates the values of pv; and for above 180 metres the curve becomes almost straight.

In the case of the gases liquefied (as, *e.g.*, CO_2 at 18°, one of the temperatures of the experiments), as also of gases which, though not liquefied, were compressed near their critical points (*e.g.*, ethylene), the only *regular* part of the curve is that at high pressure, which is nearly straight.

For hydrogen the relation between pv and p is represented on the diagram by a straight line for all except the very lowest pressures. The temperatures for which Amagat obtained curves of relation of vp to p were temperatures at intervals between about 15° and 100°, giving from 4 to 10 curves for each gas.

So far we have said nothing of experiments made as to relation of volume to pressure where the pressures are less than 760 mm., and especially when they are very small. Special investigations with this object were undertaken by Siljeström ('Pog. Ann.' 1874); by Mendeleeff with others ('Ann. Chim.' (5) ii. 1874, and (5) ix. 1876; also 'Nature,' x. 1876–7); and by Amagat ('Ann. Chim.' (5) viii. 1876; and (5) xxviii. 1883).

Experiments on Relation between Pressure and Volume of Gases at Pressures below 1 *Atmo.*

Mendeleeff and Siljeström come to the conclusion that for small pressures the compressibility is less than Boyle's law requires, and that the limiting condition of a gas is that in which the density is *nil* and the pressure finite ('Ann. de Chim. et de Phys.' 5, xxviii. p. 482).

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[1] *Annales de Chimie et de Physique* (5), xix. 1880, p. 348.

[2] *Ibid.* (5), 1881, p. 22

Amagat, on the other hand, finds the deviations from Boyle's law at low pressures sometimes positive, sometimes negative, and all within the limits of error of observation—in other words, he does not detect any deviations from Boyle's law for initial pressures under 370 mm.; any such deviations, if they occur, being unrecognisable at such small pressures.

There is, Amagat says,[1] no appearance of any sudden change in the law of compressibility of gases at the smallest pressures to which they have been submitted; it is therefore, he says, well to continue to apply Boyle's law to gases down to pressures of a few millimetres.

As to the cause of difference between his own results and those of Siljeström and Mendeleeff he suggests that—at least for Mendeleeff—the method of experimenting was favourable to giving prominence to a source of constant error, such as a slight defect in the barometric vacuum, p. 497.

In 1884 Krajewitsch[2] attacked this question of compressibility of air at small pressures, from 11·64 to 0·28 mm., with the general conclusion that the compressibility diminishes with increasing pressure up to 11·64 mm.; and he remarks that though his results are not accurate quantitatively, there is no doubt of the qualitative result as substantiating the conclusion he draws.

The following results of observation are given in his paper:—

	mm.			
For p=	11·636	he finds	pv=	108
,,	8·385	,,	,,	96
,,	4·113	,,	,,	77
,,	2·646	,,	,,	58
,,	1·947	,,	,,	46
and so on down to				
p	0·281	,,	,,	6

And he states, among other conclusions which he deduces, this, that at any given temperature air has a certain minimum density below which it loses its elasticity, this minimum density probably increasing with fall of temperature.

Volumes of Oxygen Gas at Low Pressures (Bohr).

Again, Bohr[3] has endeavoured to solve the question for the case of oxygen; and his conclusions agree in the main with those of Mendeleeff and others, while he finds, if his results are to be relied upon, a remarkable point at a certain small pressure which we will speak of after briefly describing his general method of procedure.

Without describing the apparatus in detail, it may be enough to state that the tube containing a bubble or two of perfectly dry and pure oxygen was arranged vertically side by side with a thoroughly dry barometer-tube, very completely exhausted of air, each of these two tubes standing in mercury in a separate limb of a U-tube; and that the U-tube, by means of a stop-cock at its lowest point, could be brought into communi-

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[1] *Annales de Chimie et de Physique* (5), 1883, xxviii. p. 499.

[2] Beiblätter, 1885, ix. v. p. 315.

[3] Wiedemann's *Annalen der Physik und Chemie*, 1886, iii. p. 459.

cation with a reservoir of mercury which had been thoroughly heated and dried, while the reservoir could be adjusted vertically so as to alter the level of the mercury in the open limbs of the U-tube and therefore to raise or lower the top of the column of mercury in the barometer-tubes. One of the barometer-tubes was used as a barometer for comparison with the other by a cathetometer; the other was graduated and served for the introduction of oxygen. It will be noticed that by the arrangement described above the pressure of the same quantity of oxygen could be increased or diminished at will by raising or lowering the reservoir of mercury.

After the introduction of the oxygen its volume in cc. is read and the pressure in mm. of mercury at a constant temperature. Several readings were taken at intervals of about an hour generally. No pressure was finally read off after an interval of less than two hours, and often the readings for a single pressure and volume were taken at intervals of from twelve to twenty-four hours. Each result recorded is the mean of several observations extending over some time. Another series is then taken at the same temperature after introduction of a little more oxygen; and perhaps still another. These give us data for tracing a part of the curve, say from p (abscissa)$=0·12$ mm. to $p=7·45$ m.; and pv (ordinate)$=13·215$, to $pv=139·96$; and so by other series of experiments Bohr extends the curve up to $p=15·02$; $pv=311·83$.

The point which was alluded to above is at 0·70 mm. pressure, at which this volume is (between limits) indeterminate; so that if the oxygen is at the fixed temperature of the experiment submitted to a pressure of very slightly *less* than 0·70 mm., and allowed to remain five or six hours, the volume (and the $p\,v$) will be considerably different from that which would be exerted by the oxygen after standing the same time at the same temperature at a pressure very slightly *more* than 0·70 mm.; thus on p. 472 (*loc. cit.*) for 0·70 mm. twenty-three observations gave as mean volume 47 cc., and twenty-five observations at same pressure gave 52·41 cc. The peculiarity at this point has been verified by Bohr by repeated observations specially directed to it.

As a confirmation of all these conclusions concordant results were obtained by using tubes of different internal diameter—one of 18·5 mm., the other of 32 mm.

Thus Bohr finds, for representing relation of pv to p, for oxygen at pressures from 300 mm. downwards, a line very slightly convex and nearly parallel to the axis of abscissæ for some distance, till from say 60 mm. to 0·70 mm. it curves down very considerably; and again from 0·70 mm. onwards towards 0 mm. another curve which curves rapidly down so as to tend to become nearly vertical; this shorter part of the whole he calls the small branch, and the part from 0·7 mm. to some hundreds of mm. the long branch of the whole. The volumes of oxygen varied from about 20 cc. to 200 cc. in different experiments.

The short branch of the curve he finds can be approximately represented by the formula

$$(p+0·07)v=k;$$

and the long branch by

$$(p+0·109)v=k';$$

where k (and also k') will be different numbers according to the amount of oxygen present.

The pressure of Hg-vapour as determined by Hertz[1] at 10° is 0·0005 mm., and at 20° is 0·0013 mm.; Bohr's results recorded in his paper are for pressures of 0·1 mm. and upwards, and therefore could not be seriously affected by any error due to pressure of mercury vapour; moreover, his measurements of pressure being in all cases differential with a mercury-barometer, this pressure would be almost if not entirely eliminated.

The power which the inner surface of the glass tube may have in condensing the oxygen in the conditions of these experiments must not be disregarded when such very small pressures are concerned; it may be that the walls of the tube and the surface of the mercury are not wholly without action on the gas; if any action were exerted it might well be quite imperceptible in relation to pressures of, say, over 100mm.; any source of error which might be so trifling as to be ignored at higher pressures might be important at abnormally low pressures; in these extreme cases the relation of pressure to volume as observed may possibly be not wholly determined by the molecules of oxygen, but may be partly influenced by the surface of the glass or of the mercury; cf. Amagat ('Ann. de Chim. et de Phys.' 5, xxviii. p. 499).

It must be allowed that Bohr has gone a long way to meet any doubt on this head by using two tubes of very different diameters; but further experiments with still wider tubes, and with tubes of different varieties of glass, would probably show whether the surface of the glass in contact with the oxygen is in any way concerned.

Some remarks of Regnault[2] in reference to Dalton's law of the mixture of gases with vapours as a 'theoretical law,' and showing deviations from it, due to the inner surface of the glass, are suggestive of such an influence in other cases by analogy.

Certainly, on the face of them, the observations of Bohr are remarkable, and his singular point difficult to account for in any other way than the direct and obvious one; and his experiments show the greatest pains taken to minimise the effects of the possible sources of error.

Volume and Temperature—Regnault.

Regnault determined the dilatation of dry air by many series of experiments and by different methods. Representing by $100a$ the whole expansion of unit volume of dry air at 760 mm. between 0° and 100°, his different series gave, taking the mean of the numerous determinations of each set—

1. $100a = {\cdot}36623$ with possible error ·00140.
2. $100a = {\cdot}36633$ „ „ „ ·00101.
3. $100a = {\cdot}36679$ „ „ „ .00079.
4. $100a = {\cdot}36650$ „ „ „ ·00130.

In the above experiments the dilatation was arrived at *indirectly* by observing the increased pressure of air at constant *volume* between 0° and 100°, and deducing by Boyle's laws the volume which the air at 100° would then occupy.

The mean of a fifth set of experiments, by which the value of $100a$ is determined for expansion at constant *pressure*, gave—

5. $100a = {\cdot}36706$, with possible error ·00025.

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[1] Wiedemann's *Annalen der Physik und Chemie*, xvii. p. 199.

[2] *Mémoires de l'Académie*, t. xxvi. pp. 694, 695.

The above are described in the first part of the first mémoire of Regnault in t. xxi. of the 'Mémoires de l'Académie.' Similar experiments were made (described in the second part of the same mémoire) with the following gases:—

Gas	Constant Volume	Constant Pressure
Hydrogen	·3667	·3661
Atmospheric air	·3665	·3670
Nitrogen	·3668	—
Carbon monoxide	·3667	·3669
Carbon dioxide	·3688	·3710
Nitrous oxide	·3676	·3719
Sulphur dioxide	·3845	·3903
Cyanogen	·3829	·3877

This difference in all cases between the expansion of volume at constant pressure, and the increase of pressure in constant volume, from 0° to 100°, is due to the fact that in none of the cases is Boyle's law accurately true. But the numbers for constant volume and for constant pressure are very nearly equal for hydrogen, air, and carbon monoxide.

In this mémoire it is shown for air at constant pressure (p. 99) that—

$$\begin{aligned} 100a &= \cdot 3657 \text{ for } 511 \text{ mm.} \\ &\ \cdot 3648 \text{ ,, } 149 \text{ mm.,} \end{aligned}$$

thus diminishing with diminishing *pressure*; also that the rate of expansion of air at increased pressures increases; thus (p. 110) for air at pressure 3655 mm.—

$$100a = \cdot 3709.$$

From these and from results for gases other than air, given in this mémoire, Regnault infers that the differences in the coefficient of dilatation of different gases are most striking for great pressures, and especially if these are not far removed from those under which the gases can be liquefied, and that the deviations from the coefficient for air are smaller the smaller the pressures under which the gases are examined. The coefficient a for such gases as *sulphurous* and *carbonic* acid gases, for instance, diminishes very much more rapidly with diminishing pressure than the coefficient for air.

Gay-Lussac's law of the equal dilatation of gases with equal rise of temperature is therefore considered by Regnault as a 'loi limite,' which is approached more and more nearly by each gas the smaller the density and pressure at which its dilatation is observed.

Volume and Temperature—Amagat.

Amagat[1] tests air and hydrogen for compressibility at temperatures up to 320°, and finds that the ratio $\frac{pv}{p'v'}$, where v is very nearly $2\times v$, is for *air*,

at 0° . . =1·0015,
,, 100° . . =1·00011,
,, 250° . . =1·00025,
,, 320° . . =1·00018,

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[1] *Annales de Chimie et de Physique*, 1873 (4), xxviii. p. 274.

at initial pressure of about 760 mm.; and for *hydrogen* the mean of a number of experiments at 250° gave 0·99986, which is nearer to 1 than at ordinary temperatures; as are also the above values for air (omitting that for 0°); these being in fact distinguished from 1 by numbers of the order of experimental error.

Now air was found to deviate from Boyle's law in one direction and hydrogen in the other direction when submitted to pressures of a few atmospheres, and the effect of the results here given is to show that both these gases tend at higher *temperatures* to obey Boyle's law more nearly than at lower.

In 'Ann. Chim.' [4] 1873, xxix. pp. 246–285, Amagat considers the rates of expansion with increasing temperature for SO_2, CO_2, NH_3, as well as for hydrogen and air, and gives (p. 261) the following results for $\frac{pv}{p'v'}$, where v is nearly $2v'$ for SO_2 and CO_2; *at about* 700 *mm.*

	SO_2		CO_2
At 15°	1·0185	At 8°	1·0065
„ 50°	1·0110	„ 50°	1·0036
„ 100°	1·0054	„ 100°	1·0023
„ 150°	1·0032	„ 150°	1·0014
„ 200°	1·0021	„ 200°	1·0008
„ 250°	1·0016	„ 250°	1·0006

in which it is clearly seen how these gases also, as well as hydrogen and atmospheric air, approach nearer to agreement with Boyle's law as temperature rises.

On page 279 Amagat gives a table of the coefficients of dilatation $\frac{dv}{dt}$ for different gases at different temperatures; this table also shows how nearly they approach to each other and to Gay-Lussac's law in this respect.

The following selections will exhibit this :—

The value of $\frac{dv}{dt}$ deduced from experiment.

	for SO_2	for CO_2		for SO_2	for CO_2
at 0°	„	·003724	at 100°	·003750	·003695
„ 15°	·004010	„	„ 200°	·003695	·003685
„ 50°	·003846	·003704	„ 250°	·003685	·003682
„ 75°	·003792	·003699			

The conclusion to be drawn from these results is that gases approach more and more to conformity with Gay-Lussac's law (as well as with Boyle's law) the higher the temperature, so far as the experiments have been carried at ordinary pressures.

Results at High Pressure—Amagat.

But the very thorough investigation of Amagat already mentioned (p. 102)[1] shows the relation of pv to p beyond the pressures treated of hitherto in reference to Boyle's and Gay-Lussac's laws, curves being

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[1] *Annales de Chimie et de Physique*, 1881 (5), xxii. pp. 353–398.

drawn expressing the results in reference to this relation for temperatures from 16° to 100°; and the pressures for each curve for each substance ranging from about 20 metres to 320 metres. The gases treated in this exhaustive manner are nitrogen, hydrogen, ethylene, carbon dioxide, and marsh-gas.

With the exception of the curves for hydrogen, each curve was irregular, the relation of pv to p becoming regular only after the pressure was about 120 metres, or about 160 atmos, after which the result for any substance was expressed very approximately by the equation $p\ (v-a)=b$; where b was different for different *temperatures* for any substance, and a was nearly constant for all the temperatures employed. In studying the effect of Amagat's results in this paper in extending our knowledge of Boyle's and Gay-Lussac's laws, it must be remembered that the temperatures were necessarily very restricted, being not over 100°, while the pressures were very great. But the facts brought into notice by comparing curves for the same substance for different temperatures are important; we will be content with indicating one or two of these.

At high pressures, for all the gases studied, the values of pv at any given temperature increase continually with the pressure, and are represented by an almost absolutely straight line for the increasing abscissæ p, so that if p' and v' are higher pressure and corresponding volume $\frac{p'v'}{pv}>1$; that is, the gas in this condition is less compressible than if Boyle's law were exact. The question arises, does this deviation increase or diminish as temperature rises? The case of any gas will do to try this. Taking the case of hydrogen, we extract the following data (p. 378 *loc. cit.*): if $\frac{pv}{p'v'}(<1)$ is the ratio for hydrogen at 100m. and 320m. pressures, this ratio is

at 17·7°	0·830	at 60·4°	0·853
„ 40·4	0·838	„ 100·1	0·856

whence we see that for higher and higher temperatures the ratio approaches more and more nearly to 1, or the gas deviates less and less from Boyle's law. But this approximation does not imply that Boyle's law is even a theoretical condition for these very high *pressures* at much higher temperatures; for a may approximate more and more, as *temperature* rises, to some value, for each gas, less than 1.

Dilatation of Gases at very High Pressures.

To find for high pressures the dilatation of gases, we must find $v'-v$ by finding $\frac{pv}{p}$ and $\frac{pv'}{p}$, or the ratio of the ordinate to the abscissa at two temperatures t and t', the pressure being the same in both cases, so that we have the dilatation at constant pressure. We give an extract from a table[1] which illustrates this for *hydrogen*, and therefore, for other gases, at very high pressures; the table gives the *whole* dilatation for the temperature-range stated; the coefficient may be deduced by dividing by the temperature-range in each case.

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[1] *Annales de Chimie et de Physique* [5], 1881, xxii. p. 382.

	17°—60°	60°—100°
Pressure 40 metres	0·0033	0·0029
„ 100 „	0·0033	0·0028
„ 180 „	0·0031	0·0027
„ 260 „	0·0030	0·0025
„ 320 „	0·0028	0·0024

It will be noticed, on calculating the coefficients of dilatation, how very much they differ, in this condition of very high pressure of the substance, from the coefficients at ordinary pressures; it will be seen also that the coefficients of dilatation for 1° are smaller, at same pressure, for higher than for lower temperatures.

In the equation $p\ (v-a)=b$ for the straight portions of the line—for high pressures—if p be made infinite $v=a$: now a is a constant at any given temperature for each gas, which can be determined with fair accuracy from the equation $p\ (v-a) = p'\ (v'-a)$ the pressures p and p', being a long way apart: and a is therefore a known number: hence the volume taken may be condensed by pressure to a small volume, but never to a volume smaller than a, where a varies very gradually with the temperature.

Vapour-pressures and Temperatures;—Regnault.

We must now turn to well-known investigations of relations between *vapour*-pressures and temperatures by Regnault and by others.

In a magnificent series of investigations on the vapour-pressures (elastic forces) of *water*, Regnault[1] describes various methods, and gives in separate tables the results for separate series treated by these methods for temperatures ranging from 32° to 230°; and discusses the applicability of a number of different formulæ, by which, after determination of the constants in the formula by reference to a few of the determinations the rest of his results were more or less accurately represented.

	pressure mm.		pressure mm.
At 0°	4·6	at 200°	11688·96
„ 100°	760	„ 230°	20926·40

The above samples give some idea of the rapid rise of pressure with temperature. The empirical formula by which Regnault expressed the results of his observations on other bodies[2] were of a similar exponential form to those he used for water in t. xxi., the laws by which Dalton attempted to express the relations being entirely inadequate except over a very short range: these laws of Dalton were—

(1) The elasticity of vapour of a liquid increases in geometrical progression when the temperatures follow in arithmetical progression.

(2) The vapours of all liquids have equal elastic forces at temperatures equidistant from the boiling points at ordinary atmospheric pressure.

These laws are replaced by Regnault's tabulated results, and by the empirical formulæ he adopted; for each substance fresh experiments have to be made, and no reliance placed on Dalton's laws.

For water at low temperatures—*e.g.* from − 32° to 0°—the formula used was

$$F = a + b\alpha^x,\ \text{where}\ x = t + 32°.$$

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[1] *Mém. XXI. de l'Académie,* mém. viii. pp. 465–633.

[2] *Mém. XXVI. de l'Académie,* pp. 335–760.

From 0° to 100° the formula

$$\log F = a + b\alpha^t - c\beta^t.$$

From 100° to 230°

$$\log F = a - b\alpha^x - c\beta^x; \text{ where } x = t + 20°.$$

The formulæ used here are of the form proposed by Biot.

The mere fact of choosing different formulæ for different parts of the curve of vapour-pressures, and of choosing these formulæ from among other exponential formulæ, shows that these are empirical formulæ; and from Regnault's experimental results different systems of formulæ and interpolation give tables differing slightly from Regnault's. Compare, *e.g.*, the tables given by Landolt and Börnstein, pp. 40–49, with Regnault's.

Rankine has since suggested the formula $\log F = a - \frac{b}{t} - \frac{c}{t^2}$.

Magnus[1] made determinations up to 111° with results agreeing closely with those of Regnault.

In 'Phil. Trans.' for 1860, p. 220, are given the results of experiments by Fairbairn and Tate, for the pressure and temperature of saturated vapour of water, and for each temperature the ratio of the volume of steam to that of the water for temperatures ranging from about 58° to 144°.

The Statical and Dynamical Methods of finding the Relations between Temperature and Vapour-pressure.

Two distinct methods of finding the relation between pressure and temperature of saturated vapours are used, one by readings of the pressures of the vapour over the liquid in a mercury-vacuum at known temperatures, and the other by the readings of a thermometer immersed in the vapour of a liquid boiling at known artificial atmospheric pressures.

The first of these methods is called the *statical*, and the other the *dynamical method*;[2] the former method is only applicable to moderate or low temperatures, at which as at 50° the vapour-pressure of mercury is inconsiderable; the latter may be applied at high temperatures. Examples of both are given in the case of steam,[3] and the two methods are found, when both are employed, to yield identical results for water.

In t. xxvi. p. 642, Regnault says: 'It is not *evident à priori* that for a given substance the two methods (static and dynamic) give the same relation between elastic forces and temperatures. The boiling of a liquid is in fact a very complex phenomenon. The vapour which escapes from a boiling liquid has not only to contend against the elastic atmosphere which presses on the liquid, it has to overcome the attraction which the liquid exerts on the molecules which have taken the gaseous state or which tend to take it; it has to overcome the capillary resistance of the liquid walls, which form globules, more or less easily extensible, in which the vapour is imprisoned while it traverses the liquid, &c., &c. These accessory resistances can only be overcome by an excess of heat, and there is the fear that the vapour may, on emerging from the liquid, possess at the same time an excess of elastic force (pressure) and an excess of temperature. The two excesses may neutralise each other and disappear, more or

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[1] Poggendorff's *Annalen*, lxi. p. 225.

[2] *Mémoires*, t. xxvi. p. 341.

[3] *Ibid.*, t. xxi.

less completely, in the space in which the vapour has to contend now only against the pressure of the atmosphere acting on it.'

Regnault finds that for substances of moderate volatility, for which both methods can be applied, the two methods give identical results, provided the bodies are *perfectly pure*, but not otherwise; he found that the addition to alcohol, or to carbon bisulphide, of $\frac{1}{1000}$ of a volatile substance was in each case sufficient to disturb the two curves of either and to destroy their identity. Among the subjects used by Regnault, and which led to this conclusion, were ethyl alcohol, ethyl oxide, carbon bisulphide, chloroform, benzene, carbon tetrachloride, ethyl chloride, ethyl bromide, ethyl iodide, methyl alcohol, acetone, phosphorus terchloride; these being some of the substances for which Regnault found ('Mémoires,' t. xxvi.) curves of relation of temperature and vapour-pressure by methods and formulæ similar to those used for water ('Mémoires,' t. xxi.).

When a liquid boils with bumping, as in the case of methyl alcohol, liquid SO_2, liquid NH_3, it may be heated with the vapour over it to temperatures considerably higher than the temperature at which the vapour in each case is, in the static method, in equilibrium with the atmospheric pressure (t. xxvi. p. 645).

Vapour-pressures from Solid and Liquid—Regnault.

Regnault's experiments on the vapour-pressure on water included pressures for low temperatures down to — 32°; *i.e.* for a long range of temperature during which the water is solid—ice. Regnault found that the whole curve was continuous, including this portion of it, and inferred that the solidification of water made no break in the curve of vapour-pressures; in regard to water he says (t. xxi. p. 609) it would be necessary to make corrections of 3 or 4 hundredths of a millimètre, a quantity almost inappreciable to observation, to bring about a complete coincidence between the curve given by the formula $\log F = a - b\alpha^x - c\beta^x$, in which $x = t + 20°$ and the graphic curve; on p. 599, alluding to a formula which applies very exactly to all observations of his between 0° and 100°, $\log F = a + b\alpha^t - c\beta^t$, he says that the values of the vapour-pressure for temperatures below 0° are constantly very slightly greater than those given by observation, and he therefore does not apply this formula to temperatures under 0°. The fact is that the methods which were employed were not of a nature to show at once that the vapour-pressure from solid water *below* 0° and liquid water *above* 0° formed two curves meeting at an angle at 0° or one curve. Regnault himself[1] attacks this question directly but unsuccessfully, being unable to prove, to his satisfaction, that the state, solid or liquid, of a body exerts an influence on the elastic force of its vapour at a given temperature in the barometric vacuum.

On p. 751 he says in reference to water, alluding to the experiments and results obtained for it in t. xxi.: 'I have proved that the curve constructed on the experiments [for ice below 0°] presented a perfect continuity with the curve which is given by the elastic forces of the vapours furnished by liquid water at temperatures above 0°.'

Regnault in this part of this mémoire takes other easily frozen bodies to examine; *ethylene dibromide, benzene, glacial acetic acid*; and comes to the conclusion in all these cases that (p. 759) his experiments prove that

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[1] *Mémoires*, t. xxvi. pp. 751–760.

'the passage of a body from the solid to the liquid state produces no appreciable change in the curve of the elastic forces of its vapour' (its vapour pressure); 'this curve keeps a perfect regularity before and after the transformation.'

Ethylene dibromide melts at	9·53°	(Regnault, *loc. cit.*)
„ „ „ „	8·2° to 8·4°	(J. C. S. xlv. p. 520)
Benzene „ „	4·4° „ 4·5°	(Regnault, *loc. cit.*)
Acetic acid „ „	16°	(Regnault, *loc. cit.*)
„ „ „ „	16·55°	(Pettersson, J. C. S. 42, 3)

It is seen from the convenient position of the melting-points in reference to ordinary temperatures that these bodies are well chosen for this purpose.

As an example we give some results of Regnault for acetic acid:—

Liquid acid		Solid acid	
Temp.	Vap.-pressure	Temp.	Vap.-pressure
− 0·69°	4·27 mm.	− 0·00°	4·89 mm.
− 2·40°	3·90 mm.	− 2·56°	4·26 mm.
− 5·11°	3·35 mm.	− 4·24°	3·93 mm.
		− 5·83°	3·56 mm.

Thus the curve of vapour-pressures for acetic acid (abscissæ temp., and ordinates vap.-pressures) seems to show that there is a difference of vapour-pressure due to state, and that the solid acid has a greater vapour-pressure than the liquid; but when this acid has been thoroughly dried by distilling over phosphoric anhydride, the results obtained showed the vapour-pressure for the solid acid *less* than that from the liquid; but here acetone was recognised as having been developed by the action of the phosphoric anhydride; and although most of this was removed by distillation some, no doubt, remained; the two specimens of acetic acid were thus impure, one with water, the other with acetone, and they gave contrary results. And no trustworthy results were obtained with the other substances.

Thus two interesting questions are raised by Regnault's investigations on vapour-pressures:—

(1) Whether static and dynamic methods give, when carefully performed, identical results.

(2) Whether when at the same temperature a body can exist either in the solid or in the liquid state the vapour-pressure in both states is the same; *i.e.* whether the pressure is the same from the solid as from the liquid.

Regnault decided both these questions in the affirmative; subsequent investigations have confirmed, as I think, Regnault's answer to the first question, as they have undoubtedly reversed his answer to the second.

Application of Theory to the Second Question.

It should be mentioned, in reference to the second of these questions, that in 1858 Kirchhoff, from theoretical considerations, showed that if the vapour-pressure of ice and of water were the same at any the same temperature, then $\frac{dp}{dt}$, where p is the vapour-pressure, must be different.[1] This was, from the theoretical point of view, an important step. But in

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[1] Poggendorff's *Annalen*, ciii.

reference to both the above questions, if a negative answer is given, it is important to have a quantitative determination in order that we may know whether the differences in each case are of an order to be detected by experiment, and whether they are definite. Professor James Thomson[1] published an important paper in which, by the application to Regnault's very extensive and minutely investigated results for water of a thermodynamical formula of Sir W. Thomson[2] he deduced the result that the ratio of the value of $\frac{dp}{dt}$ for water vapour to the value for ice vapour *at the same temperature* is 1·13 to 1. The argument of Professor James Thomson is briefly as follows. Take a body which can exist in three states, solid, liquid, and vapour, and which can be examined in respect to each pair, viz., liquid-vapour, vapour-solid, solid-liquid; on a plane surface mark off on an axis of abscissæ the temperature, and perpendicular to the abscissæ ordinates representing the pressures; we can then determine by experiment and draw a diagram of the relation between each of the pairs in respect of pressure and temperature; we shall thus have three lines for this relation, one representing these relations for liquid-vapour, one for solid-vapour, and one for solid-liquid. The two vapour-curves are nearly continuous, but they have a slight angle at the point at which they meet, an angle which would be evident if one of the two were prolonged; at the point of junction of these two curves there are then two values of $\frac{dp}{dt}$; the third line, for solid-liquid, passes through this same point, which is therefore called the *triple point.*

The line for liquid-vapour if extended with increasing temperature will abruptly terminate at the *critical point.*

The thermo-dynamic relation supplied by Sir W. Thomson was $\frac{dp}{dt} = \text{CM}$; in which p is the pressure, and $\frac{dp}{dt}$ its rate of increase with temperature, the volume being constant; C is Carnot's function $(=1/\text{T}$ where T is the absolute temperature), and M is the rate of absorption at which heat must be supplied to the substance *per unit augmentation of volume* to let it expand without varying in temperature.

Apply this formula first to steam with water, and second to steam with ice, at the triple point, which is almost exactly at 0° C. In either case since the vapour-pressure is for any given temperature independent of the volume, $\frac{dp}{dt}$ is the same in this case whether there is change of volume or not. Hence $\frac{dp}{dt} \Big/ \frac{dp'}{dt}$ (when p' is pressure for solid with vapour)$=\text{M}/\text{M}'$. Now, as determined by Regnault, the heat of evaporation of a gram of water at 0° into steam at $0°=606·5$; and the latent heat of fusion of ice is 79; thus $\text{M}/\text{M}'=606/\overline{606+79}$ approximately$=1/1·13$.

Professor J. Thomson took Regnault's figures for vapour-pressures from ice and water as they stand, together with the various formulæ which Regnault employed for representing different parts of the curve, and showed, by an exhaustive examination of the whole, that Regnault's actual determinations were so accurate as in fact to be available for con-

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[1] *Phil. Mag.* iv. xlvii. p. 447, 1874.

[2] *Trans. Roy. Soc. Edinburgh*, March 17, 1851.

firming this result of theory that the ice-vapour and water-vapour curves are distinct and meet at an angle.

Effect of Pressure on Melting-point.

Professor J. Thomson had proved that the melting-point of ice must be *lowered* by pressure, and had calculated the amount of this lowering of the freezing-point by a given pressure; his result was subsequently experimentally verified by Sir William Thomson. The amount of the lowering is $\cdot 0073n^{\circ}$ for n atmospheres of pressure.[1]

Mousson[2] made experiments with a very powerful hydraulic press with a view to keep ice liquid at a temperature much below zero, or to lower the melting-point of ice many degrees by immense pressure; these experiments suggested themselves to him in consequence of Sir W. Thomson's experiment in which by 17 atmospheres' pressure he lowered the melting-point of ice more than one-tenth of a degree. Mousson obtained the following results:—first, he succeeded by great pressure on water in preventing the solidification of it till its temperature was lowered to -5°; second, he lowered the temperature of a piece of ice to -18°, and liquefied it by a pressure which he calculated to have been not less than 13,000 atmospheres, and the diminution of volume he estimated at 13 per cent.

Bunsen[3] obtained results for the *raising* of melting-points of some substances which *expand* during fusion; thus spermaceti at 1 atmo fuses at 47·7°, but at 156 atmos at 50·9°. So paraffin melting at one atmo at 46·3° melts at 100 atmos at 49·9°. And Hopkins, with spermaceti, wax, sulphur, and stearine, using pressures up to 800 atmos, obtained a *rise* of melting-point with increased pressure.[4]

Professor Dewar has quite recently[5] made a series of experiments by a Cailletet apparatus on the relation between the temperature at which ice melts under different pressures. The temperatures were measured by a thermo-electric arrangement; a thermo-junction was frozen in a test-tube placed inside the iron bottle of the apparatus, whilst another thermo-junction outside was kept at the constant temperature of ice melting at atmospheric pressure; the two thermo-junctions were connected with a galvanometer, by means of the deflections of the needle of which the difference of temperature of the junctions was deduced.

The freezing-point was lowered 0·18° for 25 atmos, and 2·1° for 300 atmos, giving a mean reduction of 0·0072 for 1 atmo. Similar results up to 700 atmos agreed in giving the same reduction per atmosphere. By this method, therefore, it is possible always to graduate the pressure scale of the Cailletet apparatus or to correct the graduations.

Definitions of Boiling-points.

The view generally adopted with reference to the boiling-point of a liquid is that it is the temperature at which the vapour given off from its

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[1] *Phil. Mag.* (3) xxxvii. p. 123.

[2] *Annales de Chimie et de Physique*, 1859 (3), lvi. p. 252; Poggendorff's *Annalen*, 1858, t. cv. p. 161.

[3] Poggendorff's *Annalen*, lxxxi. p. 562.

[4] *Report Brit. Assoc.* 1854, p. 57.

[5] *Proc. Roy. Soc.* xxx. p. 533.

surface just balances the external actual or artificial atmospheric pressure. This view is, in fact, the basis of all practical attempts to measure boiling-points.

Kahlbaum has developed another view, as will be seen. In order to understand it, it is well to bear in mind circumstances, which are not uncommon, which tend to retard or prevent the ebullition and distillation of a liquid, so that a liquid may sometimes be heated far above its ordinary boiling-point without giving out vapour freely. The view commonly taken is that these circumstances are exceptional, in the sense that they may be artificially exaggerated and that the obstacle opposed to boiling is of a variable amount and that therefore no definite boiling-points can be obtained while these circumstances exist; but that if these obstacles can be removed then there is obtained the true boiling-point at the pressure (say 760 mm.), which does not differ sensibly from the temperature at which the vapour given off in vacuo exerts a pressure of 760 mm.

Kahlbaum,[1] in a mémoire published at Leipzig, 1884, develops a theory of 'specific remission' (with which we are not concerned here), and in connection with it gives an account of determinations of relations between temperature and vapour-pressure in which he asserts that the static and dynamic conditions of a liquid necessarily give different boiling-points; and whereas Regnault said that the *static* method when it can be employed is always to be relied upon as giving trustworthy results, and always to be preferred to the dynamic, Kahlbaum says the *dynamic* method alone gives the true boiling-point. It is to be borne in mind that Regnault had found that in many cases in which the two curves—one by the statical method and the other by the dynamical method—overlapped, they coincided very nearly when the substances taken were pure. It is quite clear, therefore, that the static and dynamic determinations cannot always disagree as a matter of course, and on account of the necessity of overcoming cohesion, &c.

Kahlbaum[2] explains at some length his views as to the boiling-points as found by the statical and the dynamical methods, and defines[3] boiling-point thus:—'I call by the name boiling-point that temperature of the vapour of a liquid in agitation at which its molecules can, by their united energy, overcome the collective attractions of neighbouring molecules and the external pressure.'

It cannot be doubted that, as in Dufour's and Gernez's experiments on the retardation of the boiling-point of liquids in the absence of air into which the liquid can evaporate, so in the cases mentioned by Regnault, and in others similar, the temperature of liquid and of vapour may rise in the dynamic method considerably above the temperature at which the vapour-pressure in the static method is in equilibrium with the atmospheric pressure; that is, both liquid and vapour may be superheated.

But these are exceptional cases, and bodies usually boil under circumstances such that superheating may with care be avoided. Again, it is easy enough by avoiding necessary precautions to heat the vapour above the boiling-point, and so to make the boiling-point of any liquid seem higher than it is.

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[1] *Berichte der Deutschen Chemischen G.* 1883, xvi. II. p. 2476; 1884, xvii. I. p. 1245, and p. 1263; 1885, xviii.

[2] *Ibid.* 1884, xvii. I. p. 1263.

[3] *Loc. cit.* p. 1272.

Le Chatelier[1] gives a list of dissociation-pressures, with the temperatures corresponding, as follows:—

Temperature	Dissociation-pressure
547°	27 mm.
610°	46 „
625°	56 „
740°	255 „
745°	280 „
810°	678 „
812°	763 „
865°	1,333 „

for several varieties of *calcium carbonate* from different sources, all agreeing to give the same dissociation-pressure throughout for each temperature as soon as equilibrium had been reached, which was more rapidly done the more finely divided the calcium carbonate.

At about 812° the dissociation-pressure was equal to the atmospheric pressure; on heating rapidly, however, the temperature rose higher, up to 925°, and stood for some time constantly at that point on account of the rapid consumption of heat by the decomposition of the calcium carbonate. Analogous results were obtained by Le Chatelier in the decomposition of gypsum and of calcium hydrate; results easily explained by the length of time taken by bodies undergoing dissociation in reaching their state of equilibrium. These higher dissociation temperatures suggest a somewhat similar explanation for cases of overheating such as occur with mercury and other bodies in which there is a difficulty in overcoming cohesion or capillary action.[2]

Proof by Direct Experiment *that Curves of Vapour-pressure from Solid and Liquid are different.*

The difficulty of the problem in the case of water arises from the smallness of the pressure of vapour of ice even at 0°, viz., 4·6 mm., while for ice at −17·1° the pressure is 1·04 mm. It is easy to see that by any ordinary manometric contrivance it would be difficult to get very satisfactory results for such very low pressures; however, Pettersson in 1881[3] succeeded by this means in getting a few results for temperatures at very small pressures by using a thermometer surrounded with ice, a manometer, and a 4-litre exhausted flask surrounded by a freezing mixture; an arrangement by which the ice round the thermometer distilled without melting, while the manometric pressure corresponding to each temperature of the ice could be observed. Some of the results were in fair accordance with some data given by Regnault for vapour-pressures given by ice at different temperatures below 0°.

By this method, as Pettersson points out, the pressure continuously and rapidly changes as the temperature of the ice rapidly rises; the thermometer is therefore not to be expected to indicate the temperature for each pressure accurately, seeing that the ice and the mercury cannot take up the new temperature corresponding to each new pressure instantaneously.

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[1] *Compt. Rend.* cii. 1243.

[2] Horstmann in *Berichte der Deutschen Chemischen G.* xix Ref. p. 429.

[3] *Berichte der Deutschen Chemischen G.* 14a, p. 1370.

Analogy of Vaporisation of Solid with Boiling of Liquid.

Ramsay and Young[1] have obtained results for ice by the dynamical method, which are conclusive on this point, that ice has definite temperatures of volatilisation without fusing, and for each temperature a definite pressure. In the dynamical method the substance is either boiling or volatilising when its vapour is being formed at a temperature at which the vapour has a pressure just equal to the external pressure.

Ramsay and Young used two flasks, each having a thermometer, connected at their necks by a narrow glass tube; the tube was provided with a side tube and a clip, by which it could be either closed against the outer air or attached to a pump; or, what was found more efficacious for excluding every trace of air, well-boiled water was put into the flasks and boiled down in them, so that the steam expelled the air very completely from the apparatus when the clip was closed air-tight after the thermometers had been inserted.

On placing one of the two flasks in a freezing mixture, ice at a low temperature was formed, some adhering firmly to the bulb of the thermometer.

When this flask was put in boiling water and the other in a freezing mixture what happened was this, that after a little time the bulb of the second thermometer was covered with ice, and soon the two thermometers showed the same temperature, which they kept so long as the temperature of the condenser was not altered, and so long as the bulb of the thermometer in the other flask was covered with ice.

If the temperature of the condenser was changed the two thermometers both soon showed the same lower or higher temperature, but the variation of the temperature of the water-bath had no effect on the temperatures of the thermometers—in other words, on the volatilising point.

The fixed point at which the two thermometers agreed in any experiment was the temperature at which the pressure of vapour from the ice on the bulb of the thermometer in the flask in the water-bath was just equal to the pressure of the vapour from the ice on the bulb of the thermometer in the flask in the condenser.

If the air is not completely expelled, or if a very little air is introduced, the flask in the water-bath shows a higher temperature than the flask in the condenser—for this reason, that the ice in the first flask must have a pressure of vapour more than enough to balance the pressure of ice-vapour from the condenser flask by the pressure of the air; the pressure of this small quantity of air will not vary much in any one set of experiments, and therefore by means of the different temperatures of the two thermometers in one experiment and the vapour pressures corresponding to the two temperatures we can, by taking the difference between these two pressures, get the pressure of the air in the apparatus, which pressure, being allowed for in the rest of the experiments in the series, there was found always a satisfactorily constant agreement between the volatilising temperature and the condensing temperature; and not only that, but also that the higher temperature given when air was introduced was the temperature at which the vapour-pressure from ice and the pressure of the air were jointly equal to the pressure found by Regnault as the vapour-pressure of ice at that higher temperature by the statical

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[1] *Phil. Trans.* Part I. 1884.

method. Thus the analogy is complete between the volatilisation of ice against external pressure and the boiling of a liquid against external pressure.

Similar experiments were made by Ramsay and Young with acetic acid (melting 16·4°), with naphthalene (melting 79·2°), with camphor (melting 175°); the results by heating the bulb containing solid camphor adhering to the thermometer were confirmed by the pressures obtained with solid camphor over mercury at different temperatures below 175°, the results agreeing very nearly, as shown on a diagram. The general conclusion to be drawn from this paper is that corresponding to boiling-points of liquids there are similar temperatures for solid bodies volatilising without liquefying—viz., temperatures which are constant while the solid volatilises at a constant pressure, but which are different for different pressures, the *volatilising point* of a solid rising with rise of pressure, and being lower with lessened pressure, as is the case with the boiling-point of a liquid; and moreover that the volatilising point (for any pressure) is the same as the temperature at which the solid over a mercury-vacuum has the same pressure, or *sensibly* the same; the second method giving the true vapour-pressure, while the former method gives a temperature not *absolutely* identical with that observed for the same pressure over a mercury-vacuum, though the difference is extremely minute.

It was not superfluous to prove by direct experiment the deductions made by Professor James Thomson from Regnault's numbers as to the discontinuity of the curve for the ice-vapour pressure with the curve for water-vapour pressure, and to show by direct experiment that at temperatures common to the two (below the freezing-point), the curves of vapour-pressure are distinct, the one for water-vapour pressure being continuous with the curve for water-vapour pressure above 0°; and it was important to prove that these propositions, *mutatis mutandis*, apply to other substances. This task, for water, acetic acid, benzene, and camphor, was undertaken and successfully accomplished by Ramsay and Young, and is published in 'Phil. Trans.' Part II. 1884.

Vapour-pressures from Solids and Liquids—Ramsay and Young.

In Naumann's 'Thermochemie' (Brunswick, 1882), at p. 178 is a passage, quoted by Ramsay and Young, showing that Naumann had convinced himself that from naphthalene (melting 79·5°), the same vapour-pressure is produced either from liquid or solid at the same temperature; and he alludes to former experiments (Regnault's, no doubt), which yielded similar conclusions in the cases of water, benzene, ethene bromide, acetic acid, cyanogen chloride, and carbon tetrachloride.

It will be remembered that no satisfactory results were obtained by Regnault with the substances he tried. In the paper referred to[1] Ramsay and Young first give results for solid camphor, the pressures being found for many temperatures up to the melting-point 175°, and for liquid camphor up to 198°; and it is very evident on the curve of pressures plotted out that the curves for liquid and for solid camphor meet at a re-entering angle near 175°, which is the melting-point for a pressure of one atmosphere. For *camphor* the operations were conducted by jacketing a barometer-tube, very carefully ensured from the danger of entrance

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[1] *Phil. Trans.* 1884, Part II. p. 461.

of air or moisture, the tube being heated to the required temperatures by the vapour of aniline (or methyl benzoate) at different pressures. But the method of work and the apparatus devised were varied to suit the requirements of each case.

Thus for *benzene* (melting 3·3°) a modification described in § 17 of the memoir cited on page 19[1] is used, the bulb of the thermometer being covered with cotton-wool which is soaked with benzene; the benzene persisted in solidifying just below freezing-point 3·3°.

As in the previous case of camphor, so in this case of benzene many experiments were made near the melting-point above and below it, and several with the solid at long intervals below and with the liquid at long intervals above. The lines for solid and liquid, which had slight curvature, met at a re-entering angle at a point where the temperature was between 3·0° and 3·6°.

With *acetic acid* it was found possible to cool it below the freezing-point 16·4° and keep it *liquid*, and a large number of good results was obtained; the curves meeting at about 16·3°, the two curves *below* the melting-point being very obvious, and each being the result of numerous observations. Attempts made with the greatest care by the barometer (statical) method gave, as with Regnault, no satisfactory results.

The observed difference between the solid-vapour pressure and the liquid-vapour pressure for the same temperature was nowhere much more than 1 mm. This gives some idea of the accuracy required in this kind of work.

The next—and last—case taken in this paper is *ice and water*. Comparative results, *i.e.* results at identical temperatures for ice-vapour and water-vapour were obtained from 0° to —5°; tables are given of observations of pressure for ice down to —16°; and these results when compared with the results which Professor James Thomson obtained, as mentioned, by recalculation of Regnault's data, are found to give differences of vapour-pressures of ice and water greater than his. But when the observed pressures for ice, for temperatures below 0°, were compared with the pressures calculated from a theoretical formula of Professor Thomson, the authors found that their observed results agreed more nearly with those so calculated than with those calculated from Regnault's results.

Thus Drs. Ramsay and Young have shown that curves for pressure, from a liquid and a solid state of the same substance, are not continuous in the cases of camphor, benzene, acetic acid, and water.

The process in which the thermometer-bulb is covered with cotton-wool (or asbestos fibre), and this soaked with the substance the boiling-points of which at different pressures are required, gives results, according to Ramsay and Young, in which the error due to overheating of the vapour is got rid of, for the substance adhering to the cotton-wool has so much free surface that it will, whether solid or liquid, evaporate freely at the temperature corresponding to the pressure to which it is subjected. The cotton-wool can be re-moistened continually by an arrangement described in this paper and in 'J.C.S.' January 1885.

In the last-mentioned paper they further describe their apparatus, and show how it is used for solids as well as liquids, and apply it in particular to the case of acetic acid. Regnault had obtained discordant results

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[1] *Phil. Trans.* Part I. 1884, p. 47.

with this substance, which sometimes he attributed to the presence of water and sometimes to the presence of acetone; and the least trace of impurity, as he has pointed out, affects the results seriously, especially those obtained by the statical method; for over the thermometer vacuum any accidental presence of a trace of air does not get eliminated as in the dynamical method by boiling for a short time. By their method Ramsay and Young got a series of values of pressures for solid acetic acid from −5·68° to 16·41° volatilising point, and for liquid acetic acid from 2·72° to 117·15° boiling-point. The results so obtained agree closely with those given by the usual process when a perfectly pure acetic acid was used, and disagreed with vapour-pressures previously given by Regnault,[1] Landolt,[2] Bineau,[3] and Wüllner.[4]

Vapour-pressures from Solids and Liquids—W. Fischer.

W. Fischer,[5] independently of Ramsay and Young, and by a quite different method, investigated the lines of solid vapour-pressure and of liquid vapour-pressure for water and benzene for a range of temperature throughout which, in each case, the body could exist either as solid or as liquid; he arrived at results substantially similar to those of Ramsay and Young. He showed that the curve of pressures for each substance (for temperatures below the melting-point) was lower for solid than for liquid.

In the case of ice and water he gives four sets of experiments, in each of which experiments there are given the thermometer reading below 0°, the barometer reading and the reading of an ice-pressure mercury tube and of a water-pressure mercury tube, the three tubes being near together so that they can all be read with the cathetometer, as well as the thermometers giving the temperature of the ice and water in each experiment. A fifth set of experiments was made for vapour-pressure of water at temperatures above 0°. From these he deduced two equations of the form $p=a+bt+ct^2$, which represented very accurately his observations, one for p the vapour-pressure of water, and the other for p the vapour-pressure of ice.

These results were got in the winter of 1882–3, and they did not well agree with theory, and especially gave a difference for ice and water at 0°, differing too seriously from that deduced from Clausius' formula.

In the winter 1884–5 he resumed the investigation, and succeeded in improving the method employed so as to make his results more accurate. In the equation $p=a+bt+ct^2$ he obtained the values of a, b, c, his results for the different pairs of values of p and t giving him from the equation between p and t a large number of equations in a, b, and c. This was done for water-vapour and for ice-vapour; the equation for pressure of water-vapour at temperatures between 1·35° and −10·15° was

$$p=4{\cdot}628+0{\cdot}32535t+0{\cdot}008705t^2$$

and for ice-vapour pressure

$$p=4{\cdot}641+0{\cdot}37190t+0{\cdot}011041t^2$$

the difference of $\frac{dp}{dt}$ for ice and water at 0° is ·04655; Kirchhoff calcu-

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[1] *Mém.* 1862, xxvi. p. 51.

[2] Liebig's *Annalen*, Suppt. 6, 157.

[3] *Annales de Chimie et de Physique* (3), xviii. 226.

[4] Poggendorff's *Annalen*, ciii. p. 529.

[5] Wiedemann's *Annalen der Physik und Chemie*, 1886, No. 7, p. 400.

lated it at ·044. This is, therefore, a tolerably satisfactory agreement. The two curves meet at about 0·3°.

For benzene W. Fischer found +5·3° as melting-point; Regnault had found +4·35°. The equation for the vapour-pressure over solid benzene was found to be

$$p=24{\cdot}985+1{\cdot}6856t+0{\cdot}031339t^2;$$

that for the vapour-pressure over liquid benzene was

$$p=26{\cdot}40+1{\cdot}4295t+0{\cdot}04505t^2.$$

The two curves do not meet at 5·3°, but they should meet on some point on the line of solid-liquid, and may do so at some point corresponding to a pressure higher than atmospheric. From the diagram it appears that the two curves would not meet for some distance from the melting-point; this is not certain, but it is so probable as to point to some error, perhaps arising from impurity of the benzene.

Vapour-pressures of Mercury.

The determination of the relations between temperature and vapour-pressure for mercury was found by Regnault to be very difficult, on account of the occurrence of violent bumping; the results are published in 'Mémoires,' t. xxvi. p. 520. The temperatures were measured by an air-thermometer of constant volume, but of small initial pressure, it having been partially exhausted before the beginning of a series of experiments. The formula $\log F=a+b\alpha^t+c\gamma^t$ was used, where F is the vapour-pressure, and the constants determined by a sufficient number of data from observations including a wide range; thus the table on pp. 520, 521 was calculated from the formula. Regnault's observations were too few and too doubtful, and the results given by him for vapour-pressures of mercury at low temperatures and at ordinary temperatures have been proved to be quite illusory.

A few other physicists have attacked this question; among them Hagen, McLeod, Hertz, and Drs. Ramsay and Young.

We will first give Hagen's results,[1] comparing some of them with Regnault's:—

Temperature	Vapour density in mm.	
	Hagen	Regnault
0°	0·015	0·020
10°	0·018	0·027
20°	0·021	0·037
30°	0·026	0·053
40°	0·033	0·077
100°	0·210	0·745

Hagen's differ widely from Regnault's numbers, but, unfortunately, there is good reason for thinking Hagen's results entirely untrustworthy in spite of the very great care which he took to avoid sources of error.

An experiment of McLeod's made the early numbers of Hagen (those

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[1] Wiedemann's *Annalen der Physik und Chemie*, 1882, xvi. p. 610.

for ordinary temperatures) very doubtful. It is described in the British Association volume for 1883. A shallow glass tube 14 mm. diameter containing freshly distilled mercury was suspended near the bottom of a closed flask of about 1·9 litre capacity, for nine days; the tube was then removed and boiling nitric acid poured into the flask and allowed to stand some time, the nitric acid neutralised with ammonia, the solution washed out of the flask, acidified with HCl, and treated with H_2S. By comparison with the result of operating similarly with solutions of mercury of known strengths, the mercury was found to be between ·00006 gms. and ·00012 gms.

The flask contained, therefore, as vapour about ·00009 gms. of mercury.

A second similar experiment gave ·00012 gms., therefore at ordinary temperature 1 litre of Hg-vapour contains ·00006 gms., which would correspond to pressure of mercury = ·00574 mm.; and McLeod says this number may be too large, for probably some mercury condensed on the inside of the flask.

In Wiedemann's 'Ann.' 1882, xvii. p. 177, is an elaborate investigation of the evaporation of fluids, especially mercury, by Hertz. His vapour-pressures of mercury are very different indeed from Regnault's from 0° to 100°, as will be seen:—

Regnault giving at		0°	vapour-pressure	0·02 mm.
Hertz	,,	0°	,,	0·00019 mm.
and Regnault	,,	100°	,,	0·7455 mm.
Hertz	,,	100°	,,	0·285 mm.

Ramsay and Young[1] determine, by a neat and accurate method, in which mercury in a small bulb of glass at one end of a narrow graduated tube is heated to the boiling-point of sulphur, the vapour-pressure of mercury at that temperature; and deduce, from this and a few data for lower temperatures, by means of the formula[2] $R' = R + c(t' - t)$—see further on (p. 125)—the vapour-pressures for temperatures from 360° to 130° from Regnault's vapour-pressures of *water*; and the vapour-pressures of mercury between 130° and 40° were calculated by 'extrapolation' (*loc. cit.* p. 48), by means of the known vapour-pressures of mercury at temperatures 160°, 220°, and 280°—which pressures and temperatures suffice to find the three constants in the formula $\log. p = a + b\alpha^t$, which was then applied to find p at lower temperatures.

Let us compare some of Hertz' values with those of Ramsay and Young:—

Temp. centigrade	Hertz	Ramsay and Young
At 40°	·0063 mm.	·008 mm.
,, 50°	·013 ,,	·015 ,,
,, 60°	·026 ,,	·029 ,,
,, 70°	·050 ,,	·052 ,,
,, 80°	·093 ,,	·092 ,,
,, 90°	·165 ,,	·160 ,,
,, 100°	·285 ,,	·270 ,,
,, 140°	1·93 ,,	1·763 ,,
,, 180°	9·23 ,,	8·535 ,,
,, 200°	18·25 ,,	17·015 ,,
,, 220°	34·90 ,,	31·957 ,,

[1] *J.C.S.*, January 1886, p. 37.

[2] *Phil. Mag.* January 1886.

The remarkable closeness with which these numbers of Hertz and of Ramsay and Young agree is a striking proof of the applicability of the thermal relation $R'=R+c(t'-t)$, explained in 'Phil. Mag.' Jan. 1886, to the determination, with considerable accuracy of data which almost baffle direct experimental treatment.

Crookes, in the 'Chemical News,' July 16, 1886, p. 28, writing of the mercury left in his radiant-matter tubes even at great exhaustions, says that, although in the cold it is impossible to get an induction spark through the tube, the interior of it being absolutely non-conducting, yet on heating the tube with a Bunsen flame, keeping the coil going, suddenly the current passes, lighting up the inside of the tube with a greenish blue light, in which the spectroscope shows strong mercury lines. The tube on cooling becomes non-conducting again.

This shows, according to Crookes, that in such very highly exhausted vacuum-tubes there is plenty of mercury present, not as vapour, but condensed on the metallic poles or on the inside of the glass. But a complete blockade may be established, as Crookes explains in this paper, whereby during the exhaustion of the vacuum-tube no mercury can enter; the blockade is effected by interposing between the vacuum-tube and the mercury a tube containing freshly heated sulphur and iodide of sulphur packed with freshly heated asbestos, and a glass tube containing copper to retain any sulphur. By this means the vacuum-tube is so freed from mercury that Crookes has been unable to detect mercury vapour in any of the tubes, even on heating them.

Tables for Constant Temperatures.

The fact that for each pressure there is a corresponding temperature for any volatilisable liquid, constant so long as the pressure is the same; and for each temperature a pressure of vapour, constant so long as the temperature is the same, can be utilised to secure a constant temperature by boiling a liquid at constant pressure; this is the principle of Hofmann's method of determining vapour-densities; the constant temperature being that of a given liquid boiling at the (constant) pressure of the atmosphere, different liquids must be used boiling at different temperatures to give a convenient temperature in each case.

The substances which can be used must be few, as they must satisfy the condition of being cheap, stable, and easily obtained pure.

Now the number of constant temperatures which can thus be obtained is the number of such bodies the boiling points of which can be used as the constant temperatures; the temperatures thus attainable will therefore be few and far between.

Among the liquids satisfying the conditions mentioned are carbon bisulphide, ethyl alcohol, chlorobenzene, bromobenzene, aniline, methyl salicylate, bromonaphthalene, and mercury. Their approximate boiling-points are 46°, 78°, 132°, 155°, 184°, 222°, 280°, and 358°; thus we have eight temperatures which can be used for purposes for which a constant temperature is required; and they are at fairly uniform intervals from 46° to 358°, applicable therefore to wide ranges of temperature.

By the aid of the principle stated above, we can, by keeping constant any pressure below 760 mm. for carbon bisulphide, obtain another constant temperature, and in fact a whole series of constant temperatures between 0° and 46°, or between 0° and temperatures higher than 46°, *e.g.* between 0° and 50°, by using constant pressures over 760 mm.

This in fact is what[1] Ramsay and Young have made possible by determining the pressures of the vapour of carbon bisulphide for every degree from 0° to 50° inclusive.

Thus instead of only one we have fifty constant temperatures, being boiling-points for sixty known pressures from 127·9 mm. to 857·1 mm.; the temperatures being air-thermometer temperatures; to say that fifty constant temperatures are available is sufficient perhaps; but in fact other temperatures are obtainable by interpolation between two successive degrees (up to 50°).

Similar tables have been prepared by the authors for the other substances for every degree centigrade; thus for the eight different substances there are eight tables, giving in the case of—

Carbon bisulphide	vapour	pressures	from	0°	to	50°
Ethyl alcohol	,,	,,	,,	40°	,,	80°
Chlorobenzene	,,	,,	,,	70°	,,	132°
Bromobenzene	,,	,,	,,	120°	,,	160°
Aniline	,,	,,	,,	150°	,,	185°
Methyl salicylate	,,	,,	,,	175°	,,	225°
Bromonaphthaline	,,	,,	,,	215°	,,	281°
Mercury	,,	,,	,,	270°	,,	360°

for each degree centigrade in each table the vapour pressure of the substance.

These valuable tables are founded on the definiteness and constancy of the relationship between vapour-pressure and temperature for each pressure for each substance; and as most of these results have been obtained by the dynamical method they assume that this method is as trustworthy as the statical and gives, when properly applied, as definite and constant results.

Ramsay and Young's Formula $R'=R+c\ (t'-t)$.—*Calculated and observed Tables of the Absolute Temperatures and Vapour-pressures of a Substance compared.*

In the brief sketch, p. 123, of Ramsay and Young's method of determining the vapour-pressures of mercury for various temperatures, it was stated that by certain experiments the relation between temperature and vapour-pressure of mercury was determined at about the temperature of boiling sulphur, and that, from this and from three or four data at lower temperatures, a series of pressures for a long range of temperatures was deduced from Regnault's series *for water* by the use of an equation of the form $R'=R+c\ (t'-t)$; in this R is the ratio of the absolute temperature of two bodies corresponding to any the same vapour-pressure; R' the ratio at any other pressure the same for both; t' and t are the temperatures of *one* of the bodies corresponding to the two vapour-pressures; and c a small constant.

What Ramsay and Young have proved[2] is that for the substances of widely different kind examined by them, c is very small, that it can be accurately determined, and that it is constant for any pair of substances; that when either water, ethyl alcohol, carbon bisulphide, or sulphur

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[1] *J.C.S.* September 1885, p. 640.

[2] *Phil. Mag.* January 1886.

is taken as one of the two substances, as the substance of reference, the observed pressures agree with those calculated by the formula with remarkable accuracy; and doubtless equal accuracy could be got by using other substances of reference.

We will give some results illustrative of the accuracy which this formula shows:—

1. The absolute temperatures of water at various pressures being known, the following are absolute temperatures of CS_2 calculated from the formula, and absolute temperatures of CS_2 obtained by observation. Found c=·0006568.

Pressures . . .	mm. 50	mm. 100	mm. 200	mm. 400	mm. 700	mm. 1000	mm. 2000	mm. 3000	mm. 5000
Calculated abs. temp.	254·0°	267·6°	283·2°	300·8°	316·8°	327·95°	352·5°	368·6°	391·3°
Observed abs. temp.	254·05°	267·7°	283·2°	300·75°	316·75°	328·0°	352·3°	368·7°	391·7°

The greatest difference between the observed and the calculated temperatures of CS_2 is here only 0·4° at the pressure 5000 mm.

2. The absolute temperatures of CS_2 being known for a series of vapour pressures, to find by the formula the absolute temperatures of sulphur at the same pressures.

Regnault gives[1] a list of corresponding temperatures and vapour-pressures for sulphur; taking some of these and the temperatures of CS_2 for the same pressures, and adding 273 to the temperatures to get the absolute temperatures, the value of c is found= —·0006845.

A series of absolute temperatures of sulphur can now be constructed for various pressures by calculation by the formula from the absolute temperatures of CS_2 at the same pressures; and these can then be compared with the data obtained by interpolation from the temperatures and vapour-pressures given by Regnault.

The following are among the results for sulphur:—

Pressures	mm. 400	mm. 800	mm. 1000	mm. 2000	mm. 3000
Calculated abs. temp. .	683·5°	724·6°	739·3°	788·15°	820·8°
Observed abs. temp . .	683·7°	724·6°	739·0°	788·2°	820·8°

Besides the substances mentioned, the formula was applied to methyl alcohol, ethyl chloride, ethyl bromide, chlorobenzene, bromobenzene, aniline, methyl salicylate, bromonaphthalene, ethylene, oxygen, acetic acid, nitric peroxide, chloral-alcoholate, chloral-methylalcoholate, ammonium chloride, ammonium carbonate; and[2] to carbon tetrachloride, ethyl oxide, chloroform, and mercury (which has been already mentioned).

The results in such a variety of cases being extremely accurate for elements such as oxygen and sulphur, and compounds of such different types, there can be no doubt that the relation $R'=R+c\,(t'—t)$ very accurately represents an actual relationship between temperature and vapour-pressure such that the different substances taken are in this way

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[1] *Mém.* t. xxvi. p. 527.

[2] *Phil. Mag.* February 1886.

comparable with each other; and the suggestion imposes itself upon one that this may be an expression—very approximately true—of a general law with regard to vapour-pressures and temperatures applicable to any volatilisable liquid—to any at least which can be heated with no chemical change, or none but dissociation; in other words, that bodies of this kind in the liquid state are, in spite of their apparently great divergencies in respect of relations of vapour-pressure to temperature, really very similarly constituted in that respect if compared under physical conditions, which this formula of Ramsay and Young in some way represents, at least approximately.

Application of the formula to Liquid Oxygen.

The case of oxygen is of such interest that it is impossible to leave this important paper without treating of it.

Olszewski[1] published a series of determinations by a hydrogen-thermometer of temperatures of liquid oxygen, and vapour-pressures corresponding, the temperatures varying from the critical temperature of oxygen −118·8° C. to −211·5° C.; and critical pressure being 50·8 atmos = 38,608 mm., and the pressure for the lower temperature being 9 mm. Olszewski was unable to measure any lower temperature, because at this point so much liquid oxygen had evaporated that the bulb of the thermometer was not sufficiently covered with it.

Taking *water* to compare with, c was found $= -\cdot0003932$. By interpolation from Olszewski's numbers, temperatures were determined for vapour-pressures 800, 1000, 1500, 2000, and so on up to 20,000 mm.; the critical temperature corresponding to a critical pressure 38,600 mm. of oxygen vapour being about 154° in *absolute* temperature.

The calculated and the interpolated values of absolute temperature of oxygen are as under:—

Pressure . . .	mm. 9	mm. 800	mm. 1000	mm. 2000	mm. 3000	mm. 5000	mm. 10000	mm. 15000	mm. 20000
Calculated abs. temp.	63·5°	91·6°	93·7°	101·1°	106·1°	113·2°	124·7°	132·7°	139·1°
From observed abs. temp.	61·5°	92°	93·5°	100·0°	105·5°	113·9°	125·7°	133·0°	138·1°

The same comparison of absolute temperatures is made for oxygen and *alcohol*, the vapour-pressures of alcohol and corresponding temperatures being known over a large range[2] up to 155° C. by air thermometer, at which temperature the vapour-pressure is 8259·19 mm. The temperatures calculated by the formula, from the table for alcohol, give absolute temperatures nearly agreeing with those got from Olszewski's observed values by interpolation.

Again, a third calculation of vapour-pressures and temperatures was made from the data given by Regnault for *sulphur*[3] where air-thermometer temperatures centigrade are given at intervals of 10° from 390°

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[1] *Compt. Rend.* 100, p. 350. *J.C.S.* 1885, May Abs. p. 476.

[2] Regnault in *Mémoires*, t. xxvi. p. 375.

[3] *Ibid.* p. 530.

to 570°. Here c was found as in all the other cases to be constant for several pairs of temperatures compared for the same pressure for sulphur and for oxygen; and the calculated temperatures of oxygen agree with the observed with an error of one degree at the most.

Question of Applicability of Hydrogen Thermometer to Low Temperatures.

Wroblewski[1] objects that Olszewski's results cannot be true at very low temperatures because at, for example, 61·5° (abs. temp.) = −211·5° C. at which the vapour-pressure found by Olszewski for hydrogen is 9 mm., and at temperatures not quite so low as that, we must be getting near the liquefying point of hydrogen, near enough at least to allow of the suspicion that the behaviour of hydrogen may be getting irregular, and deviating from the straight course prescribed by Amagat at temperatures above 0° C. *i.e.* above 273° of absolute temperature. And Wroblewski's criticism is probably just; the determination of the *lowest* temperatures is probably inaccurate; but the points determined by Olszewski, other than the very lowest temperatures, are probably very accurate, as hydrogen evidently has a very low liquefying point, and is far the most regular of the gases, as seen in Amagat's curves; still though we know from Amagat's results and from V. Meyer's that hydrogen at ordinary temperatures and from these up to nearly 1700° C. behaves in the most absolutely regular way in reference to volume, pressure and temperature, where at least the pressure is not excessively great, our knowledge, however highly probable with regard to its behaviour at low temperatures, is conjectural.

Wroblewski used two thermo-junctions arranged as a thermo-pile, one junction being kept at constant temperature, such as 0° or 100°, the other in the liquid the temperature of which is sought, the temperature being inferred from the deflection of the needle of a galvanometer.

The elements of the pile were copper and german silver, and results with the pile agreed with results with the hydrogen thermometer down to −193° C.; but disagreed below that temperature.

Other Formulæ of Ramsay and Young.

In the series of papers[2] the authors discuss two other formulæ, which might often be useful for getting fair approximations, but which do not give such remarkably accurate results as the formula of which we have been treating.

A recent paper[3] gives applications of the formula (p. 125) to bromine, iodine, and iodine monochloride.

The Use of Formulæ—Formula of Clausius—Formula of Van der Waals.

The application of the principles of thermo-dynamics to many chemical problems may be expected, as in the case we have enlarged upon, to economise experimental work in this way; a few data will be required, carefully worked out, and a whole set of experiments made with

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[1] *Compt. Rend.* 100, p. 979. *J.C.S.* 1885, Abs. Aug. p. 861; cf. *Compt. Rend.* 101, p. 238; and *J.C.S.* 1885, Abs. Nov. p. 1101.

[2] *Phil. Mag.* December 1885 and January and February 1886.

[3] *J.S.C.* July 1886.

some one substance. The results of these can then be used to enable us to calculate for a large variety of substances and circumstances, numerical data which could not otherwise be got without the most laborious and tedious investigations.

One case of this is that of Clausius' formula,[1] $p=\frac{RT}{v-\alpha}-\frac{k}{T\,(v-\beta)^2}$ for the relation between the pressure, volume, and absolute temperature of a gas; Sarrau[2] has determined the constants in this equation for several gases by Amagat's results, and has deduced the critical temperature, pressure, and molecular volume for oxygen, carbon dioxide, nitrogen, and marsh-gas.

In 1873 Van der Waals first published at Leiden his dissertation 'On the Continuity of the Gaseous and Liquid States,' in which he predicts some of the most striking of the results which Amagat five or six years afterwards first published, and long before his most complete and exhaustive treatment of the gases he examined was concluded; and in this dissertation, of which a German edition was published at Leipzig in 1881, he proposed a formula $\left(p+\frac{a}{v^2}\right)(v-b)=R(1+\alpha t)$ (p. 62, Leipzig edition) as a general relation between volume, pressure, and temperature for a gas; the constants in the equation must of course be determined for each gas.[3] Baynes calculates from the formula a series of values of pv for ethylene, which agree remarkably with the numbers found by Amagat by experiment. Amagat applies Clausius' and Van der Waals' formulæ to the case of CO_2, and finds[4] a portion of the gas well represented by calculations from their formulæ, but that neither his nor Clausius' formula represents the whole of his curves.

Critical Temperatures and Pressures.

Faraday having shown how certain gases might be liquefied, and having himself liquefied a number of those which under ordinary conditions are gases, Cagniard de la Tour[5] showed that when certain liquids were gradually heated in a sealed tube partly filled, suddenly at a certain temperature the line of demarcation between liquid and vapour disappeared, and there was nothing to distinguish one part from another part of the tube.

Thilorier had noticed[6] that CO_2 liquid from 0° to 30° expands four times as much as CO_2 gas between the same temperatures.

Andrews[7] investigated the effects of pressure on CO_2 at different temperatures, and arrived at the conclusion that above the temperature 30·9° C. no pressure however great can liquefy the gas, that is, separate it in the tube in which it is confined into two portions, one denser than the other, separated by a line of demarcation.

At any temperature below 30·9° he showed that by some pressure under 74 atmos the gas can be liquefied; and at a temperature the

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[1] *Wied. Ann.* 1879, t. ix. p. 127; *Annales de Chim.* 1883, xxx. p. 358.

[2] *C.R.* xciv. pp. 639 and 718; *J.C.S. Abs.* 1882, p. 686.

[3] See Baynes on 'Critical Temperature of Ethylene' in *Nature*, vol. xxiii. 1880–1.

[4] *Annales de Chimie et de Physique*, 1883 (5), xxviii. pp. 500–502.

[5] *Ibid.* (2), xxi., xxii.

[6] *Ibid.* 1835 (2), lx. p. 427.

[7] *Phil. Trans. R.S.* 1869.

least possible below 30·9° the gas just becomes liquefied by a pressure of about 74 atmos.

The temperature 30·9° and the pressure 74 atmos were called by Andrews the *critical temperature* and pressure for CO_2. In further researches Andrews had found that the critical point was not a point special to CO_2 and to this body only; he found a similar behaviour at some point for every liquefied gas or volatile liquid he examined, and in particular for nitrous oxide, hydric chloride, ammonia, ethyl oxide, and bisulphide of carbon. For each of these (and he considered the property to be general) there is a certain temperature below which the body can, by sufficient pressure, be liquefied, and above which no pressure, however great, can liquefy it. The smallest pressure which can liquefy it at *immediately* below this *critical point* is the *critical pressure.*

There can be no doubt that in reference to general properties of liquids and gases the critical temperature and pressure are of the greatest importance, and that the accurate determination of a number of these will, in conjunction with Andrews' very complete examination of CO_2 and with Amagat's results—carried, as they are, to very high pressures—be among the most valuable data towards a general theory of gases and liquids; and on the other hand the critical points may be arrived at by a theoretical method, as indicated in a paper by Thorpe and Rücker.[1] The actual critical temperatures at present known, besides those found by Andrews, have been obtained for the most part by Ramsay in 1880,[2] by Pawlewski,[3] by Olszewski and Wroblewski, by Sajotschewsky, and by Dewar.[4]

In a paper on the liquefaction of oxygen and the critical volumes of liquids,[5] Dewar [6] gives a list of twenty-one critical temperatures and pressures in atmospheres, of which we will mention a few:—

	t Critical temperature	P Critical pressure	$\frac{T}{P}$
Chlorine	141° C.	83·9	5·0
Oxygen	−113°	50	3·2
Nitrogen	−146°	35	3·6
Water	370°	195·5	3·3
Hydric sulphide	100·2°	92	4·0
Ammonia	130°	115	3·5
Marsh-gas	−99·5°	50	3·5
Ethyl hydride	35°	45·2	6·8
Cyanogen	124°	61·7	6·4
Acetylene	37°	68	4·5

where T is the absolute critical temperature $=273+t$. Of the above Dewar determined ammonia, hydric sulphide, cyanogen, marsh-gas, and ethyl hydride. Ansdell determined acetylene. For Ansdell's experimental determination of physical constants of acetylene and hydrochloric acid, see 'Proc. Roy. Soc.' xxx. 117, and xxxiv. 113.

Dewar shows in the above paper how by his modification of Cailletet's apparatus the volume and weight, and hence the density, of the

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[1] *J.C.S. Trans.* 1884, p. 135.

[2] *Proc. Roy. Soc.* vol. xxxi. p. 194.

[3] *Berichte der Deutschen Chemischen G.* xv. p. 2460, 1882; and *ibid.* xvi. p. 2633.

[4] *Phil. Mag.* 1884 (5), vol. xviii. p. 210.

[5] *Ibid.*

[6] *Ibid.* p. 214.

liquefied portion of a gas may be readily determined, and in particular the density at the critical temperature and pressure. The values of $\frac{T}{P}$ are proportional to the molecular volumes of the gases at the critical point.

We have thus the means of determining the *critical* temperature, pressure, and volume of a gas or liquid. These are the most important data for each substance, and the most important points of reference when we compare different substances, which are gasifiable, with one another.

It has already been mentioned, p. 129, that Sarrau deduced the critical temperatures and pressures of oxygen and nitrogen by applying Clausius' formula to Amagat's results.

Sarrau found for *oxygen* $t_c = -105{\cdot}4°$; $p_c = 48{\cdot}7$ atmos;
and for *nitrogen* $t_c = -123{\cdot}8°$; $p_c = 42{\cdot}1$ atmos.

The values found by Wroblewski and Oblewski for oxygen are respectively:—[1]

Oxygen, Wroblewski, $t_c = -113°$; $p_c = 50$ atmos.
,, Oblewski, $t_c = -118{\cdot}8°$; $p_c = 50{\cdot}8$ atmos.

The pressure found by both observers does not differ much from that calculated by Sarrau; but the temperature calculated is considerably higher than that observed by either.

Hydrogen has, so far as I know, not been examined as yet in the liquid state; but if not, there can be little doubt that it soon will be. Wroblewski, by means of nitrogen boiling in a vacuum, cooled hydrogen to a temperature 208°—211°, at a pressure 180—190 atmos, and found on suddenly releasing the pressure a grey mist form, which is due no doubt to the formation of liquid hydrogen in a very fine state of division.

Sarrau deduced from Clausius' formula for *hydrogen* the critical temperature $-174°$, and critical pressure 98·9 atmospheres. The ratio of absolute critical temperature to critical pressure is therefore about 1·0.

Again Olszewski[2] has obtained his lowest temperatures by the evaporation of solid nitrogen under a pressure of 4 mm., a temperature $-225°$ having been thus registered by his hydrogen thermometer, which perhaps cannot give accurate temperatures in these extreme circumstances. However, hydrogen does not seem to liquefy at this temperature; at least no meniscus was seen at $-220°$ at pressures up to 180 atmos; still the hydrogen-thermometer might, and probably would, register too low.

The *solid* nitrogen which Olszewski used was obtained by evaporation of the liquid nitrogen at 4 mm. in a glass tube surrounded by liquid oxygen.

The temperature at which nitrogen solidifies is, according to Wroblewski,[3] $-203°$.

Dewar has recently obtained *solid* oxygen, but details have not yet been published.

Pawlewski had stated, as an empirical law, that the difference between the critical temperature and the boiling-point is constant. This has been found to be by no means true. Vincent and Chappuis[4] find the critical temperature, boiling-point, critical pressure, and the ratio T/P, where T is the absolute critical temperature, for hydric chloride, methyl chloride, ethyl chloride, ammonia, and methyl-, dimethyl-, and trimethyl-amines; the differences between the centigrade critical temperatures and boiling-points for these in order are 86·5°, 165·2°, 195°, 169·5°, 157°, 155°, and

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[1] *C.R.* xcvii. 309; c. 350.

[2] *Ibid.* ci. p. 238.

[3] *Ibid.* cii.

[4] *Ibid.* ci. 427.

151·2°. In this paper the authors confirm the results of Dewar with regard to the values of T/P, which is 3·5 approximately for hydric chloride water, ammonia, and marsh-gas, and is greater than this for the more complex molecules derived from these as types. In the order in which the bodies have been named these numbers are given as 3·4, 5·7, 8·4, 3·6, 5·9, 7·9, 10·5.

In another paper[1] the same authors add critical temperatures and pressures and values of T/P for other substances; thus for propyl chloride T/P is 10, for ethylamine 6·8, for diethylamine 12·2, for triethylamine 17·4, for propylamine 9·8, and for dipropylamine 17·7.

Dilatations and Vapour-densities of Bodies in the State of Gas at High Temperatures—Experiments by V. Meyer, Crafts and Meier, and others.

The greater part of the determinations of vapour-densities of bodies whose vapour-densities had not been known or were doubtful up to the last ten years has been effected by Victor Meyer alone, or in conjunction with others; some by Crafts and Meier.[2]

After describing his apparatus as ordinarily used, V. Meyer gives results with $CHCl_3$, CS_2, H_2O, $C_6H_4(CH_3)_2$, C_6H_5Br, $C_6H_5NH_2$, cymene, C_6H_5OH, those having the highest boiling-point being heated in the vapour of boiling ethyl benzoate, the vapour-densities in all the cases taken agreeing fairly with the theoretical results calculated from Gay-Lussac's or Avogadro's law—quite nearly enough for practical purposes—thus:

For CS_2				For H_2O			
Observed			Calculated	Observed			Calculated
2·87	2·91	2·292	2·63	·69	·66	·62	·62

V. Meyer points out that in calculating the observed densities from the direct datum of each experiment the temperature of the bath does not require to be known, but must be quite constant during each determination.

By improving his process he shows how to get much more accurate results, thus:

	For *Water*		For CS_2		For Iodine	
	Found	Calculated	Found	Calculated	Found	Calculated
Density	·64	·62	2·68	2·62	8·83	8·78

and so for, besides those already mentioned, *naphthalene*, *benzoic acid*; some in a lead-bath, *e.g.*, *diphenylamine*, *mercury*, *anthracene*, *anthraquinone*, *chrysene*, *sulphur*; and, in a bath of Wood's metal, *perchlordiphenyl.*

For *indium chloride* the formula $InCl_3$ corresponded to the found vapour-density, whereas the vapour-densities found by Deville and

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[1] *Ibid.* ciii. 6.

[2] References; *Berichte der Deutschen Chemischen G.* 1878, 11. 2, pp. 1868, 2258; 1879, 12. 1, pp. 613, 1113, 1195, 1282; 12. 2. p. 1428 (V. and C. Meyer); 1880, 13. 1, pp. 423, 776, 851, 1018, 1033 (Crafts and Meier); pp. 391, 394, 401, 407; pp. 399, 404, 811 (V. Meyer and Züblin); pp. 1010, 1013, 1721, 2019; 1881, *ibid.* 14b, p. 1453; 1882, *ibid.* 15b, p. 2769; 1883, *ibid.* 16a, p. 457 (Crafts); 1884, *ibid.* 17a, 1334; 1885, *ibid.* 18 Ref. p. 133 (C. Langer and V. Meyer); a, p. 1501.

And *Pyrochemische Untersuchungen,* von Carl Langer und Victor Meyer. Brunswick, 1885.

Troost[1] gave Fe_2Cl_6, Al_2Cl_6, Al_2Br_6, Al_2I_6, from about 400° to 1040° (the boiling-point (?) of zinc). These formulæ had led V. Meyer to expect In_2Cl_6, which was not given by any vapour-density determination of indium chloride. So V. and C. Meyer find formulæ Sn_2Cl_4, $ZnCl_2$ for temperatures between 620° and 700° as determined by a block of platinum and a calorimeter.

Mitscherlich had found at 571° As_4O_6, and V. and C. Meyer find for a much higher temperature—about 1000°—the same formula As_4O_6, and for even higher temperatures Sb_4O_6, Cu_2Cl_4, and at over 900° $CdBr_2$; S_2 at about 1500° (?), while at temperatures below a bright red heat the vapour-density gave S_6. They tried potassium, sodium, and then chlorine, but found that these attacked porcelain.

The temperatures in these experiments with the calorimeter and the heated block of platinum were not very accurate when very high temperatures were to be measured. The highest estimated temperature 1567° gave O_2 (from Ag_2O), N_2, S_2 as the molecular formulæ of oxygen, nitrogen, and sulphur. For chlorine at the highest temperature of their furnace they obtained a molecular formula $\frac{2}{3}Cl_2$, that is, from Pt_2Cl_4 the chlorine given off, which at as high a temperature as about 620° had given density corresponding to formula Cl_2, had given smaller and smaller values for the densities at higher temperatures, till at the highest temperature it had a density 1·60, 1·62, a little less than 1·63 calculated for $\frac{2}{3}Cl_2$; admitting that chlorine was undergoing dissociation it was not clear that it would not at higher temperatures give still lower densities (always compared with air).

The results thus given for chlorine naturally led to speculation as to the behaviour of bromine and iodine in the same circumstances; and as Deville and Troost had (*loc. cit.*) found for iodine a normal vapour-density corresponding to I_2 at the bright-red heat required for reaching the boiling-point of zinc (1040°, as found by Deville and Troost) the result with chlorine was considered doubtful; this taken in conjunction with the fact of the porcelain being attacked by alkali metals and chlorides led to a revision of the arrangement of the apparatus. In succeeding investigations V. Meyer, in conjunction with Züblin, used a porcelain tube glazed inside and out, and placed in the furnace so as to be heated by it when necessary to the highest temperatures. The gases of the furnace were thus entirely unable to diffuse into the interior of the porcelain tube, and thus the platinum tube which was inside the porcelain tube was absolutely guarded against the action of these gases, and operations which would be vitiated by the action, either of the gases of the furnace on porcelain, or of the substance which was the subject of the experiment, could be heated with safety to the highest attainable furnace temperatures in the platinum tube. The experimental tube was filled with nitrogen, and the vapour-density determined in an atmosphere of this gas. The temperature was now accurately determined (it having been previously found that up to very high temperatures nitrogen, oxygen, mercury, and, as afterwards shown, hydrogen, when compared at the same temperature, gave always vapour-densities corresponding to the same formula; in fact, that in all these cases the absolute densities diminished as temperature rose always in the same ratio) by measuring the nitrogen which filled the tube before the experiment, and the nitrogen which filled it after the experiment.

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[1] *Annales de Chimie et de Physique*, 1860 (3), lviii. p. 257.

The nitrogen with which the tube had been filled before the experiment was expelled by CO_2 till the CO_2 was entirely absorbed by potash; this gives the amount of nitrogen left at the highest temperature of the experiment. After the furnace had quite cooled the tube was again filled with nitrogen at the temperature of the room, and the amount of nitrogen at this temperature determined in the same way. The expansion of the nitrogen is thus known between the two temperatures; the highest temperature is thus easily calculated on the faith of the accuracy of Gay-Lussac's law for nitrogen through this range of temperature. As an example of this method they apply it to the case of mercury vapour, and find in two experiments 6·89, 6·76, as against the calculated number 6·91.

The method described above for determining the temperature may be called the nitrogen-thermometer method; its applicability has been amply justified by further comparisons of its densities with those of other gases at still higher temperatures, with, among these, the gases hydrogen, oxygen, mercury.

The Behaviour of Iodine at High Temperature.

In the meantime (year 1879) Crafts, using a modification of V. Meyer's apparatus, found for chlorine no alteration of density, or at the most only a few hundredths at the highest temperature of the furnace; but for bromine, which for Br_2 should have density 5·7, was found 4·39 at the highest temperature; while the density of iodine, which for I_2 should be 8·795, was found reduced to 5·93.[1] Thus Crafts found vapour-density of iodine reduced in ratio 1·5 to 1; of bromine in ratio 1·2 to 1; and of chlorine very slightly reduced, if reduced at all.

V. Meyer also found the vapour-density of iodine reduced in ratio 1·5 to 1, being abnormal above 590°.

Crafts and Meier,[2] by a quite different experimental method from that used by V. Meyer, arrived at results which showed that the temperatures were inaccurate in Meyer's experiments with iodine, and that whereas according to V. Meyer's figures the vapour-density of iodine remains constant between 1000° and 1570°, Crafts and Meier[3] show that it continually diminishes as the temperature rises up to 1400°, when it has a density less than two-thirds the density required by the formula I_2. Since then Crafts and Meier[4] extended their experiments to higher temperatures, operating under reduced pressure. They find that they get a vapour-pressure of iodine above 1300° (at ·1 atmo pressure), which is near to half that for I_2—namely, about 4·6—and which remains nearly constant, slightly diminishing for all temperatures up to 1400°, the curves showing the vapour-densities as ordinates and the temperatures as abscissæ.

Deville and Troost,[5] on referring back to an experiment made many years ago (in 1860) on the density of vapour of selenium by comparison with that of iodine at some very high temperature, find a note appended, to the effect that there must have been some mistake made in the weight of iodine remaining in the flask, for with the number given, 0·011 gram, a temperature of nearly 2000° would be attained; they in this communication recognise that the experiment was accurate and that the smallness of the weight of iodine was due to the abnormal diminution in the vapour-

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[1] *C.R.* xc. p. 183.
[2] *Ibid.* p. 690.
[3] *Ibid.*
[4] *Ibid.* xcii. 39.
[5] *Ibid.* xci. pp. 54, 83.

density of iodine at the very high temperature—yet much below 2000°—in this experiment.

Troost had also recognised the influence of reduction of pressure on the vapour-density of iodine, and had in fact obtained for a constant temperature, 440°, a series of vapour-densities of iodine (relative to air at same temperature and pressures), as under :—

Pressures .	768 mm.	67·2 mm.	48·6 mm.	48·57 mm.	34·52 mm.
Densities .	8·70 „	8·20 „	7·75 „	7·76 „	7·35 „

The conclusion which was drawn by Crafts and Meier from their experiments was that the molecule I_2 had been gradually decomposed into molecules I. Troost considered that such a dissociation could not be effected by a simple diminution of pressure; but there are cases of chemical compounds, which can be formed at a low temperature and by sufficient pressure, which can be decomposed, partially or wholly, either by raising the temperature or *by diminishing the pressure,* or by both combined, and which can be re-formed by lowering the temperature or increasing the pressure.

A remarkable instance of this is phosphonium chloride, formed by Ogier[1] by combining PH_3 with HCl. These two gases do not combine at ordinary temperatures, but were by Ogier brought into combination by a pressure of about 20 atmos at 14°, also by lowering the temperature of the mixed gases to $-30°$. In the former method he fills over mercury the ordinary tube of 'Cailletet's elegant apparatus' with a mixture of equal volumes of PH_3 and HCl, and when a sufficient pressure has been applied brilliant crystals of PH_4Cl appear; on warming the upper part of the tube, at about 20°, a liquid layer forms which is either liquid phosphonium chloride or a mixture of the liquefied gases. Ogier says that on gradually cooling the mixed gases the deposit of crystals takes place almost suddenly at $-30°$; but he thinks it possible that the gases may be in combination at a somewhat higher temperature. That is a matter which experiment has not decided.

Now Van't Hoff,[2] by compressing a mixture of equal volumes of the mixture of PH_3 and HCl, got the laboratory-tube of a Cailletet's apparatus half-full of the white phosphonium-chloride crystals. These he heated with a water-bath; the crystals melted at 25°; and on heating further at pressure of between 80 and 90 atmos till the temperature was between 50° and 51°, the boundary between liquid and vapour disappeared; on again lowering the temperature there was noticed the hazy appearance which is characteristic of the critical point.

The liquid state (?) of the phosphonium chloride obtained by warming the crystals, or the crystals themselves obtained by pressure at 14°, on gradually diminishing the pressure, gradually disappear, being converted *without changing the temperature* of 14° into PH_3 and HCl; here is an exact analogy with the case of iodine in Troost's experiments with diminishing pressure, for we may suppose the molecules I_2 to gradually decompose, on the pressure being relieved, into molecules I.

The theory of Crafts and Meier, accepted by V. Meyer, that molecule I_2 is split into two molecules I, though not overthrown by the experiments of Troost, is barely proved by Crafts' and Meier's experiments; for

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[1] *Annales de Chimie et de Physique,* 1880 (5), xx. p. 63.

[2] *Berichte der Deutschen Chemischen G.* xviii. 2088.

these find only a small portion of curve representing a nearly constant vapour-density nearly equal to that required by the molecule I—just enough to convince all who wish to be convinced—and until by higher temperatures there can be shown a longer range during which the density of iodine vapour is always (compared with air) half what it is at ordinary temperatures, that is to say shows no tendency to diminish further, the evidence from the experiments mentioned will be accepted as conclusive only by chemists and physicists who have a predisposition to accept the conclusion. But confirmatory evidence of some fundamental change in iodine at high temperatures is given by the fact that it gives a band spectrum when subjected to electrical discharges of comparatively low tension, and a line spectrum under higher tension.[1]

The results obtained for chlorine and bromine were a diminution of density continuing up to the highest furnace temperatures under which the experiments could be performed; it is impossible to use a much higher temperature than 1700° with platinum vessels, for platinum melts a little above this—at 1775° according to Violle[2]—and is very appreciably attacked by chlorine at a white heat.

At about 970° stannous chloride was found to have vapour density corresponding to $SnCl_2$, the density found about 200° lower corresponding to Sn_2Cl_4; and Fe_2Cl_4 had density at white heat much diminished; while the formulæ Al_2Cl_6, &c., were in concordance with vapour-densities found at the highest temperature; $HgCl_2$ was found again to be the molecular weight corresponding to the vapour-density of mercuric chloride at the highest temperatures, the compound thus showing evidence of not having been dissociated at these high temperatures; and SO_2 had vapour-density for this formula at a white heat. CO was[3] partially decomposed at 1690° thus, $2CO=C+CO_2$; on this account the volume is less than it should be, and also on account of a slight diffusion of the CO through the platinum at the high temperature; hence there is found, in place of an abnormal expansion of CO, a slightly increased density (as compared with air at the same temperature); there is almost normal expansion of CO up to 1200°, but at much higher temperatures decomposition begins to set in.

N_2O is almost entirely split up at 900° into nitrogen and oxygen; and at 1690° it is split up to just about the same extent.

NO is entirely decomposed into nitrogen and oxygen at 1690°, but is unaltered at 1200°.

HCl was considerably decomposed at 1300° and higher temperatures, the hydrogen diffusing through the platinum, and the chlorine being shown by the amount of iodine liberated from potassium iodide solution.

CO_2, heated in polished platinum, was only very slightly decomposed at the highest temperature, about 1690°; in presence of fragments of porcelain Deville had found much dissociation at 1300°.

The Cumulative Evidence for Avogadro's Law—Application of the Law to the Behaviour of the Halogens at High Temperature.

In a paper on some points of the atomic theory, published in 1826, Dumas[4] gave determinations of the vapour densities of iodine and mercury,

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[1] *C.R.* lxxv. p. 76.

[2] *C.R.* lxxxix. 702.

[3] Langer and Meyer's *Pyrochemische Untersuchungen.*

[4] *Annales de Chimie et de Physique* (2), xxxiii. p. 337, 1826.

and of some volatile compounds of these and of other less volatile elements. His object was to deduce from his results, by applying to them the atomic theory as expounded by Dalton and the law of Ampère and Avogadro as to the distribution of the molecules of a gas or gasified body, the molecular weights of both the compounds and the elements. In this Dumas was only partially successful, because with Dalton he made the tacit assumption that in the case of elementary substances there was no distinction between an atom and a molecule. Chemists before Dumas' time had taken no account of the law of Avogadro and Ampère in their endeavours to determine the true formulæ of compounds and the atomic or molecular weights to be assigned to elements, with the exception of Gay-Lussac, who was guided by some adumbration of this law in his investigations into the volume relations of bodies composed of gaseous components.

In the investigation which Dumas records in this paper he not only recognises this law, but takes it as the foundation of the reasoning he applies to his experimental results; thus inaugurating a method of chemical research which was afterwards renewed by Gerhardt in 1843 and carried by him to a more successful conclusion, for Gerhardt was not only able to show how formulæ for compounds and especially for very numerous carbon-compounds were consistent with Avogadro's law, but to include the molecules of volatile *elements* also under the self-same law. These chemical consequences derived from this law are not anticipated by Dalton's atomic theory, and without some such physical conception of the constitution of matter in the gaseous state we could not have had any reason to suppose that the weights of substances in this state in equal volumes were in any relation to the chemical formulæ. But the facts, numerous as they were, which Gerhardt found to show this relation have since the publication of his memoir up to the present time been increased to a vast extent; so that it is beyond question that Avogadro and Ampère expressed, with reference to the number of molecules in a given volume, in the case of bodies in the state of perfect gas, a law which is approximately true of vapours of bodies at temperatures far removed from the point of liquefaction, and which not only physicists can use with safety in explaining physical properties but chemists to find true chemical formulæ.

There are, it is true, cases of apparent exception, but on examination it is found that in these cases the body, of which we are trying to find the formula by this law, has wholly or partly ceased to exist in the circumstances of the experiment, being replaced by two or more other bodies resulting from decomposition of the original. The applicability of Avogadro's law which is thus shown, depends of course on the approximate truth of Boyle's and Gay-Lussac's laws, which as approximations are thus indirectly confirmed; and V. Meyer and others have confirmed these laws by their results for very high temperatures, not only in the cases of hydrogen, oxygen, and nitrogen, but in the cases of mercury, mercuric chloride, arsenicum, phosphorus, arsenious oxide; aluminium chloride, bromide, and iodide, indium chloride, antimonious oxide, cupric chloride, and cadmium. Moreover, in many other cases where the results do not seem in accordance with these laws at high temperatures we have signs of a decomposition, while in other such cases the result has been shown to be capable, without any straining of the facts, of simple explanation by supposing a molecule to be split into molecules of half the mass and represented by halving the formulæ, *e.g.*, in the case of Sn_2Cl_4 which appears to obey the above laws up to a certain temperature, to deviate from them for a range of higher temperatures, and to obey them for a still higher range, all of which facts receive an obvious and natural explanation on the supposition that Sn_2Cl_4 splits up gradually into two molecules $SnCl_2$ as the temperature rises.

In face of all the above facts, which are of somewhat recent development, and which result from the long-continued labours of V. Meyer, Crafts and Meier, and others, it is difficult to hold the view expressed by Berthelot,[1] that Boyle's (or Mariotte's) law, and Gay-Lussac's law have only been proved for hydrogen, oxygen, and nitrogen, with the implied inference that iodine is probably merely one of very numerous exceptions, and that therefore Avogadro's law does not hold good for the halogens, and in the other cases which are apparent exceptions to the other two laws.

Deville and Troost—Vapour-densities determined by them in 1860—*Bearing of their Results on the Behaviour of Iodine.*

Dumas, in his paper already mentioned, recognised the importance of determinations of vapour densities as aiding the solution of chemical problems, and particularly in helping to give the correct formula to a compound. Deville and Troost[2] used substantially the same method as Dumas, except that by using porcelain globes instead of glass globes they were able to determine vapour-densities of bodies which have very high boiling-points. The matter of chief importance is to have a *fixed* temperature above the boiling-point of the substance in the flask at which the flask and its contents can be kept before closing it when it is full of the vapour at the constant temperature. They used for constant temperatures the boiling-points of mercury, sulphur, cadmium, and zinc; taken as 350°, 440°, 860°, and 1040° respectively. In this way Deville and Troost determine the vapour-densities of water and aluminium chloride at the temperature of boiling mercury; again, at the temperature of boiling sulphur, the densities of air, iodine, mercurous chloride (4 vols.), aluminium chloride, aluminium bromide, aluminium iodide, zirconium chloride, ferric chloride; in the vapour of boiling cadmium, 860°, the densities of the following: iodine, air, sulphur, selenium; in the vapour of boiling zinc, the densities of iodine, air, ammonium chloride (4 vols.), phosphorus, cadmium, selenium, and sulphur.

The boiling-points of the substances above mentioned, whose vapour-densities have been determined by Deville and Troost, were taken as: water 100°; aluminium chloride 180°; aluminium bromide 260°; zirconium chloride (?); ferric chloride 306°; iodine 250°; sulphur 440°; selenium 665°; phosphorus 287°; cadmium 860°.

It will be seen that even if these boiling-points are not so accurate as could be wished, in each case the temperature at which the vapour-density was determined was far above the boiling-point of the substance.

The substances chosen for giving invariable temperatures of boiling-point were all elements: these were probably selected, among other reasons, because elements were not likely to show any alteration at high temperatures, and, therefore, any serious deviation from Gay-Lussac's law.

The vapour-density of iodine was used three times, viz., at tempera-

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[1] *Annales de Chimie et de Physique*, 1881 (5), xxii. p. 456.

[2] *Ibid.* (3), lviii. p. 257, 1860.

ture of boiling sulphur 440°, boiling cadmium[1] [860°], and boiling zinc [1040°]. In the first and last cases it was used as the thermometric substance, *i.e.* the expansion of the iodine (assumed as obeying Gay-Lussac's law) was known by the amount left in the flask after the experiment was over; and as the vapour of iodine is heavy, iodine should be an accurate thermometric substance, used in this way by *weighing* the iodine left in the flask. Unfortunately it has since been found that iodine does not obey Gay-Lussac's law above 590°, above this temperature its rate of expansion increasing.

But in Deville and Troost's experiments the (relative) vapour-density of iodine is almost the same at [860°] as at 440°, viz., 8·7.[2] This seems inconsistent with what was said just now; there may be some error here, or it may be, as is likely from analogy, that the dissociation of iodine molecules imagined by V. Meyer, and by Crafts and Meier, may be a slow process requiring more time than was given in this experiment.

However that may be, the use of iodine as a thermometric substance for giving the boiling-point of zinc was not legitimate, and Deville and Troost themselves have since found that[3] the boiling-point of zinc was over-estimated by 100°, the true boiling-point of zinc being in fact 940°; the more than normal expansion of iodine at 940° had given a result due to a normal expansion at 1040°.

The cubic expansion of the porcelain of which the flasks were made was determined by Deville and Troost and found to amount to ·009288 between 0° and the boiling-point of cadmium, which was supposed to be 860° but is now known to be about 772°, as found by Carnelley and Carleton Williams ('J.C.S.' 1878, xxxiii. 284.)

Third Report of the Committee, consisting of Professor BALFOUR STEWART (*Secretary*), Mr. J. KNOX LAUGHTON, Mr. G. J. SYMONS, Mr. R. H. SCOTT, *and* Mr. JOHNSTONE STONEY, *appointed for the purpose of co-operating with* Mr. E. J. LOWE *in his project of establishing a Meteorological Observatory near Chepstow on a permanent and scientific basis.*

IN their last report this Committee, after expressing their opinion that the establishment of a permanently endowed meteorological observatory on a good site, such as that of Shire Newton, is a matter of undeniable scientific importance, instructed their Secretary to write as follows to Mr. Lowe:—

'The Committee request me to point out to you that the main feature of your proposal, which interests the British Association and the scientific public generally, is the prospect which it holds out of the establishment of a *permanent* institution by means of which meteorological constants could be determined, and any secular change which may take place therein in the course of a long period of years be ascertained. It will be for you and the local authorities to decide what amount of work of *local interest* should be contemplated, and on this will the scale of the observa-

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[1] *C.R.* xlix. p. 240.

[2] *Ann. Chim. et Phys.* 1860, lviii. p. 285.

[3] *C.R.* xc. p. 793.

tory mainly depend. The Committee are therefore unable to say what amount of capital would be required. They would point out four conditions which they hold to be indispensable:—

'1. The area of ground appropriated should be sufficient to ensure freedom from the effect of subsequent building in the neighbourhood.

'2. A sufficient endowment fund of at least 150*l.* annually should be created.

'3. The control should be in the hands of a body which is in itself permanent as far as can be foreseen.

'4. The land for the site shall be handed over absolutely to the abovementioned governing body.'

This communication from the Committee has been submitted to the consideration of Mr. Lowe and his friends, and a letter from Mr. Lowe has been recently received by Dr. Stewart, of which the following are extracts.

Mr. Lowe—who offers to give an acre of land, his instruments, and meteorological books, and to work gratuitously at the observatory—writes as follows (July 21, 1886):—

'Yesterday sixteen scientific men from Bristol came over to look at the proposed site of the observatory, and said that it seemed a pity that nothing was being done. . . . If any alteration in the scheme would be desirable this could be done, as all that is required is an observatory that would be useful to science. You have yourself seen the site, and if you can suggest what would improve the proposal I have no doubt it would be acted upon. . . . Newport would have had a meeting in November, but the election came on and it was thought desirable to postpone it. Then the High Sheriff died—the second that had consented to call a meeting—and you will recollect that I told you that Mr. Cartwright, another High Sheriff, had died.

'The Committee think that they see their way to getting two or three thousand pounds if the scheme were started. Since you were with me I have purchased nearly 150 acres of land in front of the observatory, and nothing could come between it and the channel as near as 1½ to 2 miles. A new road is to be made to the Severn Tunnel station, and I hear that the telegraph or telephone is likely to be carried up this road.

'If your Committee think well to recommend the observatory scheme, action would be at once taken, and we have reason to believe that the Bristol Docks would help us with 100*l.* a year. I should much like to see such an observatory in working order whilst I live, but my time is getting short.

'There is a growing interest round here about the observatory, and constant inquiries are made as to the probabilities of success.'

The Committee express their sympathy with Mr. Lowe and his friends under the unfortunate circumstances that have tended to retard local action. The Committee see such evidence of local interest in the undertaking that they desire to have an early opportunity of co-operating with the local committee. They therefore ask for their reappointment, and request that the unexpended sum of 25*l.* and an additional sum of the same amount—in all 50*l.*—be placed at their disposal for the purpose.

Report of the Committee, consisting of General J. T. WALKER, Sir W. THOMSON, Sir J. H. LEFROY, General R. STRACHEY, Professor A. S. HERSCHEL, Professor G. CHRYSTAL, Professor C. NIVEN, Professor A. SCHUSTER, *and* Professor J. H. POYNTING (*Secretary*), *appointed for the purpose of inviting designs for a good Differential Gravity Meter in supersession of the pendulum, whereby satisfactory results may be obtained at each station of observation in a few hours, instead of the many days over which it is necessary to extend the pendulum observations.*

THE Committee have issued the following circular. They subsequently learnt of the work of M. Mascart in this direction. An account of his investigation is appended.

Copy of the Circular.

The Committee hereby invite designs for an instrument to fulfil the above condition. It should aim to give some 'statical' measure of variation in the weight of a fixed mass in place of the present laborious 'dynamical' method by means of the pendulum.

The principle of a statical differential gravity meter was very clearly stated by Sir J. Herschel in his 'Outlines of Astronomy' (§ 189 in editions 1–4, § 234 in later editions). He suggested, in illustration of the principle, a weight suspended by a spiral spring, the spring being always stretched to the same length, whatever the variations of gravity, by the addition or removal of small weights. There appear to have been only three attempts to construct such an instrument, resulting in the torsion Gravimeter of the late J. Allan Broun and the two bathometers of the late Sir C. W. Siemens. A full account of Mr. Broun's instrument, by Colonel Herschel, will be found in the 'Proceedings of the Royal Society' (vol. xxxii. p. 507). An account is also given there of a proposal for a similar instrument by M. Babinet, though the proposal does not seem to have been carried out. In Mr. Broun's Torsion Gravimeter a mass is supported by a bifilar suspension; a third single wire along the axis of suspension is also attached to the mass, and this third wire is twisted till the mass is turned through 90°. If the weight increases the amount of torsion of the single wire required to keep the weight at 90° from its original position is increased. For details, see Colonel Herschel's paper, which contains a careful criticism of the instrument.

Sir C. W. Siemens' Bathometers are shortly described by Colonel Herschel (*loc. cit.* p. 515), but a full account of them will be found in the 'Phil. Trans.' 1876. The first instrument was virtually a barometer with the cistern at the bottom containing a considerable quantity of air and closed. The temperature was kept at 0° C. Any variation in gravity led to an alteration in the height of the mercury column requisite to balance the pressure of the air. The alteration in height of the mercury was magnified 300 times by the use of two other liquids, one over the other, above the mercury. The junction of the middle liquid with the mercury was in an enlargement of the tube, and its junction with the top liquid, this junction being the one observed, was in a narrow part of the tube. The top surface of the uppermost liquid was also in an enlargement of the tube. Above this was a vacuum.

The instrument did not give satisfactory results, and Sir C. W. Siemens was led to devise another form in which the weight of a column of mercury was supported by two spiral steel springs. If gravity increased the weight increased and the springs were stretched. An increase in their length was observed by a micrometer screw, the moment of contact being given by an electric signal. This instrument gave much better results than the first, but it would require much improvement before it could be brought into use for differential measures of gravity.

The Committee will be glad to receive suggestions from any who are interested in the subject, and any design submitted to them will receive careful attention.

The following conditions should be satisfied by the instrument:—

It should be portable.

It should be capable of use in ordinary buildings and under varying conditions of temperature and pressure.

Effects of change of temperature should be ascertainable, so that they may be allowed for.

The zero point should remain fixed if the temperature and gravity are the same.

It should not be affected by terrestrial magnetism.

It should give variations of $\frac{1}{100000}$ in the value of gravity.

Sir Wm. Thomson has favoured the Committee with the following account of a gravimeter, designed by himself, for circulation:—

Spring Gravimeter.

The following instrument promises to fulfil all the conditions mentioned in the preceding circular. Its sensibility is amply up to the specified degree. It is of necessity largely influenced by temperature, and it is not certain that the allowance for temperature, or the means which may be worked out for bringing the instrument always to one temperature, may prove satisfactory. It is almost certain, although not quite certain, that the constancy of the virtual zero of the spring will be sufficient, after the instrument has been kept for several weeks or months under the approximately constant stress under which it is to act in regular use.

The instrument consists of a thin flat plate of springy german silver of the kind known as 'doctor,' used for scraping the colour off the copper rollers in calico printing. The piece used was 75 centimetres long, and was cut to a breadth of about 2 centimetres. A brass weight of about 200 grammes was securely soldered to one end of it, and the spring was bent like the spring of a hanging bell, to such a shape that when held firmly by one end the spring stood out approximately in a straight line, having the weight at the other end. If the spring had no weight the curvature, when free from stress, must be in simple proportion to the distance along the curve from the end at which the weight is attached, in order that when held by one end it may be straightened by the weight fixed at the other end.

The weight is about 2 per cent. heavier than that which would keep the spring straight when horizontal; and the fixed end of it is so held that the spring stands not horizontal but inclined at a slope of about 1 in 5, with the weighted end above the level of the fixed end. In this position the equilibrium is very nearly unstable. A definite sighted position has been chosen for the weight relatively to a mark rigidly connected to the fixed end of the spring, fulfilling the condition that in this position the equilibrium is stable at all the temperatures for which it has hitherto been tested, while the unstable position of equilibrium is only a few millimetres above it for the highest temperature for which the instrument has been tested, which is about 16° C.

The fixed end is rigidly attached to one end of a brass tube about 8 centimetres diameter, surrounding the spring and weight, and closed by a glass plate at the upper end of the incline, through which the weight is viewed. The tube is fixed to the hypothenuse of a right-angled triangle of sheet brass, of which one leg inclined to it at an angle of about one-fifth radius is approximately horizontal, and is supported by a transverse trunnion resting on fixed V's under the lower end of the tube and a micrometer screw under the short approximately vertical leg of the triangle.

The observation consists in finding the number of turns and parts of a turn of the micrometer screw required to bring the instrument from the position at which the bubble of the spirit-level is between its proper marks to the position which equilibrates the spring-borne weight with a mark upon it exactly in line with a chosen divisional line on a little scale of 20 half-millimetres, fixed in the tube in the vertical plane perpendicular to its length.

The instrument is, as is to be expected, exceedingly sensitive to changes of temperature. An elevation of temperature of 1° C. diminishes the Young's modulus of the german silver so much that about a turn and a half of the micrometer screw (lowering the upper end of the tube at the rate of $\frac{2}{3}$ millimetre per turn) produced the requisite change of adjustment for the balanced position of the movable weight. About $1\frac{1}{8}$ turn of the screw corresponds to a difference of $\frac{1}{5000}$ in the force of gravity, and the sensibility of the instrument is amply valid for $\frac{1}{40}$ of this amount, that is to say, for $\frac{1}{200000}$ difference in the force of gravity. Hence it is not want of sensibility in the instrument that can prevent it measuring differences of gravity to $\frac{1}{1000000}$; but to obtain this degree of minuteness it will be necessary to know the temperature of the spring to within $\frac{1}{20}$° C. I do not see that there can be any very great difficulty in achieving the thermal adjustment by the aid of a water-jacket and a delicate thermometer. To facilitate the requisite thermal adjustment I propose, in a new instrument of which I shall immediately commence the construction, to substitute for the brass tube a long double girder of copper (because of the high thermal conductivity of copper), by which sufficient uniformity of temperature along the spring, throughout the mainly effective portion of its length, and up to near the sighted end, shall be secured. The water-jacket will secure a slight enough variation of temperature to allow the absolute temperature to be indicated by the thermometer with, I believe, the required accuracy.

M. Mascart's Instrument.

In 'Comptes Rendus,' xcv. (2, 1882), p. 126, is an account of a differential gravity meter by M. Mascart.

He employs a siphon barometer with the shorter tube closed, and containing gas to support the mercury in the longer tube. The gas chosen is carbon dioxide, to prevent oxidation of the mercury. The column of mercury supported is 1 metre in length. A scale is attached to the tube, and a vertical image of the scale is thrown by a gilded surface so as to coincide with the axis of the tube, and the level of the top of the mercury can thus be read off by a microscope without parallax. The height can be easily estimated with suitable illumination to ·01 millimetre. The barometer is enclosed in a metal vessel filled with water and containing a thermometer reading to $\frac{1}{50}$° C. A variation of ·01 millimetre would correspond to a change of less than half a second per day in a pendulum.

The empirical relation between temperature and level of the mercury was determined by preliminary experiments at the Collège de France.

In the same volume of 'Comptes Rendus,' p. 631, M. Mascart gives an account of observations which he made with this instrument at Paris, Hamburg, Copenhagen, Stockholm, Drontheim, and Tromsö, on the occasion of a journey to the north. The Copenhagen results could not be utilised through an accident.

The four northern stations gave results which compared with Paris differed from the theoretical values by the following amounts:—

—	$\frac{dg}{g}$	dl in mm.	dn
Hamburg	−·00003	−0·03	+ 1·2 sec.
Stockholm	−·00003	−0·03	+ 1·1 „
Drontheim	−·00024	−0·25	+ 10·6 secs.
Tromsö	−·00007	−0·07	+ 3·1 „

where $\frac{dg}{g}$ expresses the error in g.

dl expresses the error in the length of the seconds pendulum.

dn expresses the error in the number of seconds per day.

He suggests that there is a local variation at Drontheim, as the pendulum gives a variation from theory in the same direction, though only of half the amount.

M. Mascart remarks that the only conclusion which he draws is that the gravity barometer is easily transportable, and that its precision is not inferior to that of the pendulum. It only requires observations of the level of the mercury and of temperature, and the installation can easily be made in the room of an hotel in less than an hour.

M. Mascart has been kind enough to inform the Committee that, though he has published no further account of his investigations, he is still pursuing them. He has found a difficulty in transporting the instruments since constructed owing to the breaking of the tubes by the impact of the mercury. He thinks, however, that this difficulty may be overcome.

He is now observing with a somewhat similar instrument whether any changes of gravity in the same place can be detected, using a column of mercury about 4 metres long, balanced by the pressure of nitrogen in the cistern, the nitrogen being at about 5 atmospheres. The cistern is about 3 metres below the ground. So far he has only detected an annual variation correlative with the continuous variation of temperature. He intends to register the height of the mercury continuously by photography.

M. Mascart adds that he would be glad to advise in the construction of a similar instrument should its installation be contemplated.

The Committee desire to be reappointed, with the addition of Professor G. H. Darwin and Mr. Herbert Tomlinson.

Report of the Committee, consisting of Professor G. CAREY FOSTER, Sir W. THOMSON, Professor J. PERRY, Professor AYRTON, Professor W. G. ADAMS, Lord RAYLEIGH, Dr. O. J. LODGE, Dr. JOHN HOPKINSON, Dr. A. MUIRHEAD, Mr. W. H. PREECE, Mr. H. TAYLOR, Professor EVERETT, Professor SCHUSTER, Dr. J. A. FLEMING, Professor G. F. FITZGERALD, Mr. R. T. GLAZEBROOK (*Secretary*), Professor CHRYSTAL, Mr. H. TOMLINSON, Professor W. GARNETT, Professor J. J. THOMSON, *and* Mr. W. N. SHAW, *appointed for the purpose of constructing and issuing practical Standards for use in Electrical Measurements.*

[PLATES IV. AND V.]

THE Committee report that the work of testing resistance coils has been continued at the Cavendish Laboratory, and a table of the values found for the various coils examined is given :—

Legal Ohms.

No. of Coil	Resistance in Legal Ohms	Temperature
Warden & Muirhead, 640 . BA No. 155	·99872	11·5°
Warden & Muirhead, 641 . BA No. 156	9·98404	11·25°
Stuart, 5 . . . BA No. 157	1·00163	16·5°
Stuart, 6 . . . . BA No. 158	10·00642	17°
K. M. . . . . BA No. 159	·99729	12°
Elliott, 160 . . . BA No. 160	·99801	11°
Elliott, 161 . . . BA No. 161	·99791	11·4°
Elliott, 162 . . . BA No. 162	·99877	11·4°
C. U., 9 . . . . BA No. 163	·99982	12·6°
C. U., 10 . . . . BA No. 164	9·98927	12·3°
Warden, 654 . . . BA No. 165	·99936	12·1°
Elliott, 167 . . . BA No. 166	·99977	16·7°
Elliott, 168 . . . BA No. 167	·99960	16·5°
Elliott, 169 . . . BA No. 168	9·9968	16·1°
Elliott, 170 . . . BA No. 169	9·9975	16·1°
Elliott, 171 . . . BA No. 170	99·920	14·7°
Elliott, 172 . . . BA No. 171	99·917	14·7°
Elliott, 165 . . . BA No. 172	1·00003	17°

Messrs. Elliott Bros. called the attention of the Secretary, during the spring of the current year, to the fact that in some of the coils the paraffin used for insulation acquired in time a greenish tinge, which is most marked round the interior of the case and round the places at which the copper of the connecting rods comes in contact with the paraffin. Careful examination shows this green tinge in almost all the coils, and an analysis of the paraffin made by Mr. Robinson, of the Chemical Laboratory, Cambridge, proved the colour to be due to a very slight trace of copper. The insulation resistance of several of the standards was, therefore, tested by passing the current from 24 Leclanché cells through a high resistance galvanometer, and the coil from the case through the paraffin to the wire. This resistance for most of the coils tested was found to be from eight thousand to ten thousand megohms. One coil in particular, sent by Messrs. Elliott, in which the green coloration was most marked, had a resistance of 5000 megohms. Thus it is clear that the resistance of the coils is not hitherto seriously affected by the presence of the copper in the paraffin, but at the same time it becomes necessary to watch closely for any changes which may occur, and to select very carefully the material used. There appears to be great difficulty in getting rid of all the acid employed in the manufacture of the paraffin.

The only coil among those tested which showed an insulation resistance, so low as to be serious, was the one known in the Reports as Flat. When the galvanometer of 1700 ohms resistance was shunted with 4 ohms a deflection of 80 divisions on the scale was obtained. The same deflection was obtained when the resistance in circuit was a megohm and the shunt was about 20 ohms. Thus the insulation resistance of Flat was only about $\frac{1}{5}$ megohm, or 200,000 ohms.

Two coils of special interest have recently been sent to be tested. One from Prof. Himstedt, of Freiburg, will connect his determination of the ohm with those made in Cambridge; while the second is a coil of 10 B.A. units from the Johns Hopkins University, which has been compared with the coils used in the determination of the ohm there. The results of the observations on these coils are, however, not yet completely worked out.

The Committee wish to express their sense of the great desirability of establishing a National Standardising Laboratory for Electrical Instruments on a permanent basis, and their willingness to co-operate in the endeavour to secure the same.

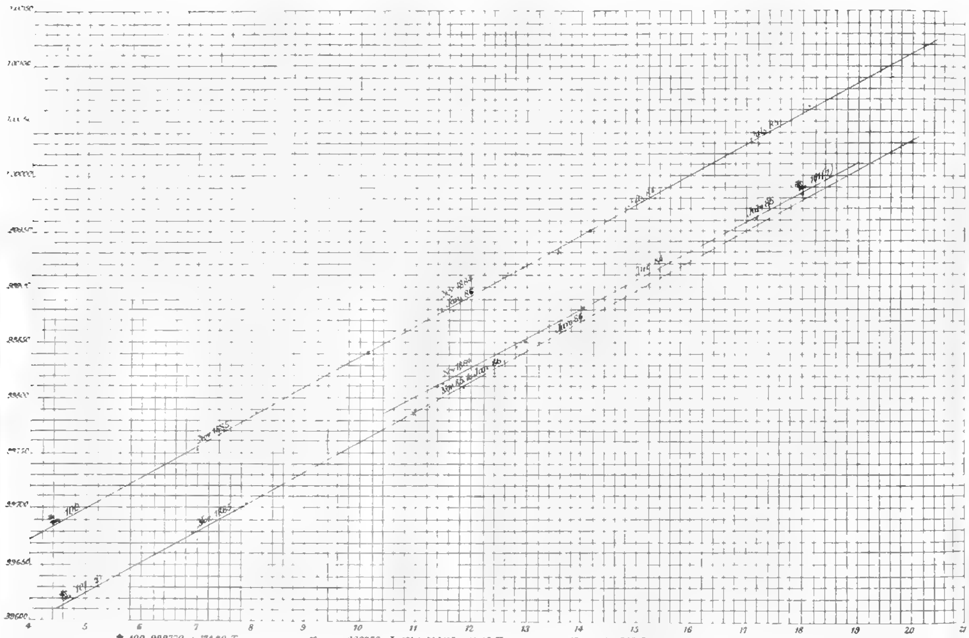
The Committee have had under consideration the question of the means to be taken to secure the general adoption of the Resolutions of the Paris Congress.

The Committee have received by the kindness of the French Government a specimen of the platinum iridium wire, of which it is proposed that the French National Standards of resistance should be constructed. They hope shortly to make a series of measurements of its specific resistance and temperature coefficient.

In conclusion they would ask to be reappointed, with the addition of the name of Mr. J. T. Bottomley and a grant of 50*l.*

CHART OF THE VALUES OF THE LEGAL OHM UNIT RESISTANCE COILS ♎ Nos 100,101

THE VERTICAL DIVISIONS ARE ·0001 LEGAL OHM THE HORIZONTAL DIVISIONS 2° CENTIGRADE



♎ 100 ·998770 at 12°·28 Temperature coefficient ·000272 ♎ 101(1) ·998815 at 14°·15 Temperature coefficient ·000259. ♎ 101(2) ·997860 at 10°·98 Temperature coefficient ·000272.

Illustrating Report on Practical Standards for use in Electrical Measurements

APPENDIX.

On the Values of some Standard Resistance Coils. By the Secretary and T. C. Fitzpatrick.

In the last report the values of the Standard Legal Ohm Coils of the Association are given. For the one-ohm coils the temperatures range from 11° to 18°, while the coils of higher resistance were examined only at temperatures near 17°. It was necessary in all cases to extend the range of temperatures in order to determine the temperature coefficient. The observations were made by the methods already described in the Reports, and the values found are given in the following tables in which the previous results are included :—

Resistance Coil, 100.

Date	Temperature	Resistance
Nov. 24, 1884	11·4°	·99876
„ 26 „	11·6°	·99888
„ 27 „	12·9°	·99916
„ 28 „	13·5°	·99930
Dec. 5 „	13·5°	·99931
„ 12 „	15·3°	·99979
July 30, 1885	17·2°	1·00027
„ 28 „	18·1°	1·00061

Mean value . . . . . . ·999510 at 14·18°.
Temperature coefficient . . . . ·000271 per 1° C.

Date	Temperature	Resistance
Nov. 21, 1885	7°	·99753
„ 24 „	7·5°	·99770
„ 23 „	8·1°	·99787
Jan. 30, 1886	11·4°	·99876
Nov. 30, 1885	11·6°	·99878
Jan. 22, 1886	12·5°	·99906
Nov. 30, 1885	12·6°	·99911

Mean value . . . . . . ·998401 at 10·10°.
Temperature coefficient . . . . ·000274 per 1° C.

Mean value of whole series . . . . . . ·998770 at 12·28°.
Temperature coefficient . . . . . . ·000272.

These results are represented graphically in Plate IV. by the curve 100, which is drawn through the means derived from the two series, and represents within the limits of accuracy of the experiments all the observations of the two series, the mean error from the curve, omitting one observation, being about ·00002.

In the diagram the circles indicate the observations of 1884–5; the dots those of 1885–6.

Resistance of Coil, TCL 101.

Date	Temperature	Resistance
Nov. 24, 1884	11·4°	·99813
„ 25 „	11·5°	·99815
Dec. 2 „	12·8°	·99847
Nov. 27 „	12·9°	·99851
Dec. 5 „	13·4°	·99865
„ 12 „	15·4°	·99917
July 30, 1885 . . .	17·2°	·99961
„ 29 „	18°	·99983

Mean value . . . . . . ·998815 at 14·15°.
Temperature coefficient . . . ·000259 per 1° C.

Date	Temperature	Resistance
Nov. 21, 1885 . . .	6·9°	·99677
„ 24 „	7·7°	·99698
„ 23 „	7·9°	·99704
Jan. 20, 1886 . . .	11·3°	·99793
Nov. 30, 1885 . . .	11·8°	·99803
Jan. 22, 1886 . . .	12·4°	·99821
Nov. 30, 1885 . . .	12·6°	·99834
Jan. 26, 1886 . . .	13·9°	·99868
„ 28 „	14·3°	·99876

Mean value . . . . ·997860 at 10·98°.
Temperature coefficient from this series . ·000272 per 1° C.

On plotting these results it becomes clear at once that the straight line joining the means of the two series will not represent the results at all. The first series is represented by the upper curve TCL 101 (1), the second series by the lower curve TCL 101 (2).

Thus it would seem that between November 1884 and November 1885 this coil had lost in resistance about ·00015 ohm at a temperature of 12° C. Again, the two curves are not parallel, so that it would seem at first sight that the temperature coefficient also has altered; but this inference is hardly justifiable, for the experiments in series (1) cover the time from November 1884 to July 1885, the high temperature observations being made at the later date; if then during that period the coil was decreasing in resistance the temperature coefficient would necessarily be too low; moreover we notice that the observations for July 1885 do not lie very far from the curve which represents the results of the second series.

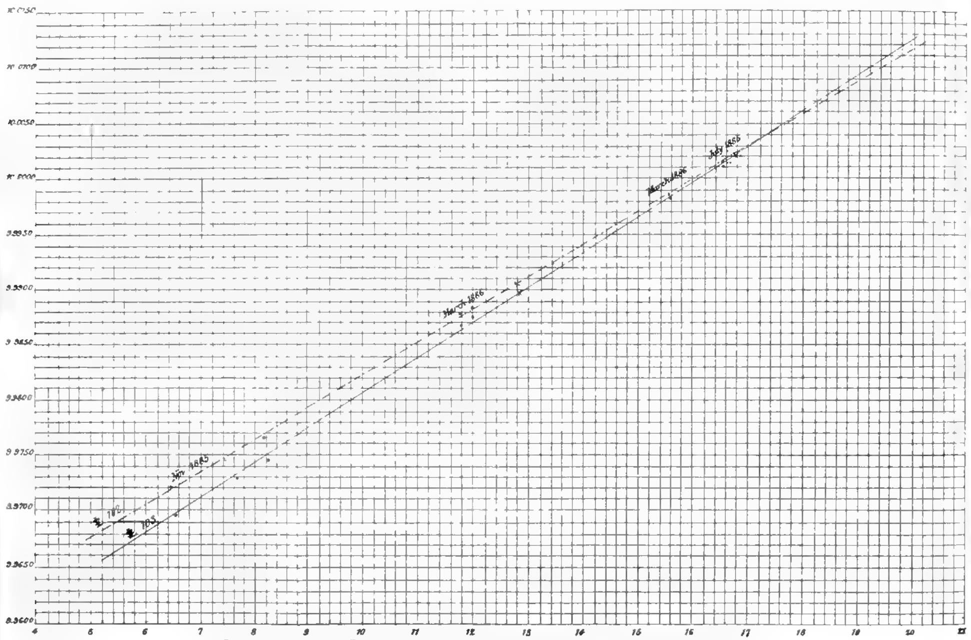
We infer then that of the two coils of platinum silver made at the same time—two years from the present date—one TCL 100 has not changed since that date, and has a value of

·998770 legal ohm at 12·28°

with a temperature coefficient of ·000272, while the other has changed by

CHART OF THE VALUES OF THE 10 LEGAL OHM COILS B.A. N^{os}. 102 AND 103.

THE VERTICAL DIVISIONS ARE ·001 LEGAL OHMS THE HORIZONTAL DIVISIONS 2° CENTIGRADE



B.A. 102 9·990597 at 12°·83 C. Temp. coefficient ·00289 per 1° C. B.A. 103 9·989714 at 12°·88 C. Temp. coefficient ·00312 per 1° C.

Illustrating Report on Practical Standards for use in Electrical Measurements.

about ·00015 ohm, and now has a value of ·997860 at 10·98° and a temperature coefficient also of ·000272.

The fact that the temperature coefficient of BA 101 is the same as that of 100 BA would appear to show that it has now reached its permanent state.

Messrs. Elliott Bros. possess a standard BA 63, made at the same time as the above two coils which in August 1884 had a resistance of

1·00027 legal ohms at 18·8°,

while in April 1886 it was found to be ·99928 at 16·6° and
·99992 at 18·6°.

From this it follows that its value at 18·8° would be ·99998, indicating a fall of ·00029 in a year and eight months.

This coil showed marked traces of the green coloration referred to in the Report, but its insulation resistance was tested and found to be 8000 megohms. Both the coils BA 100 and 101 show slight traces of the green colour; their insulation, however, is remarkably high. It would seem, then, that it is very necessary to avoid the use of newly made coils in important researches, and to keep a careful check on any secular changes by means of repeated comparison. We hope, when the permanence of BA 101 has been certainly established, to remove the paraffin and see if there is any change in the coil visible to the eye which could account for this fall in resistance.

The two ten-ohm coils BA 102, 103 have also been compared with the one-ohm in the manner described in the reports, and the values are given in the tables below. These coils are stated by Messrs. Elliott Bros. to be made of 'the same wire of platinum silver ·015 of an inch diameter and 3·52 metres long.'

Resistance of Coil, BA 102.

Date	Temperature	Value
July 1885	16·8°	10·00210
" "	16·7°	10·00222
" "	16·7°	10·00129
" "	16·6°	10·00103
March 1886	15·6°	9·99833
" "	11·9°	9·98830
" "	11·8°	9·98797
Nov. 1885	8·2°	9·97711
" "	7·5°	9·97512
" "	6·5°	9·97250

Mean value	9·990597 legal ohms at 12·83°.
Temperature coefficient . .	·00289.

This ise presented by the straight line (drawn thus - - - - - - on the diagram) BA 102, Plate V.

Resistance of Coil, TCL 103.

Date	Temperature	Value
July 1885	16·9°	10·00202
" "	16·8°	10·00197
" "	16·65°	10·00130
" "	16·6°	10·00142
March 1886 . . .	15·6°	9·99815
" "	12°	9·98767
" "	11·8°	9·98692
Nov. 1885	8·3°	9·97479
" "	7·7°	9·97315
" "	6·5°	9·96975

Mean value . . . . . 9·989714 at 12·88°.
Temperature coefficient . . ·00312.

This is represented by the second line (drawn black on the diagram) TCL 103, Plate II.

This difference between the temperature coefficients has been checked by determining the difference between the coils at different temperatures directly, and the results of the comparison are quite satisfactory.

The proportional errors of the individual observations are somewhat larger in this case than they were for the single ohms, amounting in one or two cases to ·0006, or 6 in 100,000, but the accordance is perhaps as good as can be expected. The point of interest lies in the fact that the temperature coefficients of the two coils differ so considerably as ·00289 and ·00312 per 1° C. although made at the same time from the same wire.

Similar observations have been made on the coils of 100, 1000, and 10,000 ohms, but their number is not yet sufficient for the construction of the curve of variation with temperature. These we hope to lay before the Association on some future occasion.

Second Report of the Committee, consisting of Professors A. JOHNSON (*Secretary*), J. G. MACGREGOR, J. B. CHERRIMAN, *and* H. T. BOVEY *and* Mr. C. CARPMAEL, *appointed for the purpose of promoting Tidal Observations in Canada.*

THE reply, last year, of the then Minister of Marine to the memorial presented to him by your Committee is contained in the Report of the Association. This year the Committee have again been urging on the attention of the Canadian Government the importance, looking especially to the needs of navigators, of systematic tidal observations at stations properly selected.

In last January a deputation of fifteen or sixteen—consisting of representatives of your Committee, of members of the Council of the Royal Society of Canada, and of representatives of the Board of Trade of Montreal, accompanied by Sir William Dawson as President-elect of the Association—waited on the new Minister of Marine (Hon. G. E. Foster), and subsequently on the same day had an interview with the Premier

(Sir John Macdonald), at which other members of the Cabinet, including the Minister of Marine, were present. The memorial of the Committee was very fully discussed and favourably received. The Minister of Marine, after the interview, asked for further information on practical details. This, with the aid of the data obtained from the corresponding Committee in England, was supplied to him.

The official answer was received in June, and stated that, 'while the Government is fully sensible of the importance of establishing stations for continuous tidal observations in Canadian waters, it is not proposed at present, owing to the large expense in carrying out surveys and explorations, to undertake the additional expense which would be involved in establishing the stations referred to.'

The surveys and explorations here alluded to are those in Hudson's Bay and on the Great Lakes, and your Committee were semi-officially informed that, until these are more nearly completed, it is considered unadvisable to incur the expense necessary to accomplish the tidal observations. The Committee were told, however, that 'the Government is fully alive to their importance, and much indebted to the Association for having brought the subject to their attention, and for the valuable practical hints given as to method and cost.' 'In the near future it may be able to carry out a work so necessary and useful to the commercial interests of the country.'

Under these encouraging circumstances it is thought advisable to recommend the reappointment of the Committee.

Report of the Committee, consisting of Mr. JAMES N. SHOOLBRED (*Secretary*) *and* Sir WILLIAM THOMSON, *appointed for the Reduction and Tabulation of Tidal Observations in the English Channel, made with the Dover Tide-gauge, and for connecting them with Observations made on the French Coast.*

[PLATE VI.]

YOUR Committee (having, through the courtesy of the Board of Trade, been placed in possession of the records of the self-registering tide-gauge at Dover for the four years 1880–3, and also having been presented by the Minister of Public Works of Belgium with copies of the curves of the self-registering gauge at Ostend) stated in their Report last year, that they had completed the reduction and comparison of the times and heights of high water and of low water during these four years at both places.

In order to obtain a common datum-plane for the reduction of the different levels, advantage has been taken of the international datum, which had been established by the British Association Committee 'On the Ordnance Survey of Great Britain,' and which had been made use of by the British Association Committee 'On the Stationary Tides in the English Channel,' in the reduction of the simultaneous observations taken in 1878.

This datum is 20 feet below that of the ordnance of Great Britain; and it is practically (on the assumption of an uniform mean sea-level at

Dover and at Calais) 5·50 metres below the French 'zéro du nivellement' (Bourdaloue).

Since the meeting of last year the Committee, considering that these four years' observations would, in their entirety, form too large a mass for publication, decided upon specially preparing a more limited portion of these observations.

After much consideration, as the records of the year 1883 appeared on the whole to be the most reliable and complete, selections were made of a fortnight before and after the winter, and also at the summer solstice, and of a similar period at the vernal and at the autumnal equinox in that year; those times appearing to offer most points of interest.

The high water and low water observations during these four periods are appended to this Report, as also a continuous diagram of the two sets of observations during one of the periods (the vernal equinox).

It has been repeatedly felt by the Committee that there are many points of interest which present themselves in the four-year period embraced by the entire records which are beyond the scope of the present Committee, and which would require a complete and exhaustive examination of those records to fully disclose them.

Your Committee, therefore, before closing their labours, would suggest, that, if the Committee 'On the Harmonic Analysis of Tidal Observations' considered the investigation of the tides of the English Channel to be within the scope of their inquiry, the present Committee would, with the consent of the respective authorities, be glad to place at the disposal of the Committee 'On Harmonic Analysis' the records of the Dover and of the Ostend tide-gauges; as also any further information in their possession.

In the earlier stages of the work of the present Committee it was hoped that some of the records of the self-registering tide gauges on the French coast would have been included in the comparison of the various tidal observations in the English Channel. It was found, however, that the difficulty to obtain records continuously throughout the four-year period selected was very considerable. With the more limited periods of four separate months in one year the difficulty is very materially reduced.

It is still possible, that a comparative record of at least one of these shorter periods from a point on the French coast may yet arrive so as to be presented with the other observations accompanying this Report.

In conclusion the Committee request, that the thanks of the British Association be conveyed to the President of the Board of Trade, and to the Minister of Public Works of Belgium for their courtesy in placing at the disposal of the Committee the records of the tide-gauges at Dover and at Ostend respectively. Also to the several other authorities and private individuals, for the kind assistance they have afforded to the Committee during the course of their investigations.

Plate VI

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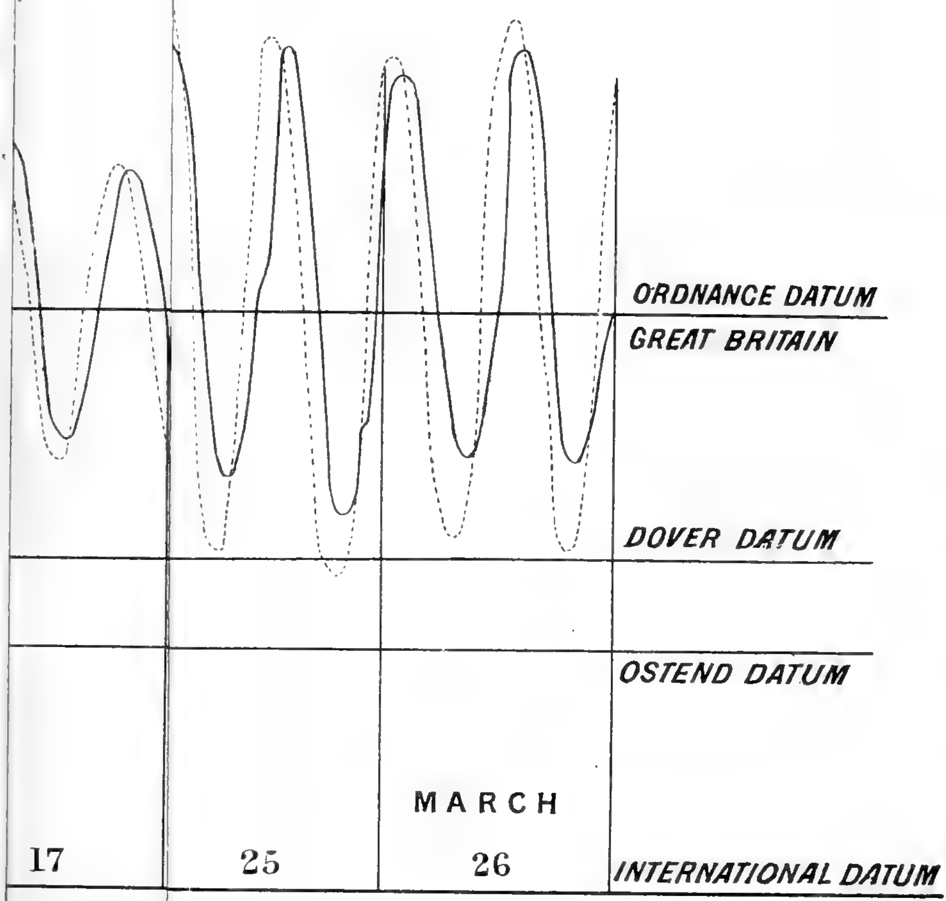
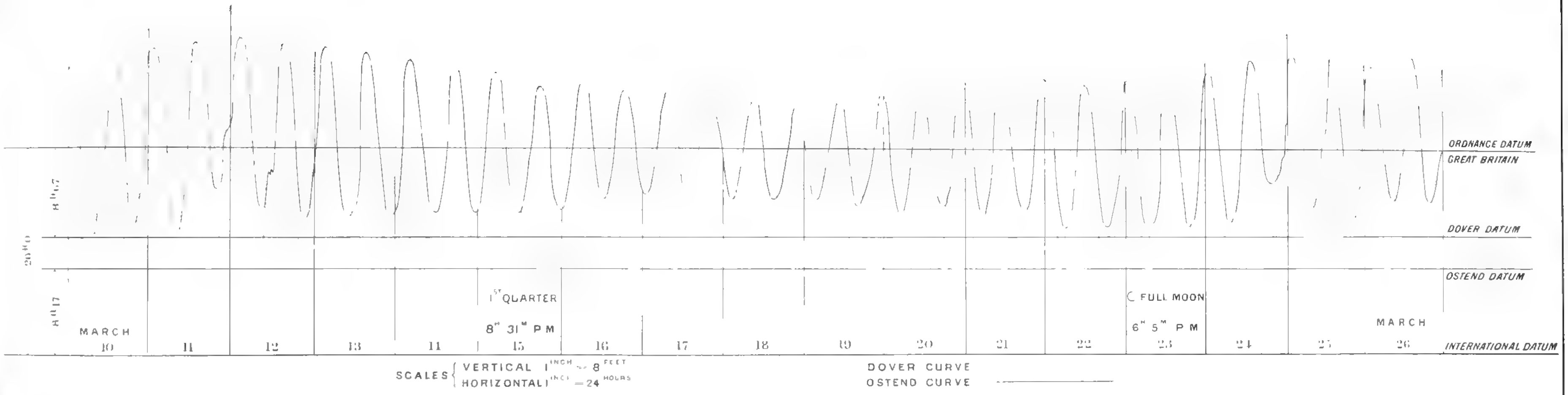


ng Report o

COMPARISON OF TIDAL CURVES AT DOVER AND AT OSTEND.

VERNAL EQUINOX—MARCH 10 TO 26, 1883.



Illustrating Report on Tidal Observations in the English Channel

Times of High Water and of Low Water, taken from self-registering gauge curves at Dover and at Ostend.

WINTER SOLSTICE.—December 7, 1882, to January 4, 1883.

DOVER					OSTEND					Remarks
Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	{ D. = Dover O. = Ostend }
		feet					feet			
December 6	1.5 P.M.	14·03	L.W.	29·16	December 6	3.44 P.M.	14·92	L.W.	29·18	
,, ,,	7.20 ,,	26·03	H.W.	NW 3	,, ,,	9.30 ,,	25·92	H.W.	SSW 1	Stormy (O.)
,, 7	1.33 A.M.	14·33	L.W.		,, 7	4.5 A.M.	15·00	L.W.		
,, ,,	7.33 ,,	27·03	H.W.	29·30	,, ,,	9.47 ,,	26·17	H.W.	29·18	
,, ,,	1.58 P.M.	13·88	L.W.	ENE 3	,, ,,	4.31 P.M.	14·67	L.W.	E 1	
,, ,,	8.28 ,,	26·48	H.W.		,, ,,	9.59 ,,	26·25	H.W.		
,, 8	2.17 A.M.	13·33	L.W.		,, 8	5.0 A.M.	14·00	L.W.		
,, ,,	9.9 ,,	25·23	H.W.	29·18	,, ,,	10.35 ,,	26·08	H.W.	29·35	
,, ,,	2.43 P.M.	12·43	L.W.	ESE 5	,, ,,	5.12 P.M.	13·83	L.W.	SSE 4	Stormy (O.)
,, ,,	8.50 ,,	27·33	H.W.		,, ,,	10.56 ,,	26·92	H.W.		
,, 9	3.4 A.M.	12·53	L.W.		,, 9	5.42 A.M.	14·08	L.W.		
,, ,,	9.12 ,,	27·53	H.W.	29·65	,, ,,	11.7 ,,	27·00	H.W.	29·70	
,, ,,	3.30 P.M.	12·03	L.W.	W 4	,, ,,	5.54 P.M.	13·58	L.W.	SSW 3	Stormy (O.)
,, ,,	9.40 ,,	27·53	H.W.		,, ,,	11.35 ,,	27·17	H.W.		
,, 10	3.51 A.M.	11·88	L.W.		,, 10	6.21 A.M.	13·33	L.W.	29·79	
,, ,,	9.50 ,,	28·03	H.W.	29·76	,, ,,	11.47 ,,	27·42	H.W.	WSW 1	● New Moon
,, ,,	4.8 P.M.	11·53	L.W.	NNE 2	,, ,,	6.28 P.M.	13·50	L.W.		3h. 38m. P.M.
,, ,,	10.11 ,,	28·68	H.W.		,, 11	0.22 ,,	27·83	H.W.		
,, 11	4.32 A.M.	11·68	L.W.		,, ,,	7.3 ,,	13·33	L.W.	29·75	
,, ,,	10.30 ,,	28·68	H.W.	29·75	,, ,,	0.26 P.M.	27·83	H.W.	WSW 3	
,, ,,	4.50 P.M.	11·33	L.W.	NNE 3	,, ,,	7.8 ,,	13·33	L.W.		
,, ,,	10.48 ,,	29·03	H.W.		,, 12	0.45 A.M.	27·83	H.W.		
,, 12	5.10 A.M.	11·33	L.W.		,, ,,	7.36 ,,	13·00	L.W.	29·82	
,, ,,	11.10 ,,	28·93	H.W.	29·75	,, ,,	1.1 P.M.	28·00	H.W.	ESE 3	
,, ,,	5.28 P.M.	11·43	L.W.	SSE 3	,, ,,	7.45 ,,	13·33	L.W.		

WINTER SOLSTICE—*continued.*

DOVER					OSTEND					Remarks
Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	{D. = Dover} {O. = Ostend}
		feet					feet			
December 12	11.38 P.M.	28·93	H.W.							
,, 13	8.45 A.M.	11·23	L.W.	29·59	December 13	1.12 A.M.	27·92	H.W.		
,, ,,	0.2 P.M.	28·43	H.W.	SSW 4	,, ,,	8.16 ,,	12·75	L.W.	29·67	
,, ,,	6.8 ,,	11·33	L.W.		,, ,,	1.43 P.M.	27·83	H.W.	SSE 1	
,, 14	0.20 A.M.	28·78	H.W.		,, ,,	8.26 ,,	13·50	L.W.		
,, ,,	6.28 ,,	11·33	L.W.	29·69	,, 14	1.58 A.M.	28·00	H.W.		
,, ,,	0.35 P.M.	28·68	H.W.	NE 2	,, ,,	8.53 ,,	13·00	L.W.	29·72	
,, ,,	6.50 ,,	11·53	L.W.		,, ,,	2.34 P.M.	28·17	H.W.	SE 3	
,, 15	0.43 A.M.	29·23	H.W.		,, ,,	9.8 ,,	13·92	L.W.		
,, ,,	7.12 ,,	11·78	L.W.	29·84	,, 15	2.46 A.M.	27·92	H.W.		
,, ,,	1.14 P.M.	28·68	H.W.	ENE 1	,, ,,	9.34 ,,	13·25	L.W.	29·89	
,, ,,	7.35 ,,	12·23	L.W.		,, ,,	3.31 P.M.	28·00	H.W.	SW 3	
,, 16	1.33 A.M.	28·53	H.W.		,, ,,	9.49 ,,	14·25	L.W.		
,, ,,	8.5 ,,	11·88	L.W.	29·96	,, 16	3.32 A.M.	27·42	H.W.		
,, ,,	2.18 P.M.	26·93	H.W.	SSE 1	,, ,,	10.44 ,,	12·67	L.W.	30·02	
,, ,,	8.25 ,,	12·23	L.W.		,, ,,	4.9 P.M.	26·75	H.W.	ESE 4	
,, 17	2.35 A.M.	26·93	H.W.		,, ,,	10.43 ,,	13·83	L.W.		
,, ,,	8.55 ,,	11·68	L.W.	29·94	,, 17	4.27 A.M.	26·17	H.W.		☽ First quarter
,, ,,	3.19 P.M.	25·33	H.W.	SW 3	,, ,,	11.36 ,,	12·25	L.W.	30·01	4h. 39m. P.M.
,, ,,	9.15 ,,	12·13	L.W.		,, ,,	5.10 P.M.	25·58	H.W.	S 3	
,, 18	4.0 A.M.	25·33	H.W.		,, ,,	11.38 ,,	13·50	L.W.		
,, ,,	9.52 ,,	12·43	L.W.	29·73	,, 18	5.29 A.M.	25·75	H.W.		
,, ,,	4.35 P.M.	25.13	H.W.	SW 4	,, ,,	,,		L.W.	29·96	
,, ,,	10.20 ,,	13·03	L.W.		,, ,,	P.M.	Break	H.W.	SE 1	
,, 19	4.47 A.M.	25·88	H.W.		,, 19	,,		L.W.		
,, ,,	11.10 ,,	12·53	L.W.	30·00	,, ,,	A.M.		H.W.	30·04	
,, ,,	5.30 P.M.	25·78	H.W.	E 3	,, ,,	1.35 P.M.	13·25	L.W.	E 1	
,, ,,	11.43 ,,	13·33	L.W.		,, ,,	7.30 ,,	26·00	H.W.		

,,	20	5.48	A.M.	26·33	H.W.	30·36	,,	20	2.5	A.M.	14·42	L.W.		
,,	,,	0.20	P.M.	12·23	L.W.	Z 0	,,	,,	7.44	,,	25·33	H.W.	30·42	
,,	,,.	6.42	,,	25·78	H.W.		,,	,,	2.53	P.M.	12·92	L.W.	ESE 1	
,,	21	0.58	A.M.	12·88	L.W.		,,	,,	8.50	,,	25·50	H.W.		
,,	,,	7.30	,,	25·33*	H.W.	29·99	,,	21	3.22	A.M.	13·50	L.W.		
,,	,,	1.28	P.M.	12·43	L.W.	WSW 6	,,	,,	8.58	,,	25·67	H.W.	30·10	
,,	,,	8.10	,,	25·83*	H.W.		,,	,,	3.58	P.M.	14·25	L.W.	SSW 3	
,,	22	2.10	A.M.	13·33	L.W.		,,	,,	9.25	,,	25·50	H.W.		
,,	,,	8.32	,,	27·23	H.W.	29·83	,,	22	4.20	A.M.	15·33	L.W.		
,,	,,	2.44	P.M.	12·43	L.W.	W 4	,,	,,	10.3	,,	27·42	H.W.	29·88	
,,	,,	8.44	,,	28·03	H.W.		,,	,,	4.44	P.M.	13·92	L.W.	SW 3	
,,	23	3.12	A.M.	12·03	L.W.		,,	,,	10.28	,,	27·25	H.W.		
,,	,,	8.56	,,	28·78	H.W.	29·50	,,	23	5.3	A.M.	14·08	L.W.		
,,	,,	3.23	P.M.	12·53	L.W.	NW 5	,,	,,	11.6	,,	28·42	H.W.	29·43	Stormy (O.)
,,	,,	9.50	,,	28·33	H.W.		,,	,,	5.29	P.M.	15·42	L.W.	W 3	
,,	24	4.0	A.M.	12·13	L.W.		,,	,,		,,		H.W.		
,,	,,	9.45	,,	29·33	H.W.	29·79	,,	24		A.M.		L.W.		○ Full Moon 3h. 41m. P.M. N.B. — The Dover H. W. levels, marked thus,* between the 21st and the 31st, are to be mistrusted; as the registration of the instrument was evidently faulty as to those points.
,,	,,	4.25	P.M.	11·33	L.W.	NW 4	,,	,,		,,		H.W.		
,,	,,	10.2	,,	29·03	H.W.		,,	,,		P.M.		L.W.		
,,	25	4.35	A.M.	10·98	L.W.		,,	,,		,,		H.W.		
,,	,,	11.2	,,	27·88	H.W.	29·66	,,	25		A.M.		L.W.		
,,	,,	4.59	P.M.	11·78	L.W.	SW 3	,,	,,		P.M.	Break.	H.W.		
,,	,,	11.5	,,	28·68	H.W.		,,	,,		,,		L.W.		
,,	26	5.5	A.M.	12·13	L.W.		,,	26		A.M.		H.W.		
,,	,,	11.30	,,	26·33*	H.W.	29·36	,,	,,		,,		L.W.		
,,	,,	5.40	P.M.	12·13	L.W.	WSW 5	,,	,,		P.M.		H.W.		
,,	,,	11.48	,,	29·53	H.W.		,,	,,		,,		L.W.		
,,	27	6.0	A.M.	11·78	L.W.	29·56	,,	27		A.M.		H.W.		
,,	,,	0.38	P.M.	26·83	H.W.	WSW 4	,,	,,		,,		L.W.		
,,	,,	6.6	,,	11·43	L.W.		,,	,,	1.27	P.M.	27·87	H.W.	29·59	
,,	28	0.40	A.M.	26·43*	H.W.		,,	,,	8.36	,,	13·67	L.W.	WSW 7	
,,	,,	6.27	,,	11·33	L.W.	29·76	,,	28	2.1	A.M.	27·77	H.W.		
,,	,,	2.0	P.M.	25·23*	H.W.	WSW 5	,,	,,	9.5	,,	13·12	L.W.	29·79	
,,	,,	6.37	,,	12·23	L.W.		,,	,,	2.30	P.M.	27·77	H.W.	WSW 7	
,,	29	1.10	A.M.	25·83*	H.W.		,,	,,	8.58	,,	14·77	L.W.		
,,	,,	7.0	,,	11·68	L.W.	29·70	,,	29	2.38	A.M.	27·87	H.W.		
,,	,,	1.55	P.M.	25·33*	H.W.	WSW 7	,,	,,	9.48	,,	12·67	L.W.	29·81	
,,	,,	7.12	,,	12·13	L.W.		,,	,,	3.10	P.M.	26·57	H.W.	SSW 4	
							,,	,,	9.48	,,	14·37	L.W.		
,,	30	2.15	A.M.	— *	H.W.	29·79	,,	30	3.30	A M.	27·57	H.W.	29·83	
,,	,,	7.34	,,	13·58	L.W.	W 5	,,	,,	10.5	,,	15·17	L.W.	SW 4	

WINTER SOLSTICE.—*continued.*

Dover					Ostend					Remarks
Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	{D. = Dover} {O. = Ostend}
		feet					feet			
December 30	2.45 P.M.	24·03*	H.W.		December 30	4.7 P.M.	28·37	H.W.		
,, ,,	8.11 ,,	14·13	L.W.		,, ,,	11.31 ,,	15·67	L.W.		
,, 31	3.20 A.M.	24·73*	H.W.		,, 31	3.45 A.M.	26·32	H.W.	30·01	
,, ,,	8.27 ,,	12·53	L.W.	29·96	,, ,,	11.21 ,,	12·92	L.W.	E 1	
,, ,,	3.45 P.M.	23·03*	H.W.	W 1	,, ,,	P.M.	Break	H.W.		
,, ,,	8.45 ,,	13·58	L.W.		,, ,,	,,		L.W.		
January 1	3.41 A.M.	25·13*	H.W.	29·81	January 1	4.45 A.M.	26·67	H.W.	29·89	
,, ,,	9.8 ,,	14·68	L.W.	SW 5	,, ,,	11.33 ,,	15·17	L.W.	W 5	☾ Last quarter 12h. 50m. P.M.
,, ,,	P.M.		H.W.		,, ,,	5.8 P.M.	25·37	H.W.		
,, ,,	,,		L.W.		,, ,,	11.53 ,,	15·47	L.W.		
,, 2	A.M.		H.W.		,, 2	5.24 A.M.	25·67	H.W.	29·85	
,, ,,	,,		L.W.	29·76	,, ,,	0.24 P.M.	16·47	L.W.	WSW 3	
,, ,,	P.M.		H.W.	WSW 6	,, ,,	6.19 ,,	26·17	H.W.		
,, 3	,,	Break	L.W.		,, 3	0.33 A.M.	18·27	L.W.		
,, ,,	A.M.		H.W.	29 93	,, ,,	6.36 ,,	26·97	H.W.	29·88	
,, ,,	,,		L.W.	WNW 4	,, ,,	1.28 P.M.	16·77	L.W.	W 4	
,, ,,	P.M.		H.W.		,, ,,	7.23 ,,	25·17	H.W.		
,, 4	,,		L.W.		,, 4	2.12 A.M.	15·67	L.W.		
,, ,,	A.M.		H.W.	30·23	,, ,,	7.55 ,,	24·17	H.W.	30·22	
,, ,,	1.50 P.M.	14·93	L.W.	E 1	,, ,,	2.48 P.M.	14·67	L.W.	NNW 1	
,, ,,	7.24 ,,	25·33*	H.W.		,, ,,	8.38 ,,	24·67	H.W.		
VERNAL EQUINOX.—March 7 to April 4, 1883.										
March 6	4.15 P.M.	17·13	L.W.	30·14	March 6	4.19 P.M.	21·47	L.W.	29·96	Stormy
,, ,,	9.16 ,,	30·99	H.W.	N 5	,, ,,	10.29 ,,	29·17	H.W.	NW 5	(D. and O.)
,, 7	4.59 A.M.	13·13	L.W.		,, 7	5.13 A.M.	15·17	L.W.		
,, ,,	9.44 ,,	28·88	H.W.	29·89	,, ,,	11.14 ,,	28·27	H.W.	29·78	Stormy
,, ,,	4.59 P.M.	11·33	L.W.	N 6	,, ,,	5.10 P.M.	14·52	L.W.	NNW 3	(D. and O.)
,, ,,	9.55 ,,	29·88	H.W.		,, ,,	11.22 ,,	28·27	H.W.		

„	8	5.32 A.M.	10·78	L.W.		„	8	5.48 A.M.	12·12	L.W.	29·61	
„	„	10.18 „	29·33	H.W.	29·62	„	„	11.37 „	28·02	H.W.	NE 3	
„	„	5.52 P.M.	9·88	L.W.	E 3	„	„	6.9 P.M.	12·47	L.W.		
„	„	10.36 „	29·88	H.W.		„	9	0.2 A.M.	27·67	H.W.		
„	9	6.12 A.M.	8·63	L.W.		„	„	6.33 „	11·07	L.W.	29·89	● New moon
„	„	11.0 „	29·43	H.W.	29·90	„	„	0.33 P.M.	27·72	H.W.	ENE 4	4h. 31m. A.M.
„	„	6.32 P.M.	8·53	L.W.	E 6	„	„	6.53 „	11·62	L.W.		
„	„	11.26 „	30·48	H.W.		„	10	0.54 A.M.	27·77	H.W.		
„	10	7.0 A.M.	7·98	L.W.		„	„	7.27 „	11·07	L.W.	29·76	
„	„	11.54 „	30·38	H.W.	29·81	„	„	1.6 P.M.	28·87	H.W.	NE 4	
„	„	7.17 P.M.	8·88	L.W.	NE 6	„	„	7.35 „	12·27	L.W.		
„	„	11.59 „	31·68	H.W.		„	11	1.12 A.M.	29·17	H.W.	29·64	Rough (D.)
„	11	7.43 A.M.	8·53	L.W.	29·66	„	„	7.58 „	11·72	L.W.	WSW 1	
„	„	0.25 P.M.	31·58	H.W.	NNW 3	„	„	2.1 P.M.	30·27	H.W.		
„	„	7.47 „	10·53	L.W.		„	„	7.59 „	15·72	L.W.		Rough (D.)
„	12	0.34 A.M.	34·03	H.W.		„	12	2.18 A.M.	31·17	H.W.		Stormy (O.)
„	„	8.35 „	10·13	L.W.	29·61	„	„	8.48 „	13·47	L.W.	29·60	
„	„	0.58 P.M.	31·48	H.W.	N 5	„	„	2.48 P.M.	29·87	H.W.	NW 4	
„	„	8.50 „	9·43	L.W.		„	„	9.0 „	12·97	L.W.		
„	13	1.28 A.M.	31·23	H.W.		„	13	2.48 A.M.	29·57	H.W.		
„	„	9.5 „	9·63	L.W.	29·98	„	„	9.29 „	13·07	L.W.	29·86	Stormy (O.)
„	„	1.50 P.M.	30·23	H.W.	NNW 4	„	„	3.18 P.M.	28·97	H.W.	WNW 7	
„	„	9.18 „	9·88	L.W.		„	„	10.0 „	13·07	L.W.		
„	14	2.18 A.M.	30·38	H.W		„	14	3.35 A.M.	28·52	H.W.		
„	„	9.43 „	9·23	L.W.	29·74	„	„	10.22 „	12·97	L.W.	29·74	
„	„	2.32 P.M.	29·03	H.W.	N 3	„	„	4.23 P.M.	27·72	H.W.	SSW 1	
„	„	10.1 „	10·88	L.W.		„	„	10.40 „	13·17	L.W.		
„	15	3.0 A.M.	28·78	H.W.		„	15	4.29 A.M.	27·37	H.W.		
„	„	10.28 „	11·53	L.W.	29·60	„	„	11.10 „	13·37	L.W.	29·63	☽ First quarter
„	„	3.32 P.M.	27·53	H.W.	E 5	„	„	5.33 P.M.	25·92	H.W.	ENE 3	8h. 31m. P.M.
„	„	10.50 „	12·03	L.W.		„	„	11.31 „	13·72	L.W.		
„	16	4.0 A.M.	27·13	H.W.		„	16	5.41 A.M.	26·82	H.W.		
„	„	11.21 „	13·23	L.W.	29·61	„	„	0.10 P.M.	14·97	L.W.	29·63	
„	„	4.35 P.M.	26·48	H.W.	NNW 1	„	„	6.10 „	25·82	H.W.	SW 3	
„	„	11.51 „	13·43	L.W.		„	17	0.48 A.M.	15·32	L.W.		
„	17	5.24 A.M.	25·68	H.W.		„	„	6.48 „	26·07	H.W.	29·65	
„	„	0.33 P.M.	14·38	L.W.	29·55	„	„	1.35 P.M.	15·37	L.W.	SSW 1	
„	„	6.6 „	25·13	H.W.	W 3	„	„	7.26 „	24·92	H.W.		
„	18	1.14 A.M.	13·88	L.W.		„	18	2.28 A.M.	14·87	L.W.		
„	„	7.2 „	24·88	H.W.	29·63	„	„	8.18 „	25·07	H.W.	29·75	
„	„	2.8 P.M.	13·58	L.W.	W 2	„	„	3.13 P.M.	14·67	L.W.	SSE3	
„	„	7.35 „	24·88	H.W.		„	„	8.58 „	23·87	H.W.	3	

VERNAL EQUINOX—*continued.*

DOVER					OSTEND					Remarks {D.=Dover} {O.=Ostend}
Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	
		feet					feet			
March 19	2.45 A.M.	12·03	L.W.		March 19	3.48 A.M.	12·97	L.W.		
,, ,,	8.26 ,,	24·68	H.W.	29·72	,, ,,	10.1 ,,	24·77	H.W.	29·72	
,, ,,	3.0 P.M.	12·78	L.W.	ENE 3	,, ,,	4.5 P.M.	14·07	L.W.	ESE 3	Stormy (O.)
,, ,,	8.44 ,,	26·23	H.W.		,, ,,	10.0 ,,	25·07	H.W.		
,, 20	3.49 A.M.	11·88	L.W.		,, 20	4.46 A.M.	13·02	L.W.		
,, ,,	9.15 ,,	26·48	H.W.	29·64	,, ,,	10.18 ,,	25·22	H.W.	29·64	
,, ,,	4.20 P.M.	12·23	L.W.	E 4	,, ,,	5.5 P.M.	13·87	L.W.	E 4	Stormy (O.)
,, ,,	9.29 ,,	27·63	H.W.		,, ,,	10.48 ,,	26·27	H.W.		
,, 21	4.42 A.M.	11·78	L.W.		,, 21	5.33 A.M.	13·22	L.W.		
,, ,,	9.50 ,,	27·88	H.W.	29·58	,, ,,	11.8 ,,	26·92	H.W.	29·63	
,, ,,	5.12 P.M.	11·78	L.W.	E 5	,, ,,	6.0 P.M.	13·47	L.W.	ENE 3	
,, ,,	10.5 ,,	27·88	H.W.		,, ,,	11.30 ,,	26·47	H.W.		
,, 22	5.34 A.M.	10·13	L.W.		,, 22	6.7 A.M.	11·72	L.W.		
,, ,,	10.30 ,,	27·33	H.W.	30·04	,, ,,	11.55 ,,	25·82	H.W.	30·06	
,, ,,	5.49 P.M.	10·13	L.W.	E 7	,, ,,	6.23 P.M.	12·07	L.W.	ENE 8	Stormy (D. & O.)
,, ,,	10.47 ,,	28·13	H.W.		,, 23	0.3 A.M.	26·17	H.W.		
,, 23	6.11 A.M.	9·78	L.W.		,, ,,	6.43 ,,	12·67	L.W.	30·14	
,, ,,	11.4 ,,	27·78	H.W.	30·14	,, ,,	0.28 P.M.	26·67	H.W.	ENE 4	○ Full moon
,, ,,	6.22 P.M.	10·13	L.W.	E 6	,, ,,	6.41 ,,	12·57	L.W.		6h. 5m. P.M.
,, ,,	11.15 ,,	29·13	H.W.		,, 24	0.19 A.M.	27·42	H.W.		Stormy (D. & O.)
,, 24	6.36 A.M.	10·23	L.W.		,, ,,	7.11 ,,	12·67	L.W.	29·97	
,, ,,	11.39 ,,	29·13	H.W.	29·96	,, ,,	0.59 P.M.	28·57	H.W.	WNW 3	Stormy (D. & O.)
,, ,,	6.31 P.M.	12·33	L.W.	N 3	,, ,,	7.9 ,,	16·37	L.W.		
,, ,,	11.33 ,,	31·33	H.W.		,, 25	0.57 A.M.	29·27	H.W.		
,, 25	7.5 A.M.	11·13	L.W.		,, ,,	7.25 ,,	14·02	L.W.	29·77	
,, ,,	11.59 ,,	30·03	H.W.	29·79	,, ,,	1.48 P.M.	28·87	H.W.	WSW 3	Stormy (D. & O.)
,, ,,	7.24 P.M.	12·33	L.W.	N 3	,, ,,	7.58 ,,	12·82	L.W.		

,,	26	0.19 A.M.	28·88	H.W.		,,	26	1.58 A.M.	28·47	H.W.		
,,	,,	7.33 ,,	11·68	L.W.	29·20	,,	,,	8.7 ,,	14·62	L.W.	29·17	Stormy (D. & O.)
,,	,,	0.23 P.M.	30·38	H.W.	N 4	,,	,,	2.8 P.M.	29·93	H.W.	SW 3	
,,	,,	7.49 ,,	11·53	L.W.		,,	,,	8.23 ,,	14·02	L.W.		
,,	27	0.39 A.M.	29·78	H.W.		,,	27	2.32 A.M.	28·17	H.W.		
,,	,,	8.0 ,,	11·13	L.W.	29·42	,,	,,	8.40 ,,	13·62	L.W.	29·38	
,,	,,	0.58 P.M.	29·23	H.W.	N 3	,,	,,	2.8 P.M.	28·07	H.W.	SW 3	Stormy (O.)
,,	,,	8.15 ,,	11·13	L.W.		,,	,,	8.51 ,,	13·52	L.W.		
,,	28	1.11 A.M.	28·53	H.W.		,,	28	2.37 A.M.	27·72	H.W.		
,,	,,	8.24 ,,	12·53	L.W.	30.00	,,	,,	8.57 ,,	13·92	L.W.	30·00	
,,	,,	1.26 P.M.	28·68	H.W.	NNW 2	,,	,,	3.3 P.M.	27·67	H.W.	SW 3	Stormy (O.)
,,	,,	8.46 ,,	11·88	L.W.		,,	,,	9.32 ,,	14·07	L.W.		
,,	29	1.38 A.M.	28·13	H.W.		,,	29	3.19 A.M.	26·87	H.W.		
,,	,,	8.58 ,,	11·33	L.W.	30·15	,,	,,	9.48 ,,	13·02	L.W.	30·26	
,,	,,	2.0 P.M.	26·83	H.W.	SSW 3	,,	,,	3.14 P.M.	25·72	H.W.	SSW 1	
,,	,,	9.5 ,,	11·43	L.W.		,,	,,	10.15 ,,	12·47	L.W.		
,,	30	2.28 A.M.	25·43	H.W.		,,	30	3.20 A.M.	24·32	H.W.		
,,	,,	9.25 ,,	10·78	L.W.	29·58	,,	,,	10.40 ,,	11·72	L.W.	29·78	
,,	,,	3.5 P.M.	23·78	H.W.	SSW 5	,,	,,	4.10 P.M.	23·62	H.W.	SSE 5	Stormy (D. & O.)
,,	,,	9.23 ,,	12·33	L.W.		,,	,,	10.19 ,,	14·97	L.W.		
,,	31	3.8 A.M.	27·23	H.W.		,,	31	4.29 A.M.	27·12	H.W.		
,,	,,	10.10 ,,	14·38	L.W.	29·88	,,	,,	11.7 ,,	15·87	L.W.	29·88	
,,	,,	3.20 P.M.	26·83	H.W.	NW 1	,,	,,	4.48 P.M.	25·82	H.W.	W 3	☾ Last quarter
,,	,,	10.38 ,,	14·23	L.W.		,,	,,	11.28 ,,	15.22	L.W.		8h. 21m. PM.
April	1	4.0 A.M.	25·88	H.W.		April	1	5.19 A.M.	25·62	H.W.		
,,	,,	11.15 ,,	14·03	L.W.	30·29	,,	,,	0.14 P.M.	15·02	L.W.	30·29	
,,	,,	4.39 P.M.	24·78	H.W.	ENE 2	,,	,,	6.7 ,,	24·17	H.W.	ENE 3	
,,	,,	11.47 ,,	14·03	L.W.		,,	2	0.43 A.M.	14·62	L W.		
,,	2	5.35 A.M.	24·78	H.W.		,,	,,	6.48 A.M.	24.87	H.W.	30·22	
,,	,,	0.34 P.M.	14·23	L.W.	30·17	,,	,,	1.29 P.M.	15·17	L.W.	SE 1	
,,	,,	6.10 ,,	25·03	H.W.	Z 0	,,	,,	7.32 ,,	24·47	H.W.		
,,	3	1.20 A.M.	13·78	L.W.		,,	3	2.18 A.M.	14·92	L.W.		
,,	,,	7.9 ,,	25·68	H.W.	30·18	,,	,,	8.25 ,,	25·77	H.W.	30·21	
,,	,,	2.7 P.M.	13·88	L.W.	Z 0	,,	,,	2.54 P.M.	15·37	L.W.	SSW 1	
,,	,,	7.28 ,,	26·68	H.W.		,,	,,	8.48 ,,	25·47	H.W.		
,,	4	2.48 A.M.	12·53	L.W.		,,	4	3.39 A.M.	13·97	L.W.		
,,	,,	8.14 ,,	26 58	H.W.	30·24	,,	,,	9.35 ,,	25·62	H.W.	30·24	
,,	,,	3.16 P.M.	12·03	L.W.	Z 0	,,	,,	4.8 P.M.	14·12	L.W.	WSW 1	
,,	,,	8.31 ,,	27·68	H.W.		,,	,,	9.55 ,,	26·42	H.W.		

SUMMER SOLSTICE.—June 7th to July 5th, 1883.

DOVER					OSTEND					
Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather Barometer Wind-force	Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather Barometer Wind-force	Remarks { D. = Dover } { O. = Ostend }
		feet					feet		29·77	
June 6	7.0 P.M.	10·68	L.W.	29·81	June 6	7.35 P.M.	12·37	L.W.	NNE 4	
„ „	11.50 „	31·03	H.W.	ENE 4	„ 7	1.21 A.M.	28·82	H.W.		Rough (O.)
„ 7	7.23 A.M.	10·98	L.W.		„ „	7.54 „	13·07	L.W.	29·71	
„ „	0.4 P.M.	31·13	H.W.	29·75	„ „	1.38 P.M.	28·57	H.W.	NE 3	
„ „	7.41 „	10·88	L.W.	ENE 3	„ „	8.24 „	12·57	L.W.		
„ 8	0.39 A.M.	30·58	H.W.		„ 8	2.3 A.M.	28.72	H.W.		
„ „	8.4 „	11·33	L.W.	29·78	„ „	8.31 „	13·57	L.W.	29·79	
„ „	0.58 P.M.	30·83	H.W.	ENE 2	„ „	2.23 P.M.	28·27	H.W.	ENE 3	
„ „	8.25 „	11·13	L.W.		„ „	9.13 „	12·37	L.W.		
„ 9	1.25 A.M.	29·78	H.W.		„ 9	2.53 A.M.	28·17	H.W.		
„ „	„			29·87	„ „	9.20 „	13·82	L.W.	29·88	
„ „	P.M.			E 2	„ „	2.22 P.M.	28·27	H.W.	WSW 3	
„ „	„				„ „	9.58 „	13·02	L.W.		
„ 10	A.M.				„ 10	3.38 A.M.	27·97	H.W.		
„ „	„			29·92	„ „	10.4 „	14·62	L.W.	29·90	
„ „	P.M.			N 1	„ „	3.48 P.M.	27·37	H.W.	SE 1	
„ „	„				„ „	10.42 „	13·57	L.W.		
„ 11	A.M.	Break			„ 11	4.25 A.M.	27·37	H.W.		
„ „	„			30·05	„ „	10.44 „	14·97	L.W.	29·99	
„ „	P.M.			NE 4	„ „	4.38 P.M.	26·77	H.W.	N 3	
„ „	„				„ „	11.31 „	14·02	L.W.		
„ 12	A.M.				„ 12	5.9 A.M.	26·27	H.W.		
„ „	„			30·30	„ „	11.43 „	14·72	L.W.	30·25	Rough (O.)
„ „	P.M.			NE 3	„ „	5.38 P.M.	25·82	H.W.	NNW 4	☽ First quarter
„ 13	A.M.				„ 13	0.21 A.M.	14·22	L.W.		2h. 42m. P.M.
„ „	11.45 „	14·58	L.W.	30·37	„ „	6.8 „	25·82	H.W.	30·37	
„ „	5.12 P.M.	26·93	H.W.	N 3	„ „	0.38 P.M.	15·37	L.W.	NNW 1	
„ 14	0.20 A.M.	14·23	L.W.		„ „	6.33 „	25·27	H.W.		
	5.44	25·78	H.W.	30·30	„ 14	1.24 A.M.	14·37	L.W.		

,,	,,	[illegible] P.M.	14·95	L.W.	WSW 2	,,	,,	7.21 ,,	25·27	H.W.	30·31	
,,	,,	6.13 ,,	26·58	H.W.		,,	,,	1.43 P.M.	15·37	L.W.	NNE 3	
,,	15	1.25 A.M.	14·48	L.W.		,,	,,	7.36 ,,	24·97	H.W.		
,,	,,	6.58 ,,	25·68	H.W.	29·92	,,	15	2.26 A.M.	14·77	L.W.		
,,	,,	1.47 P.M.	15·33	L.W.	WSW 3	,,	,,	8.24 ,,	25·27	H.W.	29·94	
,,	,,	7.17 ,,	27·03	H.W.		,,	,,	2.48 P.M.	15·37	L.W.	SSW 3	Rough (O.)
,,	16	2.29 A.M.	14·68	L.W.		,,	,,	8.39 ,,	24·97	H.W.		
,,	,,	8.3 ,,	26·58	H.W.	29·78	,,	16	3.23 A.M.	15·42	L.W.		
,,	,,	2.53 P.M.	15·43	L.W.	WNW 5	,,	,,	9.28 ,,	26·17	H.W.	29·78	
,,	,,	8.9 ,,	27·78	H.W.		,,	,,	3.48 P.M.	16·47	L.W.	WSW 5	
,,	17	3.23 A.M.	14·38	L.W.		,,	,,	9.48 ,,	25·07	H.W.		
,,	,,	8.40 ,,	27·43	H.W.	29·92	,,	17	6.10 A.M.	15·17	L.W.		
,,	,,	3.53 P.M.	14·23	L.W.	WSW 2	,,	,,	10.11 ,,	26·17	H.W.		
,,	,,	9.3 ,,	28·03	H.W.		,,	,,	4.48 P.M.	15·12	L.W.		
,,	18	4.13 A.M.	13·58	L.W.		,,	,,	10.21 ,,	26·67	H.W.		
,,	,,	9.35 ,,	28·03	H.W.	29·97	,,	18	5.5 A.M.	14·67	L.W.		
,,	,,	4.40 P.M.	13·48	L.W.	SW 2	,,	,,	10.48 ,,	26·67	H.W.	29·98	
,,	,,	9.43 ,,	28·33	H.W.		,,	,,	5.38 P.M.	14·32	L.W.	SW 3	
,,	19	5.30 A.M.	12·78	L.W.		,,	,,	11.3 ,,	26·67	H.W.		
,,	,,	10 ,,	28·43	H.W.	29·90	,,	19	5.42 A.M.	13·92	L.W.		
,,	,,	5.25 P.M.	12·43	L.W.	S 2	,,	,,	11.22 ,,	26·67	H.W.	29·91	
,,	,,	10.29 P.M.	28·53	H.W.		,,	,,	6.14 P.M.	13·67	L.W.	E. 3	
						,,	,,	11.33 ,,	26·67	H.W.		
,,	20	5.45 A.M.	12·23	L.W.		,,	20	6.23 A.M.	13·72	L.W.		○ Full Moon
,,	,,	10.49 ,,	28·88	H.W.	29·88	,,	,,	0.4 P.M.	27·02	H.W.	29·95	4h. 32m. P.M.
,,	,,	6.6 P.M.	12·13	L.W.	WSW 4	,,	,,	6.48 ,,	13·27	L.W.	WSW 3	
,,	,,	11.9 ,,	29·13	H.W.		,,	21	0.29 A.M.	27·17	H.W.		
,,	21	6.30 A.M.	11·88	L.W.		,,	,,	6.56 ,,	13·47	L.W.	29·94	
,,	,,	11.25 ,,	29·43	H.W.	29·89	,,	,,	0.41 P.M.	27·37	H.W.	SSE 4	Rough (O.)
,,	,,	6.43 P.M.	11·78	L.W.	SW 2	,,	,,	7.23 ,,	13·07	L.W.		
,,	,,	11.48 ,,	29·43	H.W.		,,	22	1.3 A.M.	27·77	H.W.		
,,	22	7.8 A.M.	11·68	L.W.		,,	,,	7.32 ,,	13 67	L.W.	29·97	
,,	,,	0.5 P.M.	29·78	H.W.	30·00	,,	,,	1.15 P.M.	27·62	H.W.	WSW 1	
,,	,,	7.25 ,,	11·23	L.W.	NNE 2	,,	,,	8.8 ,,	13·62	L.W.		
,,	23	0.28 A.M.	29·33	H.W.		,,	23	1.41 A.M.	27·47	H.W.		
,,	,,	7.43 ,,	11·23	L.W.	30·04	,,	,,	8.13 ,,	13·17	L.W.	30·09	
,,	,,	0.38 P.M.	29·78	H.W.	SW 3	,,	,,	1.55 P.M.	27·57	H.W.	S 4	
,,	,,	8.3 ,,	11·13	L.W.		,,	,,	8.48 ,,	12·57	L.W.		
,,	24	1.4 A.M.	30·68	H.W.		,,	24	2.22 A.M.	27·77	H.W.		
,,	,,	8.25 ,,	11·43	L.W.	30·03	,,	,,	8.55 ,,	13·37	L.W.	30·06	
,,	,,	1.18 P.M.	29·68	H.W.	WSW 3	,,	,,	2.33 P.M.	27·37	H.W.	SW 1	

SUMMER SOLSTICE—*continued.*

Dover					Ostend					Remarks
Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	{D.=Dover} {O.=Ostend}
		feet					feet			
June 24	8.45 P.M.	11·13	L.W.		June 24	9.33 P.M.	12·17	L.W.		
" 25	1.50 A.M.	29·13	H.W.		" 25	3.13 A.M.	27·47	H.W.		
" "	9.0 "	11·78	L.W.	29·86	" "	9.38 "	13·77	L.W.	29·86	
" "	2.0 P.M.	29·88	H.W.	E 2	" "	3.15 P.M.	27·32	H.W.	E 2	
" "	9.23 "	11·78	L.W.		" "	10.11 "	12·72	L.W.		
" 26	2.43 A.M.	28·78	H.W.		" 26	5.48 A.M.	27·42	H.W.		
" "	9.46 "	12·23	L.W.	29·79	" "	10.18 "	14·02	L.W.	29·88	Rough (O.)
" "	2.53 P.M.	29·03	H.W.	SW 5	" "	4.5 P.M.	26·92	H.W.	SW 4	
" "	10.12 "	11·88	L.W.		" "	11.5 "	12·62	L.W.		
" 27	3.35 A.M.	27·88	H.W.		" 27	4.44 A.M.	26·77	H.W.	30·04	(Last quarter
" "	10.33 "	12.23	L.W.	29·97	" "	11.13 "	13·87	L.W.	SSW 4	7h. 38m. P.M.
" "	3.40 P.M.	28·53	H.W.	WSW 4	" "	1.55 P.M.	26·32	H.W.		Rough (O.)
" "	11.3 "	12·33	L.W.		" 28	0.0	12·87	L.W.		
" 28	4.24 A.M.	27·53	H.W.		" "	5.41 A.M.	26·27	H.W.		
" "	11.23 "	12·88	L.W.	29·96	" "	0.13 P.M.	14·27	L.W.	SSW 3	
" "	4.40 P.M.	28·23	H.W.	SW 4	" "	5.51 "	26·17	H.W.		
" "	0.0 "	12·78	L.W.		" 29	1.3 A.M.	13·47	L.W.		
" 29	5.24 A.M.	27·53	H.W.		" "	6.48 A.M.	26·42	H.W.	30·08	
" "	0.36 P.M.	13·43	L.W.	30·05	" "	1.22 P.M.	14·47	L.W.	E 3	
" "	5.48 "	28·23	H.W.	E. 2	" "	7.10 "	26·02	H.W.		
" 30	1.18 A.M.	13·13	L.W.		" 30	2.10 A.M.	13·62	L.W.		
" "	6.38 "	27·43	H.W.	29·98	" "	8.8 "	26·32	H.W.	29.98	
" "	1.49 P.M.	13·43	L.W.	WSW 3	" "	2.38 P.M.	14·67	L.W.	SSW 3	
" "	6.54 "	28·23	H.W.		" "	8.26 "	26·37	H.W.		
July 1	2.32 A.M.	12·88	L.W.		July 1	3.20 A.M.	13·72	L.W.		
" "	7.53 "	27·88	H.W.	30·14	" "	9.14 "	26·47	H.W.	30·05	
" "	3.5 P.M.	12·88	L.W.	W 3	" "	3.55 P.M.	13·97	L.W.	WSW 4	Rough (O.)
" "	8.13 "	28·43	H.W.		" "	9.40 "	26·57	H.W.		

[illegible]	[illegible]	6.10 A.M.	12·23	L.W.		„	2	4.31 A.M.	13·42	L.W.		
„	„	9.0 „	28·53	H.W.	30·12	„	„	10.20 „	26·82	H.W.	30·14	
„	„	4.9 P.M.	12·33	L.W.	E 1	„	„	5.2 P.M.	13·67	L.W.	E 1	
„	„	9.11 „	29·33	H.W.		„	„	10.40 „	27·27	H.W.		
„	3	4.44 A.M.	12·13	L.W.		„	3	5.38 A.M.	13·57	L.W.		
„	„	9.48 „	29·43	H.W.	29·92	„	„	10.57 „	27·47	H.W.	29·97	
„	„	5.10 P.M.	11·68	L.W.	SW 1	„	„	5.48 P.M.	13·17	L.W.	S 3	
„	„	10.9 „	29·78	H.W.		„	„	11.28 „	27·77	H.W.		
„	4	5.38 A.M.	11·68	L.W.		„	4	6.5 A.M.	13·47	L.W.		
„	„	10.36 „	30·13	H.W.	29·85	„	„	11.48 „	27·97	H.W.	29·86	● New Moon
„	„	6.4 P.M.	11·23	L.W.	WSW 1	„	„	6.48 P.M.	12·62	L.W.	SSW 4	3h. 3m. P.M.
„	„	11.0 „	29·88	H.W.		„	5	0.13 A.M.	27·92	H.W.		
„	5	6.30 A.M.	11·13	L.W.		„	„	6.59 „	13·17	L.W.		
„	„	11.19 „	30·48	H.W.	29·93	„	„	0.28 „	27·87	H.W.	29·95	
„	„	6.51 P.M.	11·98	L.W.	SW 3	„	„	7.33 P.M.	12·17	L.W.	SSW 1	
„	„	11.52 „	30·03	H.W.								

AUTUMNAL EQUINOX.—September 7 to October 4, 1883.

September	6	8.35 A.M.	11·98	L.W.		September	6	9.13 A.M.	13·72	L.W.		
„	„	1.13 P.M.	28·88	H.W.	30·06	„	„	2.36 P.M.	26·77	H.W.	30·02	
„	„	8.46 „	11·68	L.W.	W 3	„	„	9.37 „	13·27	L.W.	WSW 3	
„	7	2.6 A.M.	28·03	H.W.		„	7	3.19 A.M.	27·47	H.W.		
„	„	8.52 „	13·03	L.W.	29·89	„	„	9.39 „	14·77	L.W.	29·90	Rough (D. & O.)
„	„	1 53 P.M.	28·68	H.W.	WNW 4	„	„	3.26 P.M.	27·07	H.W.	SW 5	
„	„	9.11 „	13·13	L.W.		„	„	9.58 „	14·57	L.W.		
„	8	2.30 A.M.	27·88	H.W.		„	8	3.48 A.M.	26·77	H.W.		
„	„	9.27 „	13·78	L.W.	29·90	„	„	10.13 „	14·97	L.W.	29·96	
„	„	2.35 P.M.	27·78	H.W.	W 3	„	„	4.8 P.M.	26·77	H.W.	SW 5	
„	„	9.44 „	13·78	L.W.		„	„	10.43 „	14·77	L.W.		
„	9	2.57 A.M.	26·83	H.W.		„	9	4.25 A.M.	25·87	H.W.		
„	„	10.2 „	14·23	L.W.	30·14	„	„	10.58 „	14·77	L.W.	30·16	
„	„	3.21 P.M.	26·33	H.W.	N 2	„	„	4.38 P.M.	25·00	H.W.	WSW 3	☽ First quarter
„	„	10.22 „	14·33	L.W.		„	„	11.24 „	14·77	L.W.		6h. 38m. P.M.
„	10	3.44 A.M.	25·58	H.W.		„	10	5.8 A.M.	24·77	H.W.		
„	„	10.39 „	15·03	L.W.	30·03	„	„	11.54 „	15·17	L.W.	30·11	
„	„	4.30 P.M.	24·88	H.W.	S 3		„	5.48 P.M.	24·57	H.W.	SE 3	
„	„	11.26 „	15·33	L.W.			11	0.33 A.M.	15·47	L.W.		
„	11	4.59 A.M.	25·03	H.W.		„	„	6.20 „	24·57	H.W.	29·99	
„	„	0.1 P.M.	16·13	L.W.	29·96	„	„	1.8 „	16·07	L.W.	Z 0	
„	„	5.47 „	25·03	H.W.	E. 3	„	„	7.16 P.M.	24·17	H.W.		

AUTUMNAL EQUINOX—*continued.*

Dover					Ostend					Remarks
Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	{ D. = Dover } { O. = Ostend }
		feet					feet			
September 12	0.59 A.M.	15·43	L.W.		September 12	2.3 A.M.	15·67	L.W.		
,, ,,	6.35	24·78	H.W.	30·12 NNE 2	,, ,,	8.0 ,,	23·57	H.W.	30·12 Z 0	
,, ,,	1.43 P.M.	15·03	L.W.		,, ,,	2.36 P.M.	15·17	L.W.		
,, ,,	7.20 ,,	25·43	H.W.		,, ,,	8.36 ,,	24·77	H.W.		
,, 13	2.20 A.M.	14·58	L.W.		,, 13	3.10 A.M.	15·27	L.W.		
,, ,,	7.42 ,,	26·23	H.W.	30·22 NNE 3	,, ,,	9.13 ,,	24·87	H.W.	30·19 ENE 3	
,, ,,	2.56 P.M.	13·78	L.W.		,, ,,	3.53 P.M.	14·47	L.W.		
,, ,,	8.22 ,,	26·68	H.W.		,, ,,	9.48 ,,	25·82	H.W.		
,, 14	3.34 A.M.	13·33	L.W.		,, 14	4.16 A.M.	14·47	L.W.		
,, ,,	8.42 ,,	27·43	H.W.	30·09 NE 3	,, ,,	10.0 ,,	25·77	H.W.	30·07 ENE 3	
,, ,,	3.59 P.M.	12·43	L.W.		,, ,,	4.48 P.M.	13·77	L.W.		
,, ,,	9.15 ,,	28·33	H.W.		,, ,,	10.36 ,,	27·07	H.W.		
,, 15	4.33 A.M.	12·23	L.W.		,, 15	5.0 A.M.	14·07	L.W.		
,, ,,	9.22 ,,	29·13	H.W.	29·95 N 2	,, ,,	10.41 ,,	26·92	H.W.	29·94 SSW 1	
,, ,,	4.55 P.M.	11·13	L.W.		,, ,,	5.36 P.M.	12·67	L.W.		
,, ,,	9.59 ,,	29·33	H.W.		,, ,,	11.15 ,,	27·77	H.W.		
,, 16	5.21 A.M.	10·98	L.W.		,, 16	5.48 A.M.	13·37	L.W.		
,, ,,	10.8 ,,	30·13	H.W.	30·14 NNE 1	,, ,,	11.27 ,,	27·77	H.W.	30·14 Z 0	
,, ,,	5.45 P.M.	10·13	L.W.		,, ,,	6.31 P.M.	11·97	L.W.		○ Full moon 9h. 41m. P.M.
,, ,,	10.34 ,,	30·03	H.W.		,, ,,	11.56 ,,	28·17	H.W.		
,, 17	6.5 A.M.	10·23	L.W.		,, 17	6.33 A.M.	12·77	L.W.	30·22 NNE 1	
,, ,,	10.48 ,,	31·03	H.W.	30·21 NE 1	,, ,,	P.M.	Break			
,, ,,	6.33 P.M.	10·23	L.W.		,, ,,	,,				
,, ,,	11.21 ,,	30·68	H.W.		,, 18	A.M.				
,, 18	6.53 A.M.	9·78	L.W.		,, ,,	,,			30·25 NNE 1	
,, ,,	11.26 ,,	31·53	H.W.	30·22 ENE 1	,, ,,	P.M.				
,, ,,	7.15 P.M.	9·08	L.W.		,, ,,	,,				
,, ,,	11.55 ,,	30·93	H.W.							

,,	19	7.34 A.M.	9·78	L.W.	
,,	,,	0.5 P.M.	31·68	H.W.	30·17 E 1
,,	,,	7.58 ,,	9·23	L.W.	
,,	20	0.44 A.M.	30·83	H.W.	
,,	,,	8.11 ,,	10·33	L.W.	29·80 E 3
,,	,,	0.55 P.M.	31·98	H.W.	
,,	,,	8.38 ,,	10·68	L.W.	
,,	21	1.16 A.M.	30·83	H.W.	
,,	,,	8.57 ,,	10·68	L.W.	29·74 SSE 3
,,	,,	1.42 P.M.	30·83	H.W.	
,,	,,	9.15 ,,	11·23	L.W.	
,,	22	2.18 A.M.	30·03	H.W.	
,,	,,	9.35 ,,	12·13	L.W.	29·61 N 2
,,	,,	2.32 P.M.	30·33	H.W.	
,,	,,	9.59 ,,	13·23	L.W.	
,,	23	3.8 A.M.	29·33	H.W.	
,,	,,	10.23 ,,	13·58	L.W.	30·05 Z 0
,,	,,	3.26 P.M.	28·53	H.W.	
,,	,,	10.49 ,,	13·58	L.W.	
,,	24	4.15 A.M.	27·13	H.W.	
,,	,,	11.22 ,,	14·13	L.W.	29·84 S 5
,,	,,	5.1 P.M.	25·68	H.W.	
,,	,,	11.44 ,,	14·58	L.W.	
,,	25	5.40 A.M.	26 68	H.W.	29·81 W 4
,,	,,	0.35 P.M.	15·23	L.W.	
,,	,,	6.20 ,,	26·93	H.W.	
,,	26	1.28 A.M.	15·23	L.W.	
,,	,,	7.0 ,,	27·28	H.W.	29·78 SSW 5
,,	,,	2.12 P.M.	14·68	L.W.	
,,	,,	8.14 ,,	26·58	H.W.	
,,	27	2.48 A.M.	14·33	L.W.	
,,	,,	8.24 ,,	26·83	H.W.	29·73 W 4
,,	,,	3.3 P.M.	13·13	L.W.	
,,	,,	9.15 ,,	27·68	H.W.	
,,	28	3.46 A.M.	14·13	L.W.	
,,	,,	9.2 ,,	28·88	H.W.	29·70 W 4
,,	,,	4.15 P.M.	13·03	L.W.	

,,	19	A.M.				
,,	,,	,,			30·20 ESE 1	
,,	,,	P.M.				
,,	,,	,,				
,,	20	A.M.				
,,	,,	,,			29·86 ESE 1	
,,	,,	P.M.				
,,	,,	,,				
,,	21	A.M.				
,,	,,	,,			29·76 SW 3	
,,	,,	P.M.				
,,	,,	,,	Break			
,,	22	A.M.				
,,	,,	,,			29·74 SSW 1	
,,	,,	P.M.				
,,	,,	,,				
,,	23	A.M.				
,,	,,	,,			30·04 W 4	☾ Last quarter 12h. 51m. P.M.
,,	,,	P.M.				
,,	,,	,,				
,,	24	A.M.			30·00 SSE 3	Stormy (D. & O.)
,,	,,	,,				
,,	,,	5.54 P.M.	24·97	H.W.		
,,	25	0.52 A.M.	15·37	L.W.		
,,	,,	6.48 ,,	25·57	H.W.		
,,	,,	1.48 P.M.	15·32	L.W.	29·85 SW 5	Stormy (D. & O.)
,,	,,	7.36 ,,	26·02	H.W.		
,,	26	2.26 A.M.	15·67	L.W.		
,,	,,	8.2 ,,	25.67	H.W.	29·71 S 5	Rough (D. & O.)
,,	,,	3.18 P.M.	15·17	L.W.		
,,	,,	8.58 ,,	25.77	H.W.		
,,	27	4.2 A.M.	14·72	L.W.		
,,	,,	9.23 ,,	25·22	H.W.	29·81 SW 7	Rough (D.) Stormy (O.)
,,	,,	4.14 P.M.	14·37	L.W.		
,,	,,	10.3 ,,	27·02	H.W.		
,,	28	4.31 A.M.	15·77	L.W.		
,,	,,	10.18 ,,	26·97	H.W.	29·71 SW 7	Rough (D.) Stormy (O.)
,,	,,	5.10 P.M.	14·07	L.W.		

AUTUMNAL EQUINOX—*continued.*

Dover					Ostend					Remarks
Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	Date	Time (Greenwich mean)	Height on Datum 20 ft. below Ordnance Gt. Britain		Weather — Barometer Wind-force	{D. = Dover} {O. = Ostend}
		feet					feet			
September 28	9.33 P.M.	28·88	H.W.		September 28	10.48 P.M.	27·32	H.W.		
„ 29	4.16 A.M.	13·43	L.W.		„ 29	5.6 A.M.	14·87	L.W.		
„ „	9.49 „	29·58	H.W.	29·27	„ „	11.1 „	27·77	H.W.	29·28	
„ „	5.4 P.M.	12·53	L.W.	W 5	„ „	5.41 P.M.	13·87	L.W.	WSW 4	Rough (D. & O.)
„ „	10.19 „	29·43	H.W.		„ „	11.28 „	27·97	H.W.		
„ 30	5.20 A.M.	12·78	L.W.		„ 30	5.54 A.M.	14·57	L.W.	29·33	
„ „	10.18 „	30·58	H.W.	29·26	„ „	11.48 „	28·17	H.W.	SE 3	
„ „	5.45 P.M.	12·33	L.W.	SE 2	„ „	6.18 P.M.	13·72	L.W.		
„ „	10.38 „	29·78	H.W.		October 1	0.4 A.M.	28·17	H.W.		
October 1	5.58 A.M.	12·38	L.W.		„ „	6.13 „	14·97	L.W.	29·49	● New Moon
„ „	10.48 „	30·83	H.W.	29·59	„ „	0.23 P.M.	29·07	H.W.	W 4	5h. 54m. A.M.
„ „	6.17 P.M.	11·88	L.W.	NNE 4	„ „	7.18 „	13·87	L.W.		
„ „	11.1 „	30·33	H.W.		„ 2	0.30 A.M.	28·67	H.W.		
„ 2	6.26 A.M.	12·13	L.W.		„ „	6.56 „	14·97	L.W.	29·76	Stormy (O.)
„ „	11.22 „	30·93	H.W.	29·86	„ „	0.48 P.M.	29·17	H.W.	SSW 3	
„ „	6.49 P.M.	11·53	L.W.	NNW 5	„ „	7.53 „	13·82	L.W.		
„ „	11.29 „	29·93	H.W.		„ 3	1.8 A.M.	28·07	H.W.		
„ 3	7.0 A.M.	11·13	L.W.	29·70	„ „	7.36 „	13·27	L.W.	29·81	
„ „	11.58 „	29·43	H.W.	W 3	„ „	1.48 P.M.	29·57	H.W.	SSW 4	
„ „	7.6 P.M.	11 68	L.W.		„ „	7.48 „	13·72	L.W.		
„ 4	0.22 A.M.	29·68	H.W.		„ 4	1.48 A.M.	28·17	H.W.		
„ „	7.20 „	12·33	L.W.	29·35	„ „	9.3 „	14·07	L.W.	29·32	Rough (D.)
„ „	0.37 P.M.	31·03	H.W.	WNW 4	„ „	1.58 P.M.	28·87	H.W.	SW 7	Very stormy (O.)
„ „	7.44 „	12·23	L.W.		„ „	8.12 „	13·97	L.W.		

[The Report of the Committee on Electrolysis will be found at p. 308.]

Report of the Committee, consisting of Professor Sir H. E. ROSCOE, Mr. LOCKYER, Professors DEWAR, LIVEING, SCHUSTER, W. N. HARTLEY, *and* WOLCOTT GIBBS, Captain ABNEY, *and* Dr. MARSHALL WATTS (*Secretary*), *appointed for the purpose of preparing a new series of Wave-length Tables of the Spectra of the Elements.*

THE Committee report that satisfactory progress has been made with the tabulation of the emission-spectra of the elements and compounds. The volumes of Reports for 1884 and 1885 contain the spectra of the elements, complete, and of the compounds up to manganese-oxide; and the remaining portion of the emission-spectra of the compounds, together with the more accurately measured absorption-spectra of the elements and compounds, are printed in the volume for the present year. Under these circumstances the Committee request reappointment.

PHOSPHORUS HYDRIDE. See PHOSPHORUS—Band Spectrum (REPORT, 1884).

SILICON CHLORIDE.

Salet	Intensity and Character	Salet	Intensity and Character
6220	6	5140	3
6120	3	5070	6
6050		γ5010	6
5950	6	4950	1
5870	3	ε4876	6
5780		4810	6
δ5670	6	4740	1
5590	3	4690	6
5510		4650	1
β5450	6	4570	3
5370	3	4520	1
5270		4460	3
α5220	6		

SILICON BROMIDE.

Salet	Intensity and Character	Salet	Intensity and Character
6200	6	5350	3
6050	1	5270	
5950	6	5220	6
5790	3	5070	6
5670	6	5010	6
5560	3	4950	1
5480		4875	3
5450	6	4770	3

SILICON IODIDE.

Salet	Intensity and Character	Salet	Intensity and Character
6200	6	5330	3
5950	6	5220	6
5670	6	5070	6
5510	3	4950	6
5450	6	4880	6

STRONTIUM CHLORIDE.

Flame Spectrum		Intensity and Character
Lecoq de Boisbaudran	Mitscherlich	
γ6729	6718	$8b_4$
β6598	6609	$9b_4$
*[δ6464	6472	5n]
α6350	6336	$9b_1$
ε6233	6195	5n

* Appears to be due to the Oxide.

STRONTIUM BROMIDE.

Mitscherlich	Intensity	Mitscherlich	Intensity
6735	5s	6488	5s
6637	5s	6402	3s
6582	2n	6336	2s
6537	2n		

STRONTIUM FLUORIDE.

Mitscherlich	Intensity	Mitscherlich	Intensity
6609	8n	5807	4s
6501	8n	5783	4s

STRONTIUM IODIDE.

Mitscherlich	Intensity	Mitscherlich	Intensity
6724	5s	6559	4s
6664	5s	6468	3s

STRONTIUM OXIDE.

Flame Spectrum Lecoq de Boisbaudran	Intensity	Flame Spectrum Lecoq de Boisbaudran	Intensity
ξ6862	$8b_8^r$	6191	1n
γ6746	$9b_{10}^r$	$\alpha \left\{ \begin{matrix} 6059 \\ 6031 \end{matrix} \right.$	10n 9n
ϵ6627	$8b_7^r$	5970	1n
δ6498	$9b_9^r$	5940	1n
η6464	$6b_6$	$\iota \left\{ \begin{matrix} 5911 \\ 5890 \end{matrix} \right.$	3n 3n
6276	1n		
θ6233	5n		

θ, probably due to the Chloride.

TIN OXIDE.

Salet	Intensity and Character	Salet	Intensity and Character
5800	$5b_{35}^v$	5160	$\left. \begin{matrix} 5b_4^v \\ 5b_6^v \\ 5b_{13}^v \end{matrix} \right\} b_{23}^v$
5660	5b	5100	
5630	5b	4970	
5560	5b	4600	$1b_{10}^v$
5370	$5b_8^v$	4390*	$3b_{10}^v$
5320	5b	4240*	$3b_9^v$
		4080	$1b_6^v$

* Triple.

WATER.

Huggins	Liveing and Dewar	Intensity and Character	Huggins	Liveing and Dewar	Intensity and Character
3276			3163		
3266			3159·5		
3262			3156		
3256			3152·5		
3252·5			3149·5		
3242·5			3145		
3232			3142·5		
3228			3139		
3223			3135		
3217·5			3133		
3211			3130		
3207·5			3127		
3201			3122·5		
3198			3117		
3192·5			3111		
3189			3105		
3184			3102		
3180			3099		
3175			3094		
3171			3090	3087·9	
3167					

WATER—*continued.*

Huggins	Liveing and Dewar	Intensity and Character	Huggins	Liveing and Dewar	Intensity and Character
3085	3085·9			2960·1	4
	Shading of			2958·0	4
	close-set lines			2954·6	2n
	3083·5			2952·1	1
3082	3081·6			2950·2	4
3080	3079·8			2944·7	1n
3077·5	{ 3078·4			2941·2	4n
	{ 3076·8			2936·4	4
3074 }	3075·4			2934·1	4
3073 }	3073·4			2933·2	4
	3071·5			2931·9	1
	3070·7			2930·4	4
3068	3068·8			2928·0	2n
	Shading of			2925·6	4
	close-set lines			2924·4	1
	3066			2922·8	4n
	3064·6			2918·8	2
	3063·5			2917·6	8
3062	3062	b^{v}		2915·7	4
	3055·9	4		2912·5	4n
	3051·2	4		2910·9	4
	3046·6	4		2908·7	2
	3042·1	4		2907·6	4
	3037·9	4		2906·8	2
	3034·1*	4		2906·1	1
	3030·5*	4		2902·9	8
	3027·8*	4		2900·3	2
	3025·4*	4		2899·8	2
	3021·8*	4		2898·7	2
	3016·8*	4		2897·0	4n
	3013·6*			2895·0*	4n
	3008·9*			2892·9	2
	3005·6*			2892·0	10
	3001·8*	4		2889·2	4
	2998·8	2		2886·7	4
	2998·0	4		2884·6	4
	2994·9*	4		2882·5	4
	2992·2	1		2881·7	4
	2990·7	1		2880·0*	2
	2989·4	2		2877·8	8
	2987·4	2		2875·5	4
	2985·9	2		2874·4	4
	2983·8*	4		2871·2	10
	2980·2	4		2869·2	4
	2977·7	1n		2867·8	4
	2974·6	8n		2865·3*	4
	2972·8	1		2863·1	4
	2971·8	1		2861·6	4
	2970·7	4		2860·2	4
	2970·2	4		2859·4	4
	2969·4	4		2857·6	4
	Several faint			2855·4*	4
	lines			2854·2	2
	2965·8†	4		2852·4	4
	2964·5‖	4		2850·6	4
	2962·7	4		2849·9	2
	2961·6	4		2848·9	2

WATER—*continued.*

Liveing and Dewar	Intensity and Character	Liveing and Dewar	Intensity and Character	Liveing and Dewar	Intensity and Character	Liveing and Dewar	Intensity and Character
2847·5	4	2836·0	2	2826·3	2	2815·7	1
2846·1	4	2835·6	2	2824·9	4	2814·1	2
2844·3	4	2834·6	1	2823·0	6	2812·7	2n
2843·0	4	2834·1	2	2821·1	4	2811·3	8n
2842·3	4	2832·3*	4	2819·5	4		
2840·8	1	2830·7	4	2817·7	6	Deslandres	
2838·9	10	2829·7	8	2816·7	4	2610·5	b^{v}
2836·9	2	2827·2	4	2816·3	4		

* Double:—the mean of pair.
‖ Double :—the more refrangible of the pair.
† Double :—the less refrangible of the pair.

AIR (ABSORPTION).

(Telluric Fraunhofer Lines.)

Ångström	Fievez	Piazzi-Smyth	Cornu	Intensity
			7690·5	
			7689·1	
		7682·3	7683·8	1
		7680·7	7682·6	1
		7680·0	7680·1	1
	7699·9	7677·3	7677·6	2
		7676·3	7676·4	2
		7670·0	7671·5	4
	7689·4	7668·6	7670·2	4
		7665·6	7665·6	6
	7683·9	7664·2	7664·5	6
	7679·1	7660·0	7660·0	7
	7678·3	7658·9	7658·9	7
	7668·3	7654·2	7654·7	8
	7667·4	7653·4	7653·6	8
	7662·9	7649·8	7649·7	9
	7662·0	7648·8	7648·4	9
	7657·9 ‡	7645·0	7644·7	10
	7657·0	7643·9	7643·5	10
	7652·9	7641·0	7640·2	12
	7651·9	7639·8	7639·0	12
	7648·2	7636·6	7635·8	12
	7647·2	7636·1	7634·7	12
	7643·8	7632·9	7631·6	10
	7643·1	7631·8	7630·4	10
	7639·3	7629·0	7627·5	9
	7638·4	7627·8	7626·2	9
	7631·8	7625·2	7623·6	9
	7631·2	7624·1	7622·4	9
7630·0	7628·2	7621·6	7620·2	10
	7623·2	7617·9	7615·4	6
	7622·1	7616·6	7614·2	8
	7620·3	7614·5	7612·5	8
	7619·3	7613·2	7611·2	8

‡ 7644·3 Abney.

AIR (ABSORPTION)—*continued.*

Ångström	Fievez	Piazzi-Smyth	Cornu	Intensity
	7617·5	7611·9	7609·7	8
	7616·3	7610·9	7608·5	8
			7607 1	9
			7606·0	9
			7604·8	9
			7603·6	9
			7602·8	9
			7601·5	8
			7600·9	8
	7613·4		7599·7	6
	7612·4	7605·4	7599·4	6
	7611·0		7598·1*	9 $8b_{0\cdot9}$
A 7604·0	7609·3		7596·7	6
	7607·2	7600·0	7595·6	7
	7604·5	7598·6	7595·0	6
	7602·0		7594·4	
	7601·0	7596·0	7593·7	$8b_{0\cdot3}$
	†7600·1		7593·0	
7315·1	7314·5			1
	7312·6			1
	7311·2			8
	7310·2			1
	7308·4			1
7307·4	7307·8			6
	7304·5			1
	7301·0			1
7300·4	7300·2			8
	7298·2			1
	7297·6			8
	7290·3			1
7289·7	7289·8			6
7288·3	7288·2			8
7285·7	7285·3			8
	7282·7			1
	7278·2			10
	7277·1			10
	7275·8			1
7274·4	7274·3			1
	7272·9			1
7271·3	7270·6			4
	7269·8			4
	7267·9			8
	7266·0			8
	7265·1			8
	7263·5			1
7262·1	7262·3			1
	7260·7			6
	7259·8			7
	7258·9			1
7256·9	7258·0			10
	7254·8			10
	7251·7			1
7249·5	7249·3			8
	7247·1			10
	7245·4			10
	7244·9			1
7241·9	7241·3			1

* Double. † 7593·7 Abney. A, due to Oxygen, Egoroff.

AIR (ABSORPTION)—*continued.*

	Ångström	Fievez	Piazzi-Smyth	Cornu	Intensity
	7237·5	7239·2			8
		7234·8			8
	7231·8	7232·5			1
	7229·2	7229·8			1
		7227·6			8
a			7208·8		
		7207·4	7207·7		4
		7206·8			
		7206·0	7206·2		10
	7204·8	7204·8	7204·5		6
	7202·4	7204·0	7203·4		10
		7200·4	7201·8		6
			7200·9		
			7199·2		1
	7198·2	7198·8	7198·7		10
		7197·8	7197·8		10
		7196·1	7195·9		10
	7195·0	7193·5	7195·3		5
			7194·6		5
			7192·3		5
		7192·8	7192·2		10
	7191·3	7191·7			
		7190·8	7190·7		10
	7189·6	7189·8	7189·9		2
		7188·8	7188·8		10
		7187·8	7186·3		10
	7184·8	7185·0	7184·7		10
		7184·3	7183·8		10
	7182·3	7182·5	7182·4		10
		7182·9			
		7182·0			
		7182·6			
		7181·2			
		7180·0			
	7179·2		7179·5		10
		7178·6	7178·2		
		7178·0	7177·2		
		7176·8	7176·0		1
	7175·7	7175·8	7175·1		8
	7171·3		7173·9		6
			7172·0		
			7171·6		2
	7168·5	7167·0	7171·2		3
			7170·5		4
			7169·6		
			7168·8		1
			7168·2		2
		7167·0	7167·8		1
			7167·0		1
		7165·0	7165·6		5
			7164·9		
			7164·0		
	7163·0	7163·0	7163·4		2
			7162·3		4
	7160·2		7160·0		
				6960·2	4

a, due to Water.

AIR (ABSORPTION)—*continued.*

Ångström	Fievez	Piazzi-Smyth	Cornu	Intensity
			6958·4	6
			6955·4	10
			†6952·7	6
			†6949·7	6
			6948·0	4
			6946·4	8
			6945·5	1
			6942·7	4
			6941·1	4
			6940·2	5
			6940·0	1
			6939·3	1
			6939·1	4
			6938·6	2
			6937·2	3
			6936·6	4
			†6934·8	7
			6934·2	4
			6933·4	4
			†6932·8	10
			†6932·5	9
			6931·2	3
			6930·8	4
			6930·3	5
			6929·6	1
			†6928·9	8
			6928·5	4
			†6928·3	9
			†6928·1	5
			6927·7	5
			†6925·7	8
			†6923·4	8
			6923·2	4
6922·4	6922·2	6922·7	6922·3	4
	6921·2	6922·0	6918·0	5
	6917·4	6917·8	6917·1	5
6917·1	6916·5	6917·0	6916·5	2
			6914·4	2
	*6913·5	*6913·0	6913·1	6
	6912·8	6912·8	6912·2	6
6912·1	6912·0	6912·0		
	6908·6	6908·2	6908·4	6
6907·8	6907·5	6907·0	6907·5	6
	6904·5	6903·6	6904·0	6
6903·2	6903·4	6902·5	6903·0	7
	6901·2	6899·4	6899·8	7
6899·0	6899·9	6898·4	6898·9	8
6898·5	6897·0	6895·6	6895·9	8
6895·4	6896·0	6894·5	6895·0	9
6894·8	6893·6	6891·8	6892·3	10
6891·8	6892·6	6890·8	6891·3	10
B 6891·0	6890·2	6888·2	6888·9	10
6888·0	6889·2	6887·1	6887·9	9
6887·2	6886·9	6885·2	6885·7	9
6885·1	6885·9	6884·3	6884·7	8
6884·3	6883·9	6882·0	6882·8‡	8
6882·2	6880·2			9

B, due to Oxygen, Egoroff. * Solar, Cornu. † due to water-vapour, Cornu. ‡ 'Raie isolée.'

AIR (ABSORPTION)—*continued.*

Ångström	Fievez	Piazzi-Smyth	Cornu	Intensity
6878·2	6877·9	6877·9	6878·9	3
	6877·0	6877·2	6878·0	6
	6875·9	6876·0	6876·6	5
	6875·0	6875·3	6874·5	7
	6873·9	6874·3	6873·6	6
	6873·0	6873·4	6872·7	6
	6872·2	6872·5	6871·8	6
	6871·5	6871·5	6871·2	9
6871·0	6871·1	6870·8	6870·2	9
	6870·5	6870·0	6869·8	6
6869·9	6869·8	6869·7	6869·0	6
	6869·2		6868·8	
	6868·8	6868·9	6868·5	6
	6868·1	6868·0	6868·0	6
6867·1	6867·5	6867·5	6867·8	6
			6867·5	6
		6867·1	6867·1	12
			6867·0	8
			6866·8	4
		6866·7	6866·5	9
			6866·6	4
		6866·3	6866·2	9
6597·0	6596·8			
6594·8	6593·5			
6592·2	6592·1			
6585·9	6586·0	6585·3		6
	6585·3	6584·4		1
6582·9	6583·0	6582·6		1
	6581·7	6582·1		
6580·6	6580·0	6580·4		
	6578·8	6579·6		2
	6576·1			
	6575·0			
6573·6	6574·1	6573·8		8
	6573·1	6573·1		
		6571·6		
6571·0	6570·7 6569·9	6571·1		6
	6569·0	6568·5		2
	6568·6			
6567·4	6567·4	6567·7		1
	6566·0			
	6564·6			
	6563·3	6563·5		5
	6562·5	6562·8		2
(6562·1	6561·6	6561·7)		
	6560·0	6560·0		2
6559·8	6559·5	6559·7		4
6558·4	6558·0	6558·4		
6557·6		6557·8		2
	6556·8	6556·8		1
6556·2	6555·7	6555·8		5
		6554·7		
	6554·0	6554·2		1
	6553·0			
	6552·6			
	6552·4	6552·4		2

AIR (ABSORPTION)—*continued.*

Ångström	Fievez	Piazzi-Smyth	Cornu	Intensity
6551·8	6552·0	6551·5		6
6550·7	6551·0	6550·8		2
	6547·9			
6544·8	6540·0			
6545·4 Fe	6545·7			
6543·2	6542·4			
6541·5	6541·0			
6534·5	6535·5			
6533·2				
6531·7	6530·0			
6530·0	6530·4			
	6529·5			
	6528·5			
	6526·3			
	6525·8			
	6525·1			
6523·1	6523·5			4
	6521·7			2
	6521·0			2
6518·6	6518·5			4
	6518·0			2
6517·6	6517·1			4
	6516·8			3
	6516·0			2
6515·8	6515·4			6
	6514·7			2
	6514·3			2
6514·1	6513·5			5
	6513·0			2
6511·6	6512·1			1
6498·2 Ca	6498·0			4
	6497·0			
6496·3 Ba	6496·1			4
	6495·4			
6495·1	6495·1			6
	6494·6			
6494·2 Fe	6494·2			
	6493·7			
6493·0	6493·2			
6492·4 Ca	6492·7			4
	6492·2			
	6491·7			
6490·1 Fe	6490·2			
6488·7	6489·4			
6485·0	6485·8			
	6484·4			
	6483·2			
6483·0	6483·0			
			6341·3†	9
			6330·9	2
			6328·6	2
			6327·8	2
			6323·5	3
			6322·7	3
	6320·8		6319·9	3
			6319·0	1
	6319·4		6318·6	5
	6318·4		6317·9	5

† due to water-vapour, Cornu.

AIR (ABSORPTION)—*continued.*

Ångström	Fievez	Piazzi-Smyth	Cornu	Intensity
	6317·0		6316·4	3
	6316·9		6316·2†	9
	6316·7		6315·2†	10
			6314·3†	9
	6314·4 }		6313·9 }	6
	6313·5 }		6313·1 }	6
	6312·0		6311·7	3
	6309·8 }		6309·5 }	7
			6309·1 }	3
	6309·1 }		6308·7 }	7
			6308·3†	9
	6305·7 }		6305·4 }	8
	6305·0 }		6304·6 }	8
	6302·0 }		6301·6 }	9
	6301·2 }		6300·9 }	9
	6298·7		6298·0 }	9
	6298·0		6297·3 }	9
6296·9	6297·1	6296·2	6296·6‡	8
			6296·1†	8
			6295·3	3
6294·2	6295·5	6295·0	6294·8 }	4
	6294·6	6294·6	6294·0 }	1
			6293·5	2
			6292·7	3
	6292·8	6292·7	6291·8 }	4
6291·8		6292·3	6291·4† }	2
6290·3	6292·0	6291·9	6291·0	4
	6290·8	6290·8	6289·8‡	5
			6289·6	
	6289·7	6289·6	6289·0 }	3
	6289·0	6288·5	6288·2 }	2
			6288·0†	
6286·7	6287·3	6286·9	6286·7† }	2
			6286·6* }	
	6285·6	6285·8	6285·0‡	1
6285·0	6285·4	6285·4	6284·6†	1
	6283·8	6284·1	6283·4	2
	6283·0	6283·2	6282·6‡	2
			6281·6	1
	6282·3	6282·2	6281·5	3
			6281·3†	8
	6281·5	6281·9	6280·8	1
6281·8	6280·8	6281·3	6280·0	4
			6279·8	2
	6280·2	6280·4	6279·5	4
6279·8	6280·0	6280·0	6279·2	4
	6279·5	6279·8	6278·7	4
		6279·2	6278·5‡	5
	6278·7	6278·9	6277·9	8
α 6278·4	6278·4	6278·4	6277·7	8
		6278·2	6277·5	1
		6278·0	6277·2	8
6277·1	6277·6	6277·4	6276·9	10
			6276·7	2
	6277·1		6276·4	4
	6277·0	6276·9 }		
	6276·8	6276·8 }	6276·2	9
	6276·7	6276·6 }	6276·1	6

α, due to Oxygen, Egoroff. * 'Raie isolée.' † Due to water-vapour, Cornu. ‡ Solar, Cornu.

AIR (ABSORPTION)—*continued.*

Ångström	Fievez	Piazzi-Smyth	Cornu	Intensity
			6275·8	4
	6276·2	6276·1	6275·6	6
6276·3	6275·9	6275·7	6275·4	7
5967·3	5967·8			2
	5966·8			4
	5966·4			2
5965·2	5965·0			2
	5964·5			1
	5964.0			2
	5958·0			6
	7·4			6
5957·2	5957·0			6
5955·6	5956·0			6
	5955·5			1
5953·9	5954·0			1
5952·0	5952·4			1
	5951·5			6
5950·4	5950·3			1
	5949·5			1
	5949·0			3
	5948·7			3
5948·4	5948·2			6
5947·6 Fe	5947·6			1
	5946·8			6
5946·0	5946·0			1
5945·0	5945·0			5
	5944·4			4
	5944·0			4
5943·6	5943·4			4
	5943·0			4
5941·7	5941·6			6
	5941·3			1
5940·9	5940·7			6
5940·4	5940·0			6
	5939·5			1
	5939·0			1
5937·4	5937·4			1
	5934·5			1
5935·0	5934·0			1
	5933·4			5
5931·8	5932·5			1
5931·2	5931·2			1
	5230·5			2
	5928·7			6
	5928·3			4
	5926·7			1
5924·0	5926·3			4
5923·0	5923·6			1
	5922·2			5
5921·7	5921·9			5
5920·8	5920·7			1
	5920·4			1
5919·1	5919·5			1
5918·4	5918·0			8
5917·5	5917·5			8
	5917·0			8
5915·6	5915·6			
	5915·1			
5914·6	5914·9			
	5914·3			
5913·3	5913·4			10
5912·1	5912·3			4

AIR (ABSORPTION)—*continued.*

Ångstrom	Fievez	Piazzi-Smyth	Intensity
5909·7	5910·0		4
5908·1	5909·1		1
5907·2	5908·8		1
	5908·0		2
	5907·5		1
	5907·3		1
	5906·7		1
	5906·2		1
	5905·8		1
	5904·4	5904·5	
	5904·2	5904·1	2
5902·7	5902·5	5902·9	1
	5202·1	5902·3	1
5901·4	5901·3	5901·0	3
5900·5	5900·3	5900·4	6
		5899·9	1
5899·1 Ti	5899·0	5898·8	9
		5898·7	
	5898·3	5898·3	2
	5898·0	5898·1	2
5898·1	5897·7	5897·9	3
		5897·4	1
5897·1	5897·0	5897·2	8
	5896·5	5896·6	4
		5896·3	1
	5896·0	5895·9	4
5895·5	5895·5	5895·6	4
$D_2$5895·1 Na	5895·0	5895·1	30
5895·0	5894·4	5894·4	1
	5894·1	5894·1	1
	5893·5	5893·6	2
5892·5	5892·7	5892·9	3
	5892·2	5892·4	3
5892·1 Ni	5892·0	5892·2	4
5891·6	5891·8	5891·7	6
5890·8	5891·3	5890·9	9
	5890·7	5890·7	1
	5890·4	5890·3	3
	5889·9		
$D_1$5889·1 Na	5889·0	5889·1	30
	5888·5	5888·7	12
	5887·4	5887·9	4
5886·7		5886·9	6
	5886·1	5886·3	6
	5885·9	5885·9	6
5885·3		5885·2	3
	5884·8		6
	5884·4		
5882·7	5882·9		5
	5882·5		7
5881·5	5881·6		1
	5881·4		1
5880·2	5880·6		1
	5879·5		1
5879·1	5879·2		1
	5878·3		1
	5878·0		1
	5876·5		1
	5876·0		1
	5875·5		1
	5874·0		1
5874·0	5873·6		1

BROMINE (ABSORPTION).

Roscoe and Thorpe	Hasselberg	Intensity and Character	Roscoe and Thorpe	Hasselberg	Intensity and Character
6801·3				5584·3	2s
6777·2			5580·6	5574·2	$2b_{0\cdot4}^{v}$
6723·6			5560·7	5557·0	$8b_{1}^{v}$
6649·1				5553·3	$2b^{v}$
6581·3			5556·8	5550·4	$4b^{v}$
6526·9				5539·5	6s
6468·9		8	5534·1	5529·4	$8b_{1}^{v}$
6455·4		4		5527·4	4n
6413·0		8		5522·3	6s
6401·0		4		5519·2*	2s
6372·6		4		5515·8*	1s
6350·5		8	5510·3	5504·9	$6b_{0\cdot7}^{v}$
6336·7		4		5502·5	2b
6312·1		4	5501·3	5495·8	2s
6292·8		8	5483·8		b^{v}
6275·4		4	5476·8	5480·7	$6b_{1\cdot4}^{v}$
6263·9		4		5477·9	6s
6240·2		8		5473·5	2s
6223·3		4		5469·0	2s
6190·9(b^{v})	6188·5	1s	5460·1	5460·2	$8b_{1}^{v}$
6169·7				5456·8§	2s
6144·1				5454·3	1n
6119·0(b^{v})	6117·9	$1b_{0\cdot5}$		5451·7	6s
6101·4(b^{v})	6098·8	2b		5449·3*	2s
6072·2	6068·7	$1b^{v}$		5445·5	6b
6053·2	6047·1	$1b^{v}$		5444·0	2s
6027·3	6023·5	$1b^{v}$	5439·9	5435·8†	$8b_{0\cdot7}^{v}$
6006·1(b^{v})	6001·5	4b		5432·4	$10b_{0\cdot2}^{v}$
5987·5(b^{v})	5982·0	1b		5421·0	2s
5956·5(b^{v})	5957·0	2b		5419·9	1s
5945·1(b^{v})	5942·0	1b	5418·2	5412·1	$6b_{0\cdot5}^{v}$
5913·9(b^{v})	5911·4	1b		5412·1	8s
5905·9		$2b^{v}$		5410·0	$6b_{0\cdot2}$
5875·5		b^{v}		5407·8*	4s
5870·7	5868·9	$4b^{v}$	5403·2(b^{v})	5400·6	2s
5835·3(b^{v})	5844·5	4b		5392·6	$2b_{0\cdot4}^{v}$
	5829·0	$6b_{0\cdot4}$		5392·6	6s
5797·7(b^{v})	5803·4	4b	5380·3	5391·0*	8s
	5800·9	4s		5388·3	$1b_{0\cdot1}$
	5791·5	$2b^{v}$		5384·6	$1b_{0\cdot3}$
5762·7(b^{v})	5762·0	$6b_{1\cdot5}$		5380·2*	4s
	5725·8	$1b_{1}^{v}$		5377·4	4s
5727·5(b^{v})	5723·5	$6b_{0\cdot4}$		5373·6	4s
	5698·0	$2b^{v}$		5370·4	$4b_{0\cdot5}^{v}$
	5688·5	$2b^{v}$	5365·8	5361·6	6s
5694·4(b^{v})	5686·8	6b		5358·1	$6b_{1}^{v}$
	5667·1	2s		5356·9	2s
5660·4	5657·4	$6b^{v}$		5352·4†	$2b_{0\cdot6}$
	5652·0	$6b_{0\cdot3}$		5346·9	$2b_{0\cdot2}^{v}$
	5648·3	$2b_{0\cdot2}$		5342·7	2s
5634·8(b^{v})	5625·7	$6b_{1\cdot5}^{v}$	5347·5(b^{v})	5342·2	$8b_{0\cdot6}$
	5621·5	$8b_{0\cdot3}$	5337·4	5336·1	1s
5624·4(b^{v})	5618·5†	$8b_{0\cdot2}$		5331·4	$2b^{r}$
	5605·0	$b_{1\cdot5}$		5326·7	2s
	5593·5	2s		5318·5	$4b_{1}^{v}$
5592·0	5586·8	$8b_{0\cdot7}^{v}$		5318·5	4s

§ Triple. * Double. † A mass of fine lines.

BROMINE—*continued.*

Roscoe and Thorpe	Hasselberg	Intensity and Character	Roscoe and Thorpe	Hasselberg	Intensity and Character
	5315·7	2s		5256·3†	s
	5312·5	$4b_{0\cdot2}$	5244·1	5248·8	$6b_{0\cdot5}^{\blacktriangledown}$
5306·8(b^{v})	5308·4	$6b_{0\cdot2}$		5246·6§	s
5298·7(b^{v})	5302·2	$7b_{0\cdot8}$		5243·2*	4s
	5301·1†	8s		5241·9	4s
	5289·3	b_1^{v}		5239·6	4s 2b
5292·2	5289·3	4s		5237·4	4s
	5287·5	$6b_{0\cdot3}$		5234·8	4n
	5283·5	$6b_{0\cdot4}$		5224·1	2s
5274·5($b^{\blacktriangledown}$)	5279·7	4b		5221·8	$6b_{0\cdot2}$
	5276·1	2s		5219·4*	2s
	5271·8	4s		5211·2	6s
5258·8($b^{\blacktriangledown}$)	5265·7	b		5208·0†	$6b_{0\cdot6}^{\blacktriangledown}$
	5259·4*	2s			

* Double. † A mass of fine lines.

DIDYMIUM CHLORIDE (ABSORPTION).

Bahr and Bunsen	Lecoq de Boisbaudran	Intensity and Character	Bahr and Bunsen	Lecoq de Boisbaudran	Intensity and Character
	7430†	4	5750	5747†	$10b_3$
7220	ε 7360†	6 $b_{18}^{\blacktriangledown}$	5730	5719†	9s
	7307†	8	5300	5312†	$3b_2$
	6894†	4n	β 5230	β 5219†	$10b_4^{v}$ $b_{12}^{\blacktriangledown}$
δ6730	θ6792†	$7b_6$	5200	5205†	$9b_1$
	6720†	1n	5170		$3b_2$
	6363	2n	5100	δ 5125†	$6b_2$
6280	6282	1n	5010	5087†	$3b_1$
6220	6225	3n	4810	γ4822*	$8b_2$
5920	5962*	$3b_3$	4760	ι4758	$5b_2$
5820	5885*	$3b_4$	4710	ζ4691*	$8b_3$
	α 5824†	$4b_3$ $b_{24}^{\blacktriangledown}$		4618	$1b_4$
α	5788†	$10b_2$	4440	η4441*	$7b_6$
				4275†	$3b_1$

* ‘Praseodidymium,’ † ‘Neodidymium;’ von Welsbach.

ERBIUM CHLORIDE (ABSORPTION).

Bahr and Bunsen	Lecoq de Boisbaudran	Intensity and Character	Bahr and Bunsen	Lecoq de Boisbaudran	Intensity and Character
	6985	1		δ5363	7n
6730	ε6837	$6b_4$		5278	1
6600	η6670	$4b_2$	α5230	α5231	$9b_2$
γ6500	β6534	$9b_4$		5208	3n
	6492	3n		5189	2n
6360	ξ6404	$5b_3$	δ4900	4921	$4b_4$
5501	5490	$1b_2$		γ4874	$9b_1$
β5440	5433	2n		4855	2n
5390	δ5409	7n	4539	4515	$4b_4$

IODINE (ABSORPTION).

Morghen	Thalén	Intensity and Character	Morghen	Thalén	Intensity and Character
6799·4	6834·0	3b^{v}	5732·3	5738·0	3b^{v}
	6778·0	3b^{v}	5719·3	5721·5	2b^{v}
6741·2	6739·0	3b^{v}	5713·8	5713·5	6b^{v}
	6724·0	2b^{v}	5693·4	5707·5	4b^{v}
6686·0	6685·0	3b^{v}	5686·2	5683·0	7b^{v}
	6647·5	2b^{v}	5664·7	5675·0	5b^{v}
6638·3	6634·0	3b^{v}	5656·4	5653·0	7b^{v}
	6594·0	2b^{v}	5636·5	5644·0	5b^{v}
6587·5	6582·5	2b^{v}	5625·4	5625·0	6b^{v}
6544·8	6541·0	4b^{v}	5610·0	5614·0	6b^{v}
	6532·5	2b^{v}	5597·5	5597·5	5b^{v}
6504·2	6503·5	3b^{v}	5582·3	5586·0	6b^{v}
6494·7	6493·0	4b^{v}	5567·0	5571·0	7b^{v}
6458·2	6455·0	4b^{v}	5554·2	5558·5	7b^{v}
6448·6	6446·5	3b^{v}	5540·6	5545·0	4b^{v}
6407·9	6407·0	4b^{v}	5531·0	5531·5	8b^{v}
6400·6	6399·5	3b^{v}	5514·8	5521·0	3b^{v}
6365·5	6369·5	2b^{v}	5506·4	5505·5	8b^{v}
6559·4	6361·0	4b^{v}	5488·1	5496·5	3b^{v}
	6354·0	1b^{v}	5480·5	5480·0	9b^{v}
6321·7	6322·5	3b^{v}	5462·3	5473·0	2b^{v}
6313·2	6316·0	3b^{v}	5457·6	5455·0	7b^{v}
6274·1	6276·0	4b^{v}		5449·5	2b^{v}
6267·2	6271·0	3b^{v}	5436·4	5432·0	7b^{v}
	6232·0	5b^{v}	5412·0	5409·5	7b^{v}
6229·2	6227·5	2b^{v}	5389·0	5388·0	6b^{v}
	6190·0	6b^{v}	5366·4	5366·0	6b^{v}
6187·4	6186·5	2b^{v}	5344·6	5346·0	5b^{v}
6148·6	6148·5	6b^{v}	5324·4	5326·0	5b^{v}
	6147·0	1b^{v}	5304·3	5307·0	5b^{v}
6108·3	6110·0	7b^{v}	5284·8	5289·0	4b^{v}
6069·5	6068·0	7b^{v}	5267·8	5272·0	4b^{v}
6031·6	6029·5	8b^{v}	5251·3	5254·0	4b^{v}
6011·0			5235·7	5239·0	4b^{v}
5991·4	5991·5	8b^{v}	5219·9	5222·5	4b^{v}
5969·0			5206·6	5208·0	3b^{v}
5951·8	5954·5	7b^{v}	5192·7	5193·0	3b^{v}
5931·8			5180·2	5181·0	3b^{v}
	5918·0	7b^{v}	5165·3	5168·0	3b^{v}
5915·0	5916·0	1b^{v}	5152·0	5155·0	3b^{v}
5898·4			5140·6	5144·0	2b^{v}
	5883·0	6b^{v}	5129·8	5132·5	2b^{v}
5879·5	5880·0	1b^{v}	5120·5	5122·0	2b^{v}
5864·0			5111·7	5112·0	2b^{v}
5848·2	5848·5	5b^{v}	5101·8	5102·0	2b^{v}
5843·3	5845·5	1b^{v}	5093·5	5093·0	1b^{v}
5816·5	5816·0	5b^{v}	5086·6		
5811·0	5811·0	1b^{v}	5079·1		
	5808·5	1b^{v}	5072·0		
5786·2	5784·0	4b^{v}	5064·4		
5778·5	5776·5	2b^{v}	5057·0		
5759·1	5772·5	2b^{v}	5050·6		
5749·8	5753·0	3b^{v}	5044·8		
5744·8	5745·0	5b^{v}	5038·6[1]		

IODINE MONOCHLORIDE (ABSORPTION).

Roscoe and Thorpe	Intensity and Character	Roscoe and Thorpe	Intensity and Character	Roscoe and Thorpe	Intensity and Character	Roscoe and Thorpe	Intensity and Character
6475·1	$3b^{v}$	6033·2	$3b^{v}$	5782·0	$4b^{v}$	5552·9	$3b^{v}$
6442·9	$3b^{v}$	6021·3	$4b^{v}$	5751·0	$3b^{v}$	5535·4	$3b^{v}$
6421·3	$3b^{v}$	6005·2	$8b^{v}$	5744·4	$2b^{v}$	5523·6	$3b^{v}$
6383·7	$3b^{v}$	5995·9	$4b^{v}$	5719·6	$8b^{v}$	5508·4	$3b^{v}$
6372·6	$3b^{v}$	5974·1	$4b^{v}$	5713·0	$4b^{v}$	5501·3	$3b^{v}$
6324·9	$3b^{v}$	5957·3	$8b^{v}$	5685·8	$3b^{v}$	5482·5	$3b^{v}$
6318·0	$3b^{v}$	5944·3	$4b^{v}$	5679·5	$3b^{v}$	5459·5	$3b^{v}$
6266·8	$3b^{v}$	5918·7	$3b^{v}$	5658·3	$3b^{v}$	5435·1	$3b^{v}$
6216·9	$3b^{v}$	5905·1	$3b^{v}$	5650·0	$3b^{v}$	5412·1	$3b^{v}$
6181·5	$3b^{v}$	5886·7	$3b^{v}$	5632·1	$3b^{v}$	5394·3	$3b^{v}$
6167·9	$3b^{v}$	5877·8	$3b^{v}$	5628·6	$3b^{v}$	5368·1	$3b^{v}$
6155·0	$3b^{v}$	5861·4	$3b^{v}$	5618·4	$3b^{v}$	5349·8	$3b^{v}$
6122·6	$3b^{v}$	5852·3	$3b^{v}$	5600·7	$3b^{v}$	5330·0	$3b^{v}$
6112·8	$3b^{v}$	5843·7	$3b^{v}$	5590·0	$3b^{v}$	5315·5	$3b^{v}$
6079·2	$3b^{v}$	5820·5	$8b^{v}$	5572·0	$3b^{v}$	5295·0	$3b^{v}$
6071·3	$3b^{v}$	5815·9	$4b^{v}$	5561·3	$3b^{v}$	5276·1	$3b^{v}$
6040·9	$3b^{v}$	5788·8	$8b^{v}$				

NITROGEN PEROXIDE (ABSORPTION).

Hasselberg	Intensity and Character	Hasselberg	Intensity and Character	Hasselberg	Intensity and Character
6853·7	4s	6417·3	$4b_{2}^{v}$	6186·6	1s
6827·5	1s	6412·1	1s	6175·8	$6b_{0\cdot3}$
6808·7	2s }	6407·0	1n	6171·8	4s
6794·0	4n } $b_{1\cdot5}$	6397·5	1s	6165·3	$6b_{0\cdot3}^{v}$
6772·5	$2b_{0\cdot1}$	6377·7	$4b_{0\cdot2}$	6164·7	$8b_{0\cdot1}$
6766·3	4s	6367·2	2n	6160·6	4s
6742·4	2b	6360·1	$4b_{0\cdot1}$	6155·5	6n
6734·6	6n	6353·3	2s	6141·3	$6b^{v}$
6725·8	4s	6350·9	1n	6136·2	$4b_{0\cdot1}$
6710·7	2s	6341·0	$2b_{0\cdot2}^{v}$	6126·4	$12b_{0\cdot4}$ }
6695·3	$4b_{0\cdot8}^{v}$	6334·2	$4b_{0\cdot2}$	6121·2	$8b_{0\cdot1}$ } $b_{1\cdot7}$
6689·0	2n	6321·5	4s }	6114·6	$6b_{0\cdot6}$ }
6678·3	$4b_{0\cdot3}$	6316·3	$4b_{1}$ }	6110·0	2s
6658·9	2s	6311·2	4 }	6107·8	4s
6558·0	1n	6305·1	1s	6090·4*	2s
6552·7	1s	6297·8	1s	6084·3	4s
6546·0	1n	6290·0	4n	6079·2	2s
6526·0*	1s	6268·7	1s	6068·0	2b
6515·6	2s	6263·4	4s	6055·8	6s
6509·8	2s	6259·2	2s	6052·3	$4b^{r}$
6502·3	$1b_{0\cdot4}$	6255·8	4s	6039·4†	$2b_{0\cdot6}$
6488·5	$2b_{0\cdot6}^{v}$	6250·7*	6s	6028·3†	$1b_{0\cdot8}$ }
6474·7	$6b_{1}^{v}$	6242·3	2s	6023·3	4s }
6468·1	$6b_{0\cdot6}$	6236·7	6s	6018·6	6s
6461·0	$6b_{0\cdot1}$	6232·3	4s	6016·0	1s
6454·8	$2b_{0\cdot1}$	6224·9	4n	6013·4	$6b_{0\cdot2}$
6448·2	$4b_{0\cdot1}$	6212·2	$1b_{0\cdot6}^{v}$ }	6002·5	$6b_{0\cdot5}^{v}$
6438·2*	1s	6206·3	$2b_{0\cdot6}^{v}$ }	5997·1	$6b_{0\cdot3}$
6433·2	4s	6201·5	$6b_{0\cdot5}^{v}$ }	5989·1	$4b_{0\cdot4}$
6424·7	4n	6194·8	$2b_{0\cdot3}$	5984·6	4s

* Double. † A mass of fine lines.

NITROGEN PEROXIDE (ABSORPTION)—*continued.*

Hasselberg	Intensity and Character
5977·5	$4b_{0\cdot1}$
5972·6	4s
5969·3	2s
5962·2	6n
5957·0	4s
5947·5	$4b^{v}$
5944·8	$6b_{0\cdot1}$
5936·0	$6b_{0\cdot2}^{v}$
5933·7	6n
5928·1	$10b_{0\cdot2}$
5924·4	4s
5920·4	$8b_{0\cdot3}$
5915·3	$6b_{0\cdot4}$
5912·6	$6b_{0\cdot1}$
5902·7	$6b_{1}$
5898·3	7s
5892·2	$6b_{0\cdot5}^{v}$
5877·9	4s
5873·2	1n
5864·2	$1b_{0\cdot5}^{v}$
5859·6	$1b_{0\cdot5}$
6853·9	6n
5850·5	$4b_{0\cdot7}$
5845·2	4s
5840·4	1s
5837·0	6s
5828·7	1n
5819·0	1s
5814·4	$1b_{0\cdot1}^{v}$
5807·5	1s
5803·0	$1b_{0\cdot5}$
5791·3	$1b_{1\cdot5}$
5789·8	8s
5776·7	6s
5770·2	6s
5768·1	1s
5752·5	8s
5747·8*	6s
5742·6	1n
5737·1	4s
5734·2	1s
5729·4	$8b_{0\cdot3}$
5719·8	$4b_{1}$
5709·2	$3b_{0\cdot5}^{v}$ $b_{1\cdot6}$
5708·2	$4b_{0\cdot2}$
5706·4	$6b_{0\cdot3}^{r}$
5699·5	$4b_{0\cdot3}^{r}$
5692·3*	1s
5689·3	4s
5689·3	$1b_{0\cdot2}^{r}$
5683·8	4s
5679·5	$6b_{0\cdot4}^{v}$ $b_{1\cdot3}$
5670·7	$4b_{1}^{v}$
5663·9	$4b_{e\cdot2}^{v}$
5653·0	$8b_{0\cdot4}^{v}$
5648·1	6s
5644·6	$10b_{0\cdot3}$ $b_{1\cdot5}$
5642·1	$10b_{0\cdot1}$
5635·7	$8b_{0\cdot2}$
5633·0	$8b_{0\cdot2}$
5627·9*	2s
5624·0	4s
5616·5	$1b_{0\cdot4}$
§5610·1	1s
*5606·4	1s
5602·1	1s
5600·2	4s
5588·0	4n
5579·9	6n
5572·5	1s
5564·6*	4s
5564·5	$1b_{0\cdot3}^{r}$
5557·0	4s
5553·5	4n
5550·9	4s
5542·8	$1b_{0\cdot4}^{v}$
5540·3	$1b_{0\cdot2}^{v}$
5537·8	$1b_{0\cdot1}$
5530·5	$8b_{0\cdot3}^{v}$
5528·2	$8b_{0\cdot1}$
5522·2	$6b_{0\cdot3}^{v}$
5516·1	$1b_{0\cdot5}$
5502·5	4s
5491·5	6n
5489·7	$8b_{1\cdot9}^{v}$
5485·3	$4b_{0\cdot4}^{v}$ $b_{3\cdot7}^{v}$
5480·8	4n
5476·5	4n
5471·4	$6b_{0\cdot4}^{v}$
5469·0	6n
5465·9	4s
5462·4	$8b^{r}$
5451·2	8n
5448·6	1s b_{3}
5440·2	4n
5432·9	$2b^{v}$
5430·3	8s
5428·5	$4b_{0\cdot4}$
5421·8	4s
5421·8	$4b_{0\cdot8}^{r}$
5420·0	6s $b_{0\cdot8}$
5417·5	4s
5415·7	2s
5411·6	1s
5404·7	2s?
5399·5	4n
5392·5	$8b_{0\cdot3}$
5389·4	8s
5387·0	2s
5384·3	$8b_{0\cdot1}$
5379·2	$8b_{0\cdot1}$
5376·1	4s
5363·7	$6b_{0\cdot1}$
5360·6	$4b_{0\cdot1}$
5349·1	1s
5345·4	4s
5343·0	$6b_{0\cdot1}$
5342·5	$1b_{1\cdot3}$ $1b_{1\cdot3}$
5339·3	$8b_{0\cdot1}$
5336·0	1s
5334·1	$2b_{2}^{r}$
5332·4	6n
5325·1	6s b_{2}
5321·6	4s
5312·8	$2b_{0\cdot5}^{r}$ $b_{1\cdot4}$
5304·6	$6b_{0\cdot9}^{r}$
5294·0	$4b_{1}^{r}$
5288·2	6s
5285·6	6n
5279·8	$6b_{0\cdot1}$ $b_{2\cdot1}$
5277·8	4s
5273·0	$4b_{1}^{v}$
5270·7	$6b_{0\cdot5}^{r}$
5263·6	$10b_{0\ 5}$
5259·2	8n $b_{2\cdot8}$
5251·3	$12b_{0\cdot8}$
5242·8†	$8b_{0\cdot5}^{v}$
5240·2	8s
5229·6	8s
5224·1	$8b_{0\cdot8}^{v}$
5219·0	8s
5214·8	$8b_{0\cdot7}^{v}$
5207·0	$10b_{0\cdot6}$
5199·9	$6b_{0\cdot5}$
5199·7	10s
5195·0	$10b_{0\cdot2}^{v}$
5190·8	$10b_{0\cdot3}^{v}$
5185·5	$4b_{0\cdot5}$
5178·4†	$6b_{0\cdot5}^{v}$
5176·5	4s
5172·1	$6b_{0\cdot3}$
5164·0*	1s
5157·1	1s
5155·1	$1b_{0\cdot4}$ $b_{0\cdot4}$
5154·6	4s
5145·0	1n
5137·1	$2b^{r}$
5124·8	$2b_{1\cdot1}$
5124·0	$8b_{0\cdot1}$
5122·0	2s $b_{1\cdot1}$
5121·2	6s
5119·4	4s
5117·5§	1s
5111·7	6n
5103·7	$2b_{0\cdot1}$ $b_{2\cdot2}$
5100·7	1s
5095·2	$8b_{0\cdot4}^{v}$
5092·9	4s
5089·7	$4b_{0\cdot1}$
5086·9	$2b_{0\cdot1}$
5083·1	$4b_{0\cdot2}$

* Double. † A mass of fine lines. § Triple.

NITROGEN PEROXIDE (ABSORPTION)—*continued.*

Hasselberg	Intensity and Character	Hasselberg	Intensity and Character
5076·6	4s	4843·4	4n
5073·5	1s	4841·5	$4b_{0\cdot3}^{\blacktriangledown}$ }
5066·2	$6b_{0\cdot2}$	4839·2	$4b_{0\cdot2}$
5063·6	$4b_{0\cdot2}$	4835·8	2s
5061·2†	$6b^{r}$	4831·0	$6b^{\blacktriangledown}$
5050·5	$6b_{1\cdot3}$	4828·0	$2b_{2}^{r}$
5045·7	$10b_{0\cdot1}$ } $b_{1\cdot3}$	4820·0	2n
5042·8	4s	4817·2	2n
5041·2	6s } $b_{0\cdot4}$	4814·3	2n
5040·0	$1b_{0\cdot4}^{\blacktriangledown}$	4812·0	8n
5035·1	1s	4810·1	6n } $b_{3\cdot5}$
5032·0	$8s_{1}b_{0\cdot3}^{r}$	4807·2	4n
5027·2	$10b_{0\cdot2}$	4802·8	4n
5024·1	4s	4797·2	10n
5022·3	2s } b_{1}	4792·8	$8b_{0\cdot7}^{\blacktriangledown}$
5020·8	1s	4787·4	2s
5018·8	1s	4783·6	1s
5009·6	$6b_{0\cdot1}$	4778·8	$6b_{0\cdot1}$
5003·3	1s	4775·2	$4b_{0\cdot2}$
5001·1	4n	4764·8	$6b_{0\cdot1}$
4998·1	2n	4760·3	$4b_{0\cdot2}$
4978·2	4n	4757·6	$4b_{0\cdot2}$
4974·7	2s	4753·5	6n
4965·6	10n	4746·6	$8b_{0\cdot8}^{\blacktriangledown}$ }
4963·8	$8b_{0\cdot8}^{\blacktriangledown}$ } $b_{1\cdot1}^{\blacktriangledown}$	4744·7	4s
4960·7	$6b_{0\cdot3}^{\blacktriangledown}$	4738·4	$6b_{0\cdot5}^{\blacktriangledown}$
4953·9	$6b_{0\cdot1}$	4736·1	$4b_{0\cdot2}^{\blacktriangledown}$ }
4946·2	$8b_{0\cdot1}$	4731·1	6s
4944·3	6s	4728·1	4s
4941·7	$8b_{1}^{\blacktriangledown}$ } $b_{2\cdot2}^{\blacktriangledown}$	4721·7	$4b_{0\cdot2}^{\blacktriangledown}$
4937·8	$6b^{\blacktriangledown}$	4718·0	6s
4931·3	4s	4715·7	$4b_{0\cdot4}^{\blacktriangledown}$ }
4929·5	$4b^{\blacktriangledown}$ } $b_{0\cdot5}^{\blacktriangledown}$	4714·5	$4b_{0\cdot2}^{r}$
4917·8	4n	4710·2	$6b_{0\cdot2}$
4915·0†	$6b_{1\cdot2}^{\blacktriangledown}$ }	4708·1	4s
4912·0	$2b_{0\cdot3}$	4702·2	$4b_{0\cdot6}^{\blacktriangledown}$ } b_{1}
4907·7	$4b_{0\cdot3}$	4698·5	$2b_{0\cdot3}^{\blacktriangledown}$
4903·0	$8b_{0\cdot4}$	4694·0	$4b_{0\cdot1}$
4896·0	$4b^{\blacktriangledown}$	4687·5	$4b_{0\cdot1}$
4891·5	$6b_{0\cdot5}$	4683·7	$4b^{\blacktriangledown}$
4885·5	$8b_{0\cdot5}$ } $b_{2\cdot6}$	4679·7	$10b_{0\cdot5}$
4882·3	$8b_{0\cdot1}$	4675·2	4n
4874·0	$1b_{0\cdot8}^{\blacktriangledown}$	4665·3	$6b_{1}^{\blacktriangledown}$
4867·6	2n	4662·9	4n
4865·3	2s	4659·5	2n
4860·6	$2b_{0\cdot3}$	4656·8	4n
4856·7	1s	4643·8	$10b_{0\cdot5}^{\blacktriangledown}$
4854·7	1s	4640·9	$6b_{0\cdot2}$ } b_{2}
4849·9	$2b_{0\cdot3}^{\blacktriangledown}$	4630·6	$6b_{1}^{\blacktriangledown}$
4846·9	4b		

† A mass of fine lines.

Potassium Permanganate (Absorption).

Lecoq de Boisbaudran	Intensity and Character	Lecoq de Boisbaudran	Intensity and Character
δ5703	$7b_{12}$	ε4861	$3b_7$
α5465	$9b_{12}$	4694	$1b_6$
β5246	$9b_9$	4543	$1b_6$
γ5045	$7b_8$		

Phosphorescent Spectra.

Yttria.

Crookes	Intensity and Character	Crookes	Intensity and Character	Crookes	Intensity and Character
6675·6	2b	5790·8	$1b_8$	5177·8	1b
6629·9	2b	5736·9	$10b_2$	4932·0	4b
6475·6	$3b_8$	5670·0	$2b_2$	4824·7	$4b^r$
6209·5	$1b_4$	5491·5	$8b_1$	4449·1	4b
6179·7	$6b_2$	5399·5	$7b_1$	4323·0	4b
5976·2	1b	5373·3	$2b_1$		

Erbia.

Crookes	Intensity and Character	Crookes	Intensity and Character
5564	4b	5318	5b
5450	3b	5197	4b

Samaria.

Crookes	Intensity and Character	Crookes	Intensity and Character
6402	$2b_6$	5976	$4b_6$
6093·7	10s	5620	$2b_8$

APPENDIX.

HYDROGEN. (See REPORT, 1884, p. 390.)

Compound Line Spectrum Hasselberg		Intensity and Character	Compound Line Spectrum Hasselberg		Intensity and Character
Eye Observation	Photographic Observation		Eye Observation	Photographic Observation	
4497·5	4497·4	3n		4223·9	1
	4495·9	1		4223·4	2
	4494·3	1		*4222·0	3
4492·8	4492·6	2		4221·6	3
4489·7	4489·6	3		*4211·8	4
	4488·4	1		4211·3	1
	4486·9	2		4209·5	2½
4485·2	4485·1	3		4208·5	2
	4481·0	1		4205·5	1½
	4479·2	1		*4204·4	6
	4477·8	1		*4199·2	3½
4476·6	4476·1	2		4197·7	2
	4474·9	1		*4195·0	3½
4473·7	4473·3	2		4181·5	3
	4470·9	1		4179·5	3
4466·6	4466·2	2		4179·0	2
	4463·1	1		4177·1	2½
*4460·6	4460·3	3		*4176·5	6
4458·6	4458·2	1		4174·5	3
4456·4	4456·1	2		*4170·7	4
4455·3	4454·9	2		4166·9	1
	4453·7	1		4164·6	1½
4452·6	4452·2	1		4163·0	1½
4450·3	4450·1	1		*4161·3	2½
4449·2	4449·1	2		4158·7	2
*4447·2	4447·0	3		*4155·9	3
4444·7	4444·6	2		4145·4	1
4443·6	4443·5	1		4144·8	1
	4442·2	1		4109·4	1
	4440·7	1		4108·7	1
	4425·2	1		4107·3	1
	4422·6	1		4107·1	1
	4422·0	1		4105·6	1
	4419·6	1		*4101·2	8
	4418·7	1		4096·9	1½
4416·8	4416·7	2		4095·9	1
*4411·7	4411·7	3		4095·4	1
	4409·9	1		4094·9	1
	4400·2	2		4087·2	2½
	4390·3	2		4084·7	1½
	4388·5	1½		4082·4	1
	4386·8	1		4081·8	1½
	4378·8	2		4080·9	1
	4347·1	5		4077·3	5
	*4340·1	10		4073·6	1
	4338·3	3		4072·4	1
	4242·7	2		4070·7	1½
	4235·9	2		*4069·2	4
	4233·2	2		*4066·4	3½
	4232·9	2		4064·7	1
	4232·1	1		4063 2	2
	4226·8	1		*4062·1	3

* Vogel 4459, 4448, 4413, 4340, 4220 4210, 4201, 4195, 4193, 4174, 4168, 4158 ? 4152 ? 4101, 4067, 4065, 4060.

NITROGEN.

	Positive Band Spectrum Ångström and Thalén	Positive Band Spectrum Hasselberg	Intensity and Character	
a	6621·8	*6622·4	4	
		6618·7	1½	
		6615·7	1	
	6614·2	6612·9	3b^{r}	
		6606·7	2	
		6603·9	1½	
		6601·4	1½	
		6598·7	1½	
		6595·4	1½	
	6594·7	6593·1	3	
		6590·6	1½	
		6587·4	2b	
		6583·0		
		6580·1	2½	
		6577·3	1½	
		6574·7	1½	
		6571·9	2	
		6569·1	1	
		6566·5	1	
		6558·8	1	
		6555·2	1½	
		6551·9	1	
		6548·2	1½	
b	6542·3	*6543·4	4	
		6539·8	1	
		6536·0	1	
	6533·8	6533·4	3	
		6527·7	2½	b
		6524·9	2	
		6522·0	1½	
		6519·9	1½	
		6516·6	2	
	6516·3	6514·4	3	
		6512·6	2	
		6509·3	2½b	
		6505·3		
		6501·7	2	
		6499·1	1½	
		6496·4	1½	
		6493·7	2½	
		6490·2	1½	
		6488·1	2	
		6485·7	1	
		6482·9	1b	
		6480·0		
		6477·5	1½	
		6474·1	1½	
		6470·8	1½	
	6465·5	*6467·3	3	
		6464·4	2	
		6460·3	1	
	6458·6	6457·5	4	
		6452·4	1½	b^{r}
		6441·5	1	

	Positive Band Spectrum Ångström and Thalén	Positive Band Spectrum Hasselberg	Intensity and Character
c	6440·6	6439·5	2½
		6437·4	1½
		6434·3	1
		6429·4	1
		6427·1	1
		6423·5	1
		6422·2	1
		6419·5	1½
		6417·1	1
		6414·4	1½
		6409·1	1
		6403·3	1
		6400·6	1
		6397·5	1
δ	6392·5	*6393·2	3
		6390·0	1½
		6385·8	1
	6384·8	6383·5	4
		6378·3	1½
		6371·1	1
		6369·9	1
	6366·8	6367·8	3
		6365·9	1½
		6363·6	1
		6358·1	1
		6356·1	1½
		6354·0	1
		6350·9	1
		6348·5	2
		6345·7	1
		6343·0	2
		6338·0	1
		6326·3	1
ε	6321·0	*6321·4	4
		6318·0	2
		6314·2	1
	6313·8	6311·6	4b^{r}
		6305·8	1½
		6302·3	1
		6300·3	1
		6298·5	1
		6296·7	1
	6294·9	6294·8	3
		6293·2	2
		6290·7	1
		6285·0	1
		6283·2	2
		6281·0	1½
		6278·3	1½
		6275·8	2
		6273·3	1½
		6270·9	2
		6268·2	1

* Denotes the chief lines whose wave-lengths were first determined.

NITROGEN—*continued*

	Positive Band Spectrum		Intensity and Character
	Ångström and Thalén	Hasselberg	
f	6249·2	*6251·6	2
		6248·3	1
		6244·9	1
	6242·6	6242·2	3
		6236·5	1½
		6231·4	1
		6229·8	1
		6227·8	1
	6225·5	6225·7	2
		6224·3	2
		6221·6	1
		6219·3	1
		6217·8	1
		6216·4	1
		6214·4	1½
		6211·6	1
		6209·3	1
		6207·3	1½
		6204·7	1
		6202·4	1½
g	6183·2	6184·6	2
		6178·1	1
	6175·1	*6174·3	3
		6168·5	1
	6158·2	6157·2	2
h	6125·4	*6126·0	4b^{r}
	6118·8	6118·7	3b^{r}
		6114·1	2
		6110·6	1
		6107·9	1
	6102·1	6101·2	2
		6099·1	1½
		6082·9	1½
		6077·9	1
i	6066·3	*6068·3	5
	6060·6	6060·9	4
		6058·6	1
		6056·0	3
		6053·2	2
		6050·4	2
		6048·3	1
		6045·5	1
	6043·3	6043·9	3
		6041·9	2
		6040·0	1
		6036·7	1
		6034·9	1
		6032·1	1
		6029·2	1
		6026·3	2
		6021·2	2
		6017·4	1
		6014·9	1
k	6011·8	*6012·4	5
	6004·6	6005·1	4
		6000·3	3
		5997·6	2
		5995·1	2
		5993·1	1
		5991·7	1
		5990·3	1
	5987·8	5988·7	3
		5986·6	2
		5984·6	1
		5981·5	1
		5979·9	2
		5977·0	2
		5974·4	1
		5971·5	1½
		5969·1	1
		5966·8	1½
		5963·2	1
		5960·9	1
l	5957·3	*5957·9	5
	5950·5	5950·6	4
		5946·0	3
		5943·4	2
		5940·9	2
		5939·1	1
		5937·8	1
		5936·4	1
	5933·3	5934·6	3
		5933·1	2
		5930·7	1
		5928·0	1
		5926·1	2
		5923·4	2
		5920·9	1
		5918·1	2n
		5913·4	2n
		5910·1	1
		5907·4	1
m	5904·6	*5904·6	5
	5897·5	5897·5	4
		5893·0	3
		5890·6	2s
		5888·3	2
		5886·8	1
		5884·7	1
		5883·5	1
	5882·5	5882·0	3
		5880·7	2s
		5878·2	1
		5875·6	1s
		5873·9	2s
		5870·8	2s
		5868·8	1

* Denotes the chief lines whose wave-lengths were first determined.

NITROGEN—*continued.*

Positive Band Spectrum		Intensity and Character
Ångström and Thalén	Hasselberg	
	5866·3	2n
	5863·7	1
m	5861·3	2n
	5858·1	2
	5855·5	1
5853·0	*5853·1	5
5846·1	5845·9	4
	5841·3	2
	5839·4	2
	5838·2	1
	5836·6	1½
	5835·2	1
	5833·7	1
	5832·4	1
5830·5	5830·7	3
	5829·5	3
n	5828·0	1
	5827·0	1
	5825·7	1
	5824·7	1
	5822·7	2n
	5821·0	1
	5819·8	1½
	5818·1	1
	5815·9	1½n
	5813·2	1
	5810·8	1½n
	5807·4	1
	5805·0	1
5801·8	*5802·9	5
5795·3	5795·7	4
	5792·2	1
	5791·3	2
	5789·9	2
	5788·6	1
	5787·1	1
	5785·8	1
	5784·1	1
	5782·8	1
5780·6	5780·9	3
	5779·9	3
o	5778·7	1
	5777·5	1
	5776·1	1
	5775·0	1
	†5773·0	1
	5771·4	1
	5770·2	1
	5768·6	1
	5766·7	2
	5764·1	1
	5761·9	2
	5758·5	1
	5756·4	1

Positive Band Spectrum		Intensity and Character
Ångström and Thalén	Hasselberg	
5752·0	*5753·8	5
5745·6	5746·4	4
	5743·0	1
	5742·0	1
	5740·6	1
	5739·6	1
	5738·1	1
	5736·7	1
	5735·0	1
5730·7	5733·6	1
	†5731·5	3
p	5729·7	1
	†5726·2	1
	†5724·5	1
	5722·6	1
	5721·3	1
	5719·9	1
	5718·0	2
	5715·5	1
	5713·6	2
	5710·0	1
	5707·9	1
5703·8	*5706·3	3
	5703·9	1
	5702·3	1
	5700·2	1
	5698·1	1½
	5695·5	1½
q	5693·0	1½
	5690·3	1½
	5687·5	1n
5682·5	5684·7	2
	5681·6	1½
	5678·8	1
	5671·8	1
5657·9	*5659·2	3
r	5652·0	1
5637·2	5638·1	1
5612·6	*5613·8	3
	5606·3	1½
	5602·1	
s	5596·0	
4·2	5593·2	1½
	5591·0	2
	5586·0	1
5567·9	*5569·0	3½
	5567·1	1
5563·0	5561·8	2½
	5560·0	1
	5557·2	1
t	5555·4	1
5551·8	5552·1	3
	5549·3	1½
	5547·2	1½
	5545·5	1½

* Denotes the chief lines whose wave-lengths were first determined. † Double.

NITROGEN—*continued.*

	Positive Band Spectrum		Intensity and Character
	Ångström and Thalén	Hasselberg	
t		5543·5	1
		5542·0	1
		5535·1	1
		5531·3	1n
	5525·2	5525·4	4s
		5523·5	1
		5522·0	1
	5518·7	5518·1	3
		5515·9	1
u	5513·4	*5514·3	4
		5509·5	2
		5507·9	2
	5506·0	5506·3	2½
		5504·6	1½
		5502·8	1½
		5500·9	1½
		5498·8	1½
		5496·6	1½
		5494·7	2
	5493·7	5493·6	2
		5491·6	1½b^r
	5482·8	5483·3	2½b^r
		5479·8	1
v	5476·9	*5477·5	4
		5476·2	2
	5472·6	5472·2	2½
		5471·4	1½
		5469·3	1½
		5464·3	2
		5457·4	2
		5455·5	1½
		5453·1	1½
		5451·3	1½
		5448·6	1½
		5445·8	1
		5443·7	1
w	5441·9	*5441·2	4
	5437·0	5436·0	3½
		5434·1	2
		5432·5	3
		5428·6	1½
		5427·9	2
		5426·2	1
		5424·2	1
	5422·1	5421·7	4
		5419·8	1½
		5417·7	1½
		5415·9	1½
		5413·0	1
		5411·6	1
		5410·1	1
	5406·4	*5406·2	5
		5403·6	1
	5401·7	5401·0	3
x		5399·2	2
		5397·5	3
		5393·9	1½
		5393·0	1½
		5391·4	1½
		5389·7	1
		5388·4	1
	5487·4	5387·1	4
		5385·2	1½
		5383·2	1½
		5381·7	1½
		5380·2	1
		5378·3	1
		5375·8	1
		5373·7	1
y	5371·7	*5371·6	5
	5366·7	5366·4	3
		5364·6	2
		5362·9	3
		5359·4	
		5357·4	
		5355·7	
		5354·3	
	5353·2	5352·8	4
		5350·8	
		5349·4	
		5347·7	
		5346·2	
		5345·0	
		5342·9	
		5340·9	
z	5339·7	*5338·6	4
		5337·2	1½
		5335·5	1½
		5333·4	b^r
		5327·4	
		5326·7	1
		5324·5	1½
		5322·2	1½
		5320·0	1½
		5316·8	1
		5313·7	1
		5309·4	
		5306·9	
a′	5306·3	*5305·8	4
		5303·9	Weak but Sharp Lines
		5302·0	
		5300·2	
		5298·2	
		5296·2	
		5294·1	
		5287·4	
		5284·4	

* Denotes the chief lines whose wave-lengths were first determined.

NITROGEN—*continued.*

	Positive Band Spectrum				Positive Band Spectrum		
	Ångström and Thalén	Hasselberg	Intensity and Character		Ångström and Thalén	Hasselberg	Intensity and Character
		5281·5		*f′*		5142·4	1
		5278·2			5138·7	5137·8	3
b′	5273·8	*5274·0	3			5134·6	1½
		5268·4		*g′*	5126·5	*5126·1	4
	5256·3	5256·0				5124·7	1
c′	5244·6	*5243·1	4			5123·1	2
	5239·3	5237·8	2			5121·2	2½
		5234·5	1½			5120·6	2½
		5232·2	1½			5117·9	2
	5226·5	5225·6	1½			5110·1	1½
d′	5213·1	*5212·7	4½			5106·7	1½
		5210·8	1			5100·9	2
		5209·3	1	*h′*	5097·7	*5098·7	3
	5207·7	5207·8	3			5093·5	1
		5205·3	1½			5090·3	1
		5204·0	2½			5083·5	1
		5201·8	2			5076·8	2
		5200·2	1s			5071·8	2
		5198·6	1s	*i′*		*5068·3	2½
		5197·1	1s			5066·9 ‡	3
	5196·1	5195·5	4		5065·6	5065·3	4
		5191·2	Weak but Sharp Lines			5063·7	2
		5189·7				5062·4	2
		5188·4				5060·9	2
		5186·6				5059·7	2
		5185·2				5058·7	2
e′	5183·4	*5183·5	5			5057·0	2
		5181·7	2			5055·5	3s
		5180·5	2			5053·6	3s
		5178·9	3			5051·7	1
	5179·3	5177·9	4			5049·5	1
		5176·5	2			5047·3	1
		5174·8	3			5044·8	1
		5173·0	1s			5042·6	1
		5171·6	1s			5040·0	1
		5170·2	1s			5037·1	1
		5169·1	1s			5034·3	1
		5168·0	1s		5032·0	5030·8	3n
	5165·8	5166·5	4	*k′*		*4975·7	2½
		5164·7	Weak but Sharp Lines			4974·0 ‡	3½
		5162·5			4972·0	4972·2	4½
		5161·3				4970·2	2
		5159·9				4969·1	2
		5158·5				4967·8	2
		5157·1				4966·5	2
		5155·9				4965·2	2
f′	5153·7	*5154·5	5			4963·8	b
		5153·1	1½			4960·8	
		5151·6	2½			4959·5	2½
	5149·0	5149·4	3			4957·5	3
		5148·4	3½			4955·3	2½
		5147·1	1			4953·4	2½
		5145·8	3			4950·9	2
		5144·1	1½			4947·8	2

* Groups *a* to *k* by eye-observation. Groups *a* to *o* recorded by photography. ‡ Strong triplets.

NITROGEN—*continued.*

Positive Band Spectrum		Intensity and Character
Ångström and Thalén	Hasselberg	
	4945·6	2
	4943·8	1½
	4940·8	1½
	4937·7	1½
	4934·5	1½
	4931·1	1
4919·0	4917·5 ‡	3
	4916·7 ‡	4
	*4915·7 ‡	5
	4914·7	2
	4913·8	2
	4913·0	2
	4911·9	2
	4910·7	2
	4909·8	2
	4909·1	2
	4908·3	2
	4907·2	3
	4905·7	3
	4903·9	3
	4902·0	1
	4900·2	2
	4898·6	2
	4897·6	2
	4896·2	2
	4895·0	2
	4893·8	2
	4892·6	2
	4891·3	3
a	4889·9	1½
	4888·5	3
	4887·1	Weak Lines
	4885·9	
	4885·1	
	4884·1	
	4882·7	
	4882·0	
	4881·0	
	4880·0	
	4878·8	
	4877·7	
	4876·7	
	4875·4	1½
	4874·3	1½
	4873·5	1½
	4872·0	1
	4870·9	1
	4869·8	1
	4868·1	2
	4866·6	1
	4865·1	1
4814·0	*4814·0 ‡	4
48130·	4813·0 ‡	5
4811·7	4812·0	6
	4811·2	3
4810·4	4810·4	3
4809·3	4809·4	3½
4808·2	4808·5	3½
4807·2	4807·4	3½
	4806·4	2½
	4805·8	2½
	4805·1	2½
	4804·2	2½
4803·7	4803·8	2½
4802·4	4802·6	4
4800·7	4800·8	4
4899·2	4799·2	3½
	4798·4	2½
4897·3	4797·2	2½
	4796·2	2½
4895·3	4795·3	2½
	4794·9	2½
4893·6	4793·4	2½
	4792·7	2
4891·1	4791·3	3
	4790·1	2
4888·7	4788·8	3
	4787·8	2
4886·1	4786·2	3
a	4785·0	2
	4783·8	2
	4783·3	2
	4782·3	2
	4781·1	2
	4780·3	2
	4779·3	2
	4778·3	1
	4777·2	1½
	4776·2	1
	4772·8	1
	4771·9	1½
	4770·7	1½
	4769·7	1½
	4768·7	1½
	4767·4	1½
	4766·3	1½
	4765·4	1½
	4763·7	1½
	4762·8	1½
	4759·9	1
	4759·0	1½
	4758·2	2
	4756·3	2
	4755·4	1½
	4754·5	1
	4752·3	
	4751·3	

* Groups *a* to *k* by eye-observation. Groups *a* to *o* recorded by photography. ‡ Strong triplets.

NITROGEN—*continued.*

	Positive Band Spectrum		Intensity and Character
	Ångström and Thalén	Hasselberg	
		4750·5	Very Weak Triplets
a		4748·2	
		4747·4	
		4746·4	
		4743·9	
		4743·1	
		4742·3	
		4739·7	
		4738 9	
		4738·1	
		4735·5	
		4734·7	
		4733·8	
		4730·8	
		4729·8	
		4728·9	
		4725·9	
β	4722·7	*4722·7	4
	4722·0		
	4721·5	4721·6 ‡	5
	4720·2	4720·4	6
		4719·4	3
	4718·4	4718·4	3½
	4717·2	4717·3	3½
	4716·0	4716·3	3½
		4715·1	3½
		4714·1	2
		4713·4	2
		4712·8	2
		4711·7	3b^r
	4709·9	4710·0	4
		4709·2	1
	4708·2	4708·3	4
	4706·3	4706·6	3
		4706·1	1½
	4704·5	4704·7	3
		4703·8	2
		4703·0	2
	4702·7	4702·5	2
		4701·5	2
	4700·9	4700·9	2
		4700·2	2
	4698·8	4698·9	3
		4697·8	1½
	4696·2	4696·4	3
		4695·5	1½
	4693·7	*4693·6	3
		4692·5	1
	4691·0	4690·9	2½
		4689·6	2
		4688·4	Weak Lines
		4685·6	
		4684·8	
		4683·8	

	Positive Band Spectrum		Intensity and Character
	Ångström and Thalén	Hasselberg	
β		4682·7	Weak Lines
		4681·7	
		4680·6	
		4679·6	
		4678·5	
		4677·5	
		4676·6	
		4675·2	
		4674·3	
		4673·2	
		4671·7	
		4670·9	
		4669·9	
		4668·1	
		4667·3	
		4665·8	2
	4666·0	4665·2	3
		*4664·4	4
		4663·8	2
		4663·1	3
		4662·4	2
		4661·6	2
		4660·8	2
		4659·8	2
		4659·3	1½
		4658·7	1½
		4658·0	2
		4657·4	1
		4656·6	3
		4656·0	1
		4655·1	2½
		4653·8	2
		4653·0	1½
		†4652·2	2
		4651·1	2
		4650·6	2
		4650·0	2
γ	4649·0	*4648·6	4
	4648·6		
	4647·2	4647·3 ‡	5
	4645·7	4645·9	6
	4644·8	4644·7	3
	4644·0	4644·1	3½b^r
	4642·8	4642·9	4
	4641·8	4641·8	3
	4640·7	4640·8	4
	4639·6	4639·7	4
	4638·2	4638·4	4
		4637·3	2½
		4636·6	3½
		4636·0	2½
		4635·0	3½
		4634·5	2½
	4632·9	4633·1	4

* Groups *a* to *k* by eye-observation. Groups *a* to *o* recorded by photography. † Double. ‡ Strong triplets.

NITROGEN—*continued.*

	Positive Band Spectrum		Intensity and Character		Positive Band Spectrum		Intensity and Character
	Ångström and Thalén	Hasselberg			Ångström and Thalén	Hasselberg	
γ	4631·3	4631·4	4	δ		4564·5	3½
		4630·9	2½			4563·1	4
	4629·6	4629·7	3			4561·7	4
		4628·8	2½			4560·3	3½
	4627·5	4627·7	3			4559·4	1½
		4626·7	2			†4558·6	2½
		4625·8	2			4557·5	2
		4625·2	1½			4557·0	2
		4624·3	2			4556·4	2
		4623·7	1½			4555·5	2½
		4623·1	1			4554·5	2
		4622·5	1			4553·3	3½
	4621·5	4621·9	3			4552·3	2
		4620·7	2			*4551·1	3½
	4619·2	*4619·2	3			4550·0	2
		4618·0	2			4548·8	2½n
	4616·7	4616·7	2½			4547·6	2
		4615·5	1½			4546·7	2
	4614·0	4614·1	2½			4546·0	1½
		4612·8	1½			4545·2	2
	4611·4	4611·5	2			4544·3	1½
		4611·1	2			4543·4	1½
		4610·0	1			4542·7	1½
	4608·7	4608·8	2			4541·7	2
		4608·2	2			4540·8	
		4607·3	2			4540·0	
		4606·1	2			4539·1	
		4605·1	1			4538·0	
		4604·2	2			4537·1	
		4603·0	1			4536·2	
		4602·2	2			4535·0	
		4601·1	1½			4534·2	
		4600·0	1½			4533·5	
		†*4599·0	2½			4532·0	
		4597·8	Weak Lines			4531·2	
		4596·7				4530·4	
		4596·0				4528·8	
		4595·3				4528·1	
		4594·4				4527·4	
		4593·6				4525·5	
		4592·3				4524·9	
		4591·2				4524·2	
		4590·2				4522·2	
δ	4574·0	*4573·5 ‡	4			4521·6	
		4572·8	5			4520·9	
		4572·0	6			4518·9	
		4570·7	3			4518·3	
		4570·1	3			4517·7	
		4569·2	3			4515·3	2
		4568·3	3			4514·6	1
		4567·5	3			4514·0	1
		4566·6	2½			4510·9	1
		4566·0	2½			4510·2	1
		4565·4	2½			4509·3	2

* Groups *a* to *k* by eye-observation. Groups *a* to *o* recorded by photography. † Double. ‡ Strong triplets.

NITROGEN—*continued.*

Positive Band Spectrum		Intensity and Character	Positive Band Spectrum		Intensity and Character
Ångström and Thalén	Hasselberg		Ångström and Thalén	Hasselberg	
	4507·2	1½n		4442·7	
	4506·6	1		4440·9	
	4504·0	1½n		4440·2	
	4502·7	1½n		4439·5	
	4501·3	1½n		4437·6	
4489·0	*4489·4	4		4437·0	
	4488·6 ‡	5		4436·4	
	4487·7	6		4434·3	
	4486·8	3		4433·5	
	4486·0	3½	ε	4432·9	
	4485·2	3½		4430·8	
	4484·3	3½		4430·1	
	4483·5	3½		4429·6	
	4482·6	2½		4427·2	
	4482·3	2½		4426·7	
	4481·6	2½		4426·0	
	4480·8	3b^r		4423·6	
	4479·4	4		4423·0	
	4478·0	4b^r		4422·4	
	4476·5	3	4417·0	*4415·9	4
	4475·9	2		4414·7 ‡	5
	4474·9	3n		4413·6	6
	4474·1	2½		4413·4	2½
	4473·4	2½		4412·8	3
	4473·1	2½		4411·9	3
	4472·2	2		4411·1	3
	4471·7	2½		4410·3	2½
	4471·0	2½		4410·0	2½
	4469·9	2½		4409·3	2½b
ε	4469·0	2		4408·8	
	4467·9	3		4408·1	2½b
	4466·8	2		4407·5	
	*4465·9	3		4407·0	2
	4464·8	1½		4406·3	3
	4463·8	2		4405·9	2
	4463·5	1½		4404·7	4
	4462·5	1½	η	4403·3	4
	4461·6	1½		4401·9	3½
	4460·9	1½		4401·4	2
	4460·1	1½		4400·4	3
	4458·4	1½		4399·5	2
	4457·5	1		4398·8	2
	4454·9	1		4398·5	2
	4454·1	1½		4397·7	2
	4452·9	1½		4397·1	2
	4452·2	1½		4396·5	2
	4451·0	1½		4396·0	2
	4450·0	1½		4395·2	2
	4449·3	1½		4394·5	2
	4448·5	1½		4393·4	2½
	4447·1	1½		4392·5	2
	4446·3	1½		4391·2	2½
	*4444·2			4390·2	
	4443·4			*4389·3	2

* Groups *a* to *k* by eye-observation. Groups *a* to *o* recorded by photography. ‡ Strong triplets.

NITROGEN—*continued.*

Positive Band Spectrum		Intensity and Character	Positive Band Spectrum		Intensity and Character
Ångström and Thalén	Hasselberg		Ångström and Thalén	Hasselberg	
η	4388·1	1·2	ζ	4338·8	4
	4387·0			4337·9	2½
	4385·7			4337·3	3
	4384·7			4336·7	2
	4384·1			4336·1	4
	4383·2			4335·4	1
	4382·3			4334·8	4
	4381·4			4333·7	4
	4380·7			4333·0	1½
	4379·8			4332·4	2
	4378·8			4331·5	3
	4378·0			4331·0	2b
	4377·1			4330·4	
	4376·1			4329·7	3½
	4375·2			4329·0	1
	4374·4			4328·0	3
	4373·1			4327·3	2
	4372·4			4326·1	3
	4371·7			4325·3	2
	4370·2			4324·3	2½
	4369·5			4323·4	1½
	4368·7			4322·4	2
	4367·9			4322·1	1
	4367·1			4321·4	1½
	4366·4			4320·6	2
	4365·6			4319·9	1½
	4364·0			4319·2	2
	4363·4			4318·4	2
	4362·6			4317·6	1½
	*4356·9	4		4316·9	1½
	4355·8	5		4316·2	1½
	4355·0	2		4315·3	1
	4354·5	6		*4314·6	1½
	4353·4	3		4313·9	1½
	4352·8	4		4312·9	Weak Triplets
	4351·8	4		4312·2	
	4350·9	4		4311·5	
	4349·9	3½		4310·3	
	4349·2	2		4307·7	
	4348·9	3		4301·1	
	4347·9	4		4307·7	
	4346·8	2		4307·1	
	4346·4	2½		4306·5	
	4345·8	2		4305·1	
	4345·1	2		4304·4	
	4344·4	4		4303·8	
	4343·8			4302·1	
4346·0	*4343·2	6 b		4301·6	
	4342·6			4301·0	
	4342·2	2 b		4299·2	
	4341·6	4		4298·6	
	4341·0	1½		4298·2	
	4340·3	4		4296·3	
	4339·6	4		4295·7	

* Groups *a* to *k* by eye-observation. Groups *a* to *o* recorded by photography.

NITROGEN—*continued.*

Positive Band Spectrum		Intensity and Character	Positive Band Spectrum		Intensity and Character
Ångström and Thalén	Hasselberg		Ångström and Thalén	Hasselberg	
	4295·2			4236·9	
ζ	4293·2			4236·3	
	4292·6			4235·5	
	4292·1			4234·4	
4271·0	*4269·4	4		4233·8	
	4268·8 ‡	5		4233·1	
	4268·0	6		4231·7	
	4267·4	2		4231·1	
	4266·8	4		4230·5	
	4266·2	4		4229·1	
	4265·5	3½		4228·5	Weak Triplets
	4264·6	3		4227·9	
	4264·1	3		4226·3	
	4263·7	2		4225·8	
	4263·1	3		4225·1	
	4262·7	2		4223·4	
	4262·4	2	ι	4222·9	
	4262·0	1½		4222·4	
	4261·5	4		4220·5	
	4260·9	2		4219·9	
	4260·3	4		4219·4	
	4259·7	1		4217·5	
	4259·1	3½		4216·9	
	4258·8	2		4216·3	
	4257·9	3½		4214·2	
	4257·2	2		4213·7	
	4256·6	3		4213·2	
	4256·2	2		4211·0	Very Weak
ι	4255·5	2½		4210·5	
	4255·1	2½		4210·0	
	4254·6	2½		4208·3	
	4253·9	2½		4206·8	
	4253·7	2½		4204·4	
	4253·0	2½		4203·3	
	*4251·9	3½	4203·0	*4201·0	4
	4251·2	2		4200·3 ‡	5
	4250·2	3½		4199·6	6
	4249·3	2½		4199·0	3
	†4248·3	2		4198·5	4
	4247·4	2		4197·8	4
	4246·6	2½		4197·2	3½bʳ
	4246·1	2		4196·4	3½
	4245·4	2½		4195·7	3n
	4244·5	2½		4195·5	3n
	4243·9	2	ι	4194·9	3
	4243·4	1b		4194·5	3
	4243·0			4194·0	2½
	4242·4	2		4193·4	3
	4241·6	2		4193·0	4
	4241·0	2		4192·2	4
	4240·2	2		4191·7	1½
	4239·4	2		4190·9	4
	4238·7	2		4189·7	3½
	*4237·9	2		4189·3	2½

* Groups *a* to *k* by eye-observation. Groups *a* to *o* recorded by photography. † Double. ‡ Strong triplets.

NITROGEN—*continued.*

Positive Band Spectrum		Intensity and Character	Positive Band Spectrum		Intensity and Character
Ångström and Thalén	Hasselberg		Ångström and Thalén	Hasselberg	
κ	4188·4	3n	λ 4144·0	*4141·1	4
	4187·7	2½		4140·2 ‡	5
	4187·0	3		4139·5	6
	4186·8	3		4138·7	3
	4186·2	2½		4138·3	3½
	4185·7	3		4137·8	2
	4185·1	3		4137·4	3½
	4184·3	2½		4136·7	3½
	4184·1	2½		4136·1	2½
	4183·4	3		4135·6	2½
	*4182·7	3½		4135·1	3b
	4181·9	2½		4134·7	
	4180·9	3½		4134·0	3b
	4180·0	2		4133·7	
	†4179·1	2½		4133·1	2
	4178·1	2		4132·6	3
	4177·2	2		4132·2	2½
	4176·7	2		*4131·3	4
	4176·0	2½		4130·7	1
	4175·2	1		4130·1	4
	4174·6	1½		4128·8	3½
	4173·6	1		4128·4	2½
	4171·8	1		4127·5	3½
	*4170·8	2½		4126·9	2½
	4170·0	2		4126·3	2½
	4169·3	2		4125·9	2½
	4168·6	2		4125·3	2½
	4167·6	2		4124·8	2½
	4166·9	2		4124·3	2½
	4166·2	2		4123·6	2
	4165·1	1½		4123·2	2½
	4164·5	1½		4122·7	2
	4162·6	1½		4121·7	2½
	4161·9	1½		4120·9	1½
	4161·2	1½		*4120·1	3
	4159·9	1½		4118·3	2
	4159·3	1½		4117·3	1½
	4158·7	1½		4116·4	1
	4157·2	1½		4115·2	<1
	4156·6	1½		4114·5	<1
	4156·1	1½		4114·0	<1
	4154·3	1		4113·3	1½
	4153·8	1		4112·5	1½
	4153·2	1		4111·9	1½
	4151·5	1		4111·1	1
	4151·0	1		4110·3	1½
	4150·4	1		4109·6	1½
	4148·5	Very Weak		4108·9	1½
	4147·9			4108·2	1
	4147·4			4107·3	
	4145·5			4106·6	
	4145·0			4105·9	
	4144·4			4104·9	
				4104·2	

* Groups *a* to *k* by eye-observation. Groups *a* to *o* recorded by photography. † Double. ‡ Strong triplets

NITROGEN—*continued.*

Positive Band Spectrum		Intensity and Character	Positive Band Spectrum		Intensity and Character
Ångström and Thalén	Hasselberg		Ångström and Thalén	Hasselberg	
	4103·6			4064·9	
	4102·4			4064·1	
	4101·8			4063·7	
	4101·1			4062·7	
	4099·9			4062·0	
	4099·3			4061·1	
	4098·6			4060·6	
	4097·2			4059·8	
	4096·7		4063·0	*4058·7	4½
	4096·0			4058·3 ‡	5
4098·0	*4094·2	4		4057·9	6
	4093·7	2		4057·3	4
	4093·2	5		4056·8	4
	4092·1	6		4056·3	4
	4091·6	2½		4055·8	3½
	4091·0	2½		4055·5	3
	4090·5	2½		4055·2	3
	4090·2	2		4054·7	3½
	4089·6	3n		4054·3	3
	4088·9	3		4053·9	3½
	4088·3	2½b^r		4053·5	3
	4087·3	2½		4053·1	3
	4086·9	2½		4052·7	3½
	4086·1	3		4052·2	1½n
	4086·0	3		4052·0	1½n
	4085·2	2½		4051·5	4½n
	4084·9	2½		4051·1	1
	4084·3	2		4050·9	1b^r
	4083·6	3		4050·5	4b^r
	4083·3	2		4049·4	3½
	4082·3	4		4048·9	3
μ	4081·0	4	ν	4048·3	3
	4079·7	3½		4048·1	3
	4079·4	1		4047·7	3
	*4078·3	3½		4047·2	3
	4077·7	1½		4046·8	3
	4077·0	2		4046·2	2½
	4076·8	2		4045·8	3
	4076·1	2		4045·4	3
	4076·5	2		4045·0	1
	4075·1	2		4044·6	3½
	4074·4	2		4043·9	2½
	4074·0	2		*4043·2	4s
	4073·4	2		4042·6	2½
	4072·6	2		4041·7	3n
	4072·4	2		4040·9	3
	4071·7	2		4040·2	2½
	4070·8	2½		4039·8	2½
	4069·9	1½		4039·2	2½
	4068·9	2½		4038·5	2½
	4068·0	1n		4038·0	2½
	4067·0	1½		4037·4	2½
	4066·0			4036·7	2½
	4065·2			4036·1	2½

* Groups *a* to *k* by eye-observation. Groups *a* to *o* recorded by photography. ‡ Strong triplets.

NITROGEN—*continued.*

Positive Band Spectrum		Intensity and Character	Positive Band Spectrum		Intensity and Character
Ångström and Thalén	Hasselberg		Ångström and Thalén	Hasselberg	
ν	4035·5	2½	o	3993·7	2½
	4034·9	2½		3993·5	2½
	4034·2	2½		3993·0	2½
	4033·6	2½		3992·7	2
	4033·0	2½		3992·3	3
	4032·2	2½		3991·9	3
	4031·6	2½		3991·5	2½
	4031·1	2½		3991·3	2½
	4030·0	2		3990·8	3½
	4029·5	2		3990·4	1
	4029·0	2		3989·8	4
	*4027·8	2		3989·4	1
	4027·3	2		3989·1	1
	4026·8	2		3988·7	4
	4025·6	2		3988·5	2
	4025·1	2		3987·7	3½
	4024·6	2		3987·1	2½
	4023·2	1½		3986·6	3
	4022·8	1½		3986·3	3
	4022·3	1½		3985·8	3
	4020·8	1½		3985·4	3
	4020·4	1½		3985·0	3
	4019·9	1½		3984·3	2½
	4018·4	1		3984·1	2½
	4017·9	1		3983·6	2½
	4017·5	1		3982·8	3½
	4015·8	1		3982·1	2½
	4015·4	1		*3981·2	3½
	4015·0	1		3980·5	2½
	4013·2	Extremely Feeble Triplets		3979·7	3
	4012·7			3979·5	3
	4012·4			3978·9	2½
	4010·5			3978·1	2½
	4010·1			3977·8	2½
	4009·7			3977·2	2½
	4007·7			3976·5	2½
	4007·3			3976·0	2
	4006·9			3975·5	1
	4004·9			3975·3	1½
	4004·5			3974·8	2½
	4004·1			3974·1	2
	4001·9			3973·5	2
	4001·5			3972·9	2
	4001·1			3972·2	2
o 4002·0	*3997·8	4		3971·6	2
	3997·2 ‡	5		3971·1	2
	3996·6	6		3970·2	2
	3996·4	4		3969·6	2
	3995·9	3		3969·0	2
	3995·4	4		3968·1	1½
	3994·9	3		3967·6	1½
	3994·7	2		3967·0	1½
	3994·3	3		3965·9	1½
	3993·9	2½		3965·4	1½

* Groups *a* to *k* by eye-observation. Groups *a* to *o* recorded by photography. ‡ Strong triplets.

NITROGEN—*continued.*

Positive Band Spectrum		Intensity and Character	Positive Band Spectrum		Intensity and Character
Ångström and Thalén	Hasselberg		Ångström and Thalén	Hasselberg	
o	3964·9	1½	*o*	3956·6	Very Feeble Triplets
	3963·8	1½		3956·1	
	3963·2	1½		3955·7	
	3962·7	1½		3954·1	
	3961·4	1		3953·6	
	3960·9	1		3953·2	
	3960·4	1		3951·5	
	3959·1	1		3951·1	
	3958·6	1		3950·7	
	3958·1	1			

NITROGEN—*continued.*

Negative Band Spectrum		Intensity and Character	Negative Band Spectrum		Intensity and Character
Ångström and Thalén	Hasselberg		Ångström and Thalén	Hasselberg	
A 4709·3	*4708·6	5	B	4633·3	1
	4706·8	1		4632·7	2½
	4704·6	1		4631·1	1
	4702·8	1		4629·9	3
	4701·0	2		4629·0	1
	4699·9	1		4627·2	1½
	4698·7	2½		4625·1	1
	4697·2	1		4624·6	1
	4695·9	3		4620·8	2½
	4694·4	1		4616·1	1½
	4692·8	3		4609·0	1½
	4691·1	1		4606·5	1½
	4689·4	3		4600·9	1½
	4687·5	1			
	4685·6	2½	C 4601·2	*4599·4	5
	4683·6	1		4597·7	2
	4681·5	2		4596·5	2
	4679·3	1		4594·3	1½
	4677·2	1½		4593·2	1
	4674·7	1		4592·2	2
	4672·3	1		4591·2	1
	4667·3	1		4590·1	2½
B 4653·5	*4651·2	5		4588·8	1½
	4649·2	2		4587·4	3
	4644·8	1		4586·1	1½
	4643·8	2		4584·7	3
	4642·6	1½		4583·1	1½
	4641·5	2½		4581·5	3
	4640·2	1½		4579·8	1½
	4638·8	2½		4578·1	2½
	4637·4	1½		4576·1	1
	4635·9	2½		4574·3	1
	4634·3	1½		4570·2	2

* Groups *a* to *k* by eye-observation. Groups *a* to *o* recorded by photography.

NITROGEN—*continued.*

	Negative Band Spectrum		Intensity and Character
	Ångström and Thalén	Hasselberg	
D	4555·2	4553·8	5
		*4552·9	5
		4549·0	1½
		4548·0	1
		4547·0	2
		4546·0	1
		4545·0	2b$^{\mathrm{r}}$
		4543·8	1
		4542·9	2
		4542·0	2
		4540·9	2
		4539·5	1½
		4538·0	1
		4536·4	2
		4535·3	1
		4534·0	1
		4533·3	1
		4532·5	1½
		4529·8	1½
		4529·1	1½
		4525·7	1
		4525·4	1
		4521·4	1
E	4516·5	*4515·3	5
		4514·3	1½
		4513·4	1½
		4512·7	1½
		4512·2	1½
		4510·1	1½
		4509·2	1
		4508·3	2
		4507·3	1
		4506·2	2½
		4505·1	1
		4503·9	3
		4502·6	1
		4501·3	3
		4499·9	1
		4498·5	2½
		4496·9	1
		4495·3	2
		4493·6	1
		4491·9	2
F		4484·9	4
		4484·3	4
G	4281·0	*4278·0	5
		4276·9	3
		4276·5	3
		4276·1	3
		4275·6	2½
		4275·0	3
		4274·4	2
		4272·9	2½
		4272·1	2

	Negative Band Spectrum		Intensity and Character
	Ångström and Thalén	Hasselberg	
H		4271·2	3½
		4270·2	2½
		4269·2	4
		4268·0	2½
		4266·9	4
		4265·7	2½
		4264·5	4
		4263·1	3
		4261·7	4
		4260·3	2½
		4258·8	4
		4257·2	2½
		4255·5	3½
		4253·9	2
		4252·2	3
		4250·3	2
		4248·5	2½
		4246·5	1½
		4244·6	2
		4242·6	1
		4240·4	1
		4236·5	1
I	4239·0	*4236·3	5
		4235·1	3½
		4234·3	3
		4233·9	2
		4233·3	2½
		4232·8	1½
		4231·3	2
		4230·4	1½
		4229·5	3
		4228·6	2
		4227·6	3½
		4226·6	2½
		4225·5	4
		4224·4	2½
		4223·1	4
		4221·9	2½
		4220·5	3½
		4219·4	1
		4219·1	1
		4218·4	1½
		4217·6	2
		4216·1	2
		4215·4	1
		4214·5	2
		4214·1	2
		4212·7	2
		4211·1	2
		4209·3	1
		4207·6	1½
		4203·6	1

* Groups *a* to *k* by eye-observation. Groups *a* to *o* recorded by photography.

NITROGEN—*continued.*

Negative Band Spectrum		Intensity and Character	Negative Band Spectrum		Intensity and Character
Ångström and Thalén	Hasselberg		Ångström and Thalén	Hasselberg	
I 4203·0	*4198·7	5	I	4187·3	1
	4198·3	4		4186·1	3
	4197·7	3½		4185·0	1½
	4196·9	3½		4183·6	3
	4196·4	2		4182·3	1½
	4195·9	2		4180·9	2½
	4195·3	2		4179·4	1
	4193·9	1½		4177·9	2
	4193·3	2		4176·4	1½
	4192·3	2		4174·7	1
	4191·4	1½		4172·9	<1
	4190·6	2½		4171·3	1
	4189·6	1	K 4175·0	*4166·3	3
	4188·4	3		*4165·6	3

Second Report of the Committee, consisting of Professor TILDEN, Professor W. RAMSAY, *and* Dr. W. W. J. NICOL (*Secretary*), *appointed for the purpose of investigating the subject of Vapour Pressures and Refractive Indices of Salt Solutions.*

I. *Vapour Pressures of Salt Solutions.*

FOUR salts, NaCl, KCl, $NaNO_3$, and KNO_3, have been completely examined, in solutions varying in strength from one molecule of salt per 100 water-molecules up to solutions nearly saturated at the temperature of experiment.

The method employed was similar to that described in the previous Report of the Committee, with this difference, that in this case the solutions were kept of constant strength and the temperature was the variable. As before, the pressures at definite temperatures were determined, and not the converse.

The experiments, though covering the same ground, are completely distinct from those described in the previous Report, and are not only more complete, but more reliable, being means of four independent observations, and it is believed as free from the effect of superheating as it is possible to obtain them by this method. The zinc introduced to prevent succussive boiling has been proved to have no influence on the results.

The solutions were of the following strengths:—

NaCl 2, 4, 5, 6, 8, 10 molecules
KCl 2, 4, 6, 8, 10 „
$NaNO_3$ 2, 4, 5, 6, 8, 10, 15, 20, 25 molecules
KNO_3 1, 2, 3, 4, 5, 10, 15, 20, 55 „

all in 100 H_2O, and the temperatures were 70°, 75°, 80°, 85°, 90°, 95°.

The results confirm in all respects those obtained in the previous preliminary experiments. They are as follows:—

(α) When temperature is constant and concentration (n) varying, then $\frac{p-p^1}{n}$ increases rapidly with NaCl, more slowly with KCl; diminishes slowly with $NaNO_3$, and very rapidly with KNO_3, the order being NaCl, KCl, $NaNO_3$, KNO_3. The figures show a clear agreement with those of Tammann (Wiedemann 'Ann.' xxiv), obtained by the barometric method. This is entirely at variance with Wüllner's statement (Pogg. 'Ann.' cx.) that $\frac{p-p^1}{p}$ is constant for all salts; a statement not borne out by his figures, discordant as they are.

(β) When n is constant and temperature varying, then the value of $\frac{p-p^1}{np}$, *i.e.*, the restraining effect of each salt molecule, is a diminishing quantity in the case of NaCl, practically constant with KCl, slowly increasing with $NaNO_3$, and rapidly increasing with KNO_3, the order being the same but reversed. This also is confirmed by Tammann, and agrees with the results of Legrand ('Ann. Chim. et Phys.' 1835).

(γ) When, too, the temperature and concentration increase, the salts form the same series: decrease of restraining effect with NaCl, less so with KCl, no change with $NaNO_3$, and a marked increase with KNO_3.

Connected with the above are:—

(δ) The order is the same when the solubility as a function of the temperature is considered. NaCl has its solubility only slightly affected by rise of temperature, KCl more so, $NaNO_3$ still more, and KNO_3 greatly so.

(ε) The value of $\frac{p-p^1}{n}$, where $n=1$, is very nearly the same for all four salts at the same temperatures.

(ζ) The heat of solution for—

$NaCl = -1{\cdot}180$	$KCl = -4{\cdot}400$
$NaNO_3 = -5{\cdot}200$	$KNO_3 = -8{\cdot}500$

Again the same series.

The behaviour of these four salts can be satisfactorily explained on the lines of the theory of solution laid down in a paper on the nature of solution ('Phil. Mag.' 1883); but for the details reference must be made to the memoir.

II. *Refractive Indices of Salt Solutions.*

The work of nearly all previous experimenters on this branch of the subject of solution is unavailable for any systematic examination of the point, inasmuch as but few salts have been examined, and only a few solutions of each; while even in these cases the results require recalculation, as the solutions examined were of percentage composition, and the conversion of these into terms of even molecules of salt per 100 H_2O is a laborious process, requiring a large amount of interpolation, for which the data are generally insufficient.

Recently, however, a paper by Ostwald has come into our hands ('Volum. u. Optisch-Chem. Studien,' Dorpat, 1878), which contains the necessary data for a partial examination of the subject. Ostwald's experiments were conducted with solutions containing one equivalent in grammes of the base or acid in one litre of the solution. Consequently the salt solutions obtained on neutralisation contain one equivalent in grammes of the salt in the two litres. These solutions, though not strictly comparable, are still nearly so, and are of the approximate strength, MR. $110H_2O$.

The results obtained by Ostwald are as follows:—

(α) When a solution of a base (potash or soda) is neutralised by the requisite amount of the solution of an acid (fourteen organic and inorganic acids), the difference between the sum of the refractive indices of the two solutions before mixing and twice the refractive index of the resulting salt solution is a value almost identical for both bases, no matter what may be the acid. There is thus complete parallelism between the change of refractive index and of molecular volume on neutralisation.

(β) The conclusion is that the alteration in the physical constants, brought about by combination, has a constant value for each constituent which enters into the combination, and is therefore independent of the other constituents with which the first may combine.

Thus there is little room for doubt that in other cases also alteration in molecular volume will be accompanied by parallel changes in the refraction equivalent. Unfortunately, Ostwald's results are not of a form to permit their conversion into refraction equivalents, or it would be possible to show, even more clearly, the close connection between these physical constants.

III. *Saturation of Salt Solutions.*[1]

It has long been known that a salt is able to drive another out of solution in very many cases, partially or completely, while in other cases the solubility of one or both salts is largely increased.

When the two salts are capable of forming *well-defined* double salts, then either salt added to a saturated solution of the other *completely* expels it from solution. On the other hand, when the two salts are *isomorphous*, and are thus able to form *mixed* crystals, then the expulsion from solution is only *partial* (Rudorff. Wiedem. 'Annalen,' xxv. 626).

This may be explained as follows:—

Double salts do not exist as such in solution; the saturated solution of a double salt is therefore not necessarily saturated for either of its constituents, but may be able to dissolve more of one or other of the single salts. As the amount, however, of this salt increases there arrives a point at which the solution has become so rich in this salt (B) that any one molecule of the other salt (A) may be regarded as being in contact with a molecule of B; aggregation or combination to form the double salt (AB) is then possible, and crystallisation proceeds *pari passu* with the solution of B, and results finally in the complete expulsion of A from the solution in cases where the attraction between A and B exceeds the cohesion of either A or B. While, on the other hand, if this is not the case the expulsion is only partial. This explanation is strongly supported by the stability and definite character of the well-defined double salts, which are totally expelled from solution, and by the instability of those salts which are only partially expelled, and also by the

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[1] Published *Phil. Mag.* January 1886.

fact that the saturated solutions of pairs of salts which do not crystallise together are unaffected by excess of either salt.

IV. *Expansion of Salt Solutions.*

The results described in the previous Report have been completely examined, and will soon be published. The following may be added to the conclusions already arrived at:—

The effect of heat on the volume of a solution of a salt depends on the solubility of the salt as a function of the temperature. If the solubility be little affected by temperature then the volume curve approaches more nearly to a straight line than when the solubility is largely dependent on temperature.

In the former case the effect of heat is simpler than in the latter. In the one the solution is practically of the same strength throughout. In the other the rise of temperature is attended not only by expansion, but also by what is practically dilution of the solution. Thus it is at present impossible to trace out a further connection between solubility and rate of expansion of a salt in solution.

V. *Water of Crystallisation.*

An examination of the evidence derivable from the results of thermochemical investigations, and also a comparison of the molecular volumes of dissolved salts, lead to the conclusion that no part of the water in a solution of a hydrated salt can be said to be in a different relation to the salt from that of the remainder of the water. In other words, water of crystallisation cannot be recognised in solution either by thermal or volume changes—it is indistinguishable from the rest of the water. The argument based on colour changes of solutions of $CoCl_2$, &c., does not affect the above, for it is not contended that the salt is anhydrous in the same sense as it is when dried at 150° C.

Second Report of the Committee, consisting of Professors RAMSAY, TILDEN, MARSHALL, *and* W. L. GOODWIN *(Secretary), appointed for the purpose of investigating certain Physical Constants of Solution, especially the Expansion of Saline Solutions.*

GRAHAM, in a series of interesting experiments, has shown that saline solutions absorb water-vapour from a saturated atmosphere ('Edin. Journ. of Science,' xvi. 1828, pp. 326–335; also Schweigger, 'Journ.' liii. 1828, pp. 249–264). This process he called *invaporation.* His experiments were made by enclosing, in a tin canister containing water, glass basins in which were equal weights of (generally) saturated solutions. After a few days the canister was opened, the dishes weighed, and the gain of water by invaporation thus determined. The relative rates of invaporation thus became approximately known. But these rates estimated in this way are influenced by the rate of diffusion of water-vapour in air, and by the rates of diffusion of the salts in water. The latter especially must be taken into account in interpreting Graham's results. A salt with strong attraction for water, but low rate of diffusion, might show less invaporation than one with a weaker attraction for water but a higher rate of diffusion. Thus, potassic chloride diffuses faster than sodic chloride, but the latter has the greater attraction for water vapour. If solutions of these two salts were confined in a space containing water, the sodic chloride solution would at first attract water more rapidly, but the consequent dilution of the surface layer would not be counterbalanced by diffusion so rapidly as in the case of potassic chloride; so that the rates of invaporation might become equal, or that of potassic chloride even greater. Some experiments made by us have given indications of these phenomena.

If the rates of invaporation, not complicated by diffusion, could be accurately measured, a comparison of such measurements would be valuable, by giving indications of the formation of hydrates in solution. They would also be of value in considering the 'Correlation of Physical Properties of Solution with Concentration,' in the manner indicated by D. Mendeléeff ('Ber. Deut. Ch. Ges.' xix. 370–389). But the subject can be investigated in a different way and with promise of more fruitful results. When two salts are enclosed in the same space with a certain quantity of water, the salts tend to keep the atmosphere dry by condensing the water-vapour. This goes on until all the water is evaporated except that small portion which remains in the condition of vapour. The question at once presents itself, in what proportion will the two salts divide the water between them? The proportion will be influenced, probably, by the relative masses of the salts and the water, and by the temperature, as well as by the relative attractions of the salts for water. If the salts are in molecular proportion, they might be expected to divide the water between them much in the same way as equivalents of caustic soda and potash with a simple equivalent of sulphuric acid in solution. That is, if the attraction of salts for the water which dissolves them is of the same nature as that between acids and bases, the partition would be in proportions representing the relative attractions of the salts for water. It was to test the correctness of this reasoning that the following experiments were made.

The salts were carefully dried, and weighed out in small test-tubes (5·5 cm. long and 1 cm. diam.). The quantities used were in the ratio of the molecular weights. Thus, in the first experiment (I.) the masses of the salts were two-hundredths of the gram-molecules, and the quantity of water eight-hundredths of the gram-molecule. As a rule, the water was divided between the two salts, because by so doing we thought to hasten the completion of the experiment. Experience, however, has decided us to abandon this method in favour of enclosing the water along with the salts, the three in separate small tubes, so that the process of invaporation may be watched from the beginning. The salts and water were sealed in a large glass tube (about 10 cm. long and 4 cm. in diameter) before the blowpipe. When the small tube containing the water appeared to be dry, the enclosing tube was opened, the small tubes with their contents weighed, and then resealed. Invaporation was very slow, owing to the small surface exposed by the liquids in the narrow tubes. Shallow vessels would have been better, but the hermetical enclosing of these presented such difficulties that the narrow tubes were used in preference. Heating to 100° C. and cooling gradually was also tried as a means to hasten invaporation. This was found to have the desired effect up to a certain point, beyond which the water began to condense on the enclosing tube. The results of the experiments are here put in tabular form. In the first column the formulæ of the substances in the small test-tubes are given; in the second, the masses of the substances in grams; in the third the number of days between the first sealing and the first opening of the enclosing tube; in the fourth, the quantities of water adhering to the salts at the time of first opening; and following are pairs of columns giving similar data for the second, third, and fourth times of opening. The quantities of salts and of water are also given in molecules, 100 molecules of water being taken as the basis of calculation. The 'period' in each case is the time elapsed from the beginning of the experiment.

Experiment I.

Substances	Mass in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams
NaCl. .	1·1672	56	0·8058	159	1·1978	172	1·2392
KCl . .	1·4882	—	0·6292	—	0·2332	—	0·1900
H_2O . .	1·44	—	1·4350	—	1·4310	—	1·4292
	Number of molecules		Water in molecules		Water in molecules		Water in molecules
NaCl. .	25	—	55·96	—	83·18	—	86·06
KCl . .	25	—	43·69	—	16·19	—	13·19
H_2O . .	100	—	99·65	—	99·37	—	99·25

Experiment II.

Substances	Mass in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams
NaCl	0·5836	111	0 9516	155	1 1160	276	1·3331	290	1·3386
KCl.	0·7441	—	0·4866	—	0·3166	—	0·0991	—	0·0976
H_2O.	1·44	—	1·4382	—	1·4326	—	1·4322	—	1·4362
	Number of molecules		Water in molecules		Water in molecules		Water in molecules		Water in molecules
NaCl	12·5	—	66·08	—	77·50	—	92·58	—	92·96
KCl.	12·5	—	33·79	—	21·99	—	6·88	—	6·78
H_2O.	100	—	99·87	—	99·49	—	99·46	—	99·74

EXPERIMENT III.

Substances	Mass in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams
NaCl	0·1459	111	0·6788	143	0·7020	249	0·7493	262	0·7539
KCl.	0·1860	—	0·7710	—	0·7370	—	0·6831	—	0·6785
H_2O.	1·44	—	1·4498	—	1·4390	—	1·4324	—	1·4324
	Number of molecules		Water in molecules		Water in molecules		Water in molecules		Water in molecules
NaCl	3·125	—	47·14	—	48·75	—	52·03	—	52·35
KCl.	3·125	—	53·54	—	51·18	—	47·44	—	47·12
H_2O.	100	—	100·68	—	99·93	—	99·47	—	99·47

EXPERIMENT IV.

Substances	Mass in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams
NaCl. .	0·5836	36	1·1271	131	1·4300	144	1·4294
KCl . .	0·3721	—	0·3129	—	0·0053	—	0·0059
H_2O . .	1·44	—	1·44	—	1·4353	—	1·4353
	Number of molecules		Water in molecules		Water in molecules		Water in molecules
NaCl. .	12·5	—	78·27	—	99·31	—	99·26
KCl . .	6·25	—	21·73	—	0·37	—	0·41
O_2H . .	100	—	100	—	99·68	—	99·67

EXPERIMENT V.

Substances	Mass in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams
NaCl	1·1672	24	0·0034	56	0·0024
LiCl	0·8474	—	1·1506	—	1·1551
H_2O	1·44	—	1·1540[1]	—	1·1575
	Number of molecules		Water in molecules		Water in molecules
NaCl	25	—	0·24	—	0·17
LiCl	25	—	79·90	—	80·22
H_2O	100	—	80·14[1]	—	80·39

EXPERIMENT VI.

Substances	Mass in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams
NaCl	0·5836	42	0·0031	77	0·0019	171	0·0005	184	0·0006
LiCl.	0·4237	—	1·4459	—	1·4466	—	1·4443	—	1·4445
H_2O	1·44	—	1·4490	—	1·4485	—	1·4448	—	1·4451
	Number of molecules		Water in molecules		Water in molecules		Water in molecules		Water in molecules
NaCl	12·5	—	0·22	—	0·13	—	0·03	—	0·04
LiCl.	12·5	—	100·62	—	100·46	—	100·30	—	100·31
H_2O.	100	—	100·84	—	100·59	—	100·33	—	100·35

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[1] Part of the water was lost in closing the outer tube. Before opening the first time the tube was kept at 12° C. for three days, and before opening the second time for six hours at 100° C.

EXPERIMENT VII.

Substances	Mass in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams	Period of invaporation in days	Water in grams
NaCl	0·5836	62	0·4562	177	0·6219	191	0·6365
LiCl	0·4237	—	2·4154	—	2·2434	—	2·2284
H_2O	2·88	—	2·8716	—	2·8653	—	2·8649
	Number of molecules		Water in molecules		Water in molecules		Water in molecules
NaCl	6·25	—	15·84	—	21·59	—	22·10
LiCl	6·25	—	83·87	—	77·90	—	77·38
H_2O	100	—	99·71	—	99·49	—	99·48

In discussing these experiments it is to be noted that when the two salts were potassic and sodic chlorides, the water was divided as nearly as possible equally between them, a little being, however, left in its small tube. The first weighing was not made until *all* the water seemed to be invaporated by the salts. When the two salts were sodic and lithic chlorides, the greater part of the water was given to the latter before enclosing in the large tube. Experiments I., II., and III. were made to discover the effect produced by increasing the relative quantity of water (an accident spoiled the experiment coming between II. and III.). It is evident from these experiments that sodic chloride invaporates water more powerfully than potassic chloride, for, as all the experiments show, the sodic solution increases in weight at the expense of the potassic. A preliminary experiment made this very apparent. The three tubes were enclosed *without* dividing the water between the salts: after 24 hours the sodic chloride had begun to deliquesce, while the potassic chloride was quite dry; after 25 days about one-half of the water was invaporated, and, while the potassic chloride was only slightly moist, the sodic chloride was dissolved to a considerable extent. In repeating and extending our experiments this method (as above indicated) will be followed. Our *chief* object, so far, has been to determine how the water is divided between the two salts when a condition of equilibrium is reached. As might be expected, when the relative quantity of water is increased, the process is retarded, as the weaker solutions invaporate more slowly. But even with 32 molecules of water to 1 of each of the salts, the sodic chloride goes on steadily stealing water from the potassic (III.), although, after 151 days, it has succeeded in abstracting only 5 per cent. of the whole quantity of water.

Experiment I., with the greatest relative quantity of salts, is not yet completed. The sodic chloride has, after 172 days, 86 per cent. of the water, and is still invaporating. In experiment II., which has lasted 290 days, the process of invaporation is apparently nearly complete, and the result is somewhat surprising. There are 100 molecules of water to 12·5 of each of the salts. The sodic chloride has nearly 93 per cent. of the water. It is possible that in course of time all the water may be attracted by the sodium salt; in which case we should conclude that the force in operation is different from chemical affinity.

Experiment IV. was made to ascertain the effect of increasing the relative quantity of sodic chloride. The effect is to hasten the invaporation of water by this salt. After 144 days it has over 99 per cent. of the water. Now, it is known that even a saturated solution of sodic chloride gives off water-vapour to a dry atmosphere, so that in this final condition of experiment IV. the potassic chloride is in the presence of water-vapour. If the force of invaporation (which is probably intimately connected with the force of solution) were of the nature of chemism, it would cause combination of the potassic chloride with the water, and the condition of equilibrium would be one in which the relative quantities of water held by the two salts would be a measure of their affinities for water. The discussion of this point will, however, be better postponed until our experiments have been further extended.

In experiments V., VI., VII., sodic chloride is pitted against the highly deliquescent lithic chloride. In V., with the same number of molecules as in I., the lithic chloride takes all but about one-third per cent. of the water; VI. and VII. show the effect of increasing the relative quantity of water. (Owing to the rapid deliquescence of the lithic chloride, the water is sometimes in slight excess of the theoretical quantity.) VI. shows that when the relative quantity of water is doubled, the lithic chloride still takes nearly all after 42 days, and quite all after 173 days. In this case 12·5 molecules of the salt have invaporated 100 molecules of water. When the relative quantity of water is again doubled, as in VII., an unexpected result is obtained. As in V. and VI., the greater part of the water was given to the lithic chloride before enclosure. After 177 days, we find that the sodic chloride is *gaining* water, and this continues until in 129 days it has gained about 6 per cent. of the whole quantity. The condition of equilibrium is not yet reached, but there is clearly a limit to the quantity of water which the lithic chloride can hold against the attraction of the sodic chloride.

There is a wide field of research opening up in the direction indicated by these few experiments. We shall extend the investigations to other salts, particularly chlorides, with a view to testing more fully the effect of increasing the relative quantities of water and of one of the salts; and shall also attempt to determine the influence, if any, of temperature. With large proportions of water, experiments conducted at the temperatures at which cryohydrates are formed may yield interesting results.

Report (Provisional) of the Committee, consisting of Professors McLeod *and* W. Ramsay *and* Messrs. J. T. Cundall *and* W. A. Shenstone *(Secretary), appointed to investigate the Influence of the Silent Discharge of Electricity on Oxygen and other Gases.*

The Preparation and Storage of Oxygen Gas in a Pure State.

By W. A. Shenstone *and* J. T. Cundall.

For the purposes of this investigation it is necessary to provide oxygen and other gases in as pure a state as possible, in considerable quantities, and to preserve them for long periods without change, in order that the results of series of experiments made at intervals of several days or of weeks shall not be subject to unknown errors. In dealing with oxygen the presence of nitrogen must especially be guarded against, for it combines more freely with oxygen (when the latter gas is present in excess) under the influence of the electric discharge than is commonly known to be the case.

The mercury gasholder invented by Bunsen, which has been described in 'Watts' Dictionary' and elsewhere, is hardly suitable for collecting gases in the rather large quantities that will be required. A similar but much larger gasholder, in which the mercury was replaced by sulphuric acid, has been tried. But, apart from the risk of air gaining admittance through the sulphuric acid, in which it is to some extent soluble, we find that even thoroughly washed oxygen, prepared from chlorate of potassium, carries with it a sufficient quantity of suspended matter to result in the presence of slight traces of chlorine tetroxide in the gas after the gasholder has been refilled several times. After the failure of this method of storing oxygen, an attempt was made to prepare it by electrolysis of dilute sulphuric acid almost saturated with chromic anhydride. When the superficial area of the negative electrode employed greatly exceeded that of the positive electrode, pure oxygen was obtained in this way. When the evolution of oxygen was conveniently rapid, however, some bubbles of hydrogen escaped the oxidising action of the chromic acid and made their appearance. Finally, after the failure of an attempt to store pure oxygen by compressing it in iron bottles, the apparatus next described was constructed for producing the gas in smaller quantities as required.

In the diagram, A is a cylinder having a capacity of one litre. It can be filled with mercury from a reservoir, not shown, through an india-rubber tube O, the entrance of bubbles of air carried by the mercury being prevented by the air-trap B. E is a flask connected to A by the tube J H. In E is placed the material from which oxygen is to be produced. G contains phosphorus pentoxide[1] to remove moisture as far as possible from the gas before it is delivered through P into the receiver in which it is to be collected. Beyond G is one of Mr. Cetti's patent vacuum taps. As this will not prevent the passage of air in the direction a to b, however, it is trapped at C. This trap can be filled with mercury to any desired level from a reservoir, as shown at R and S. The only joints not made before the blowpipe are those shown at J, H, and F. These are all protected with mercury in the now familiar manner, the india-rubber connections being well lubricated and firmly bound with iron wire.

The materials from which oxygen is to be prepared having been placed in E, and everything being in order, A is filled with mercury, t^1 is closed, t^2 and t^3 are opened, and the apparatus is exhausted through P. Oxygen is then generated in E until the whole apparatus, including A, is filled. This process of exhausting and refilling is repeated at intervals of a few hours two or three times; and after the third operation a specimen may be collected and examined. Such specimens have been found to be very fairly satisfactory; two samples of oxygen which had been confined in A for several weeks contained respectively 99·97 and 99·96

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[1] We find this substance to be admirably suited for removing suspended solid matter from gases.

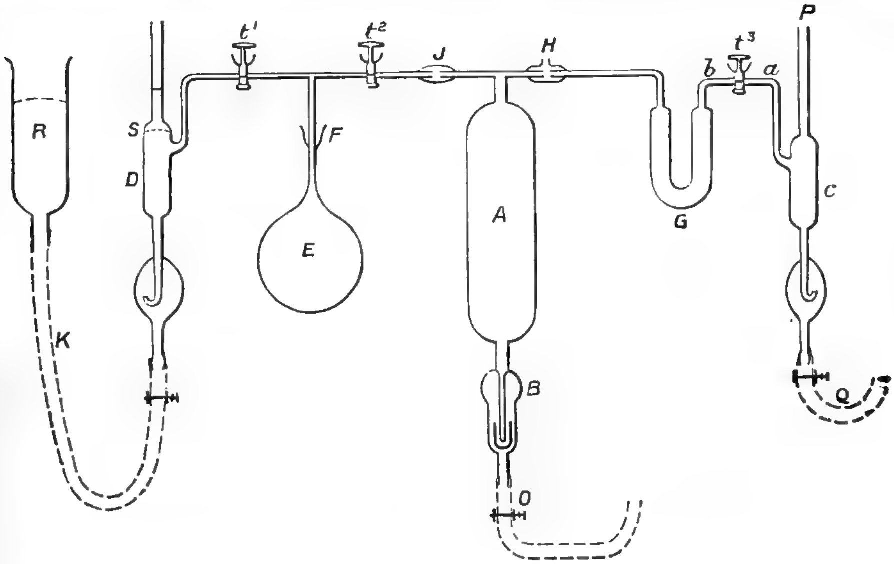
per cent. of oxygen; that is to say, 99·97 and 99·96 per cent. of the gas was absorbed by melted phosphorus in experiments made upon the two samples.

When the apparatus is not in use the taps t^1, t^2, t^3 are closed, and the traps C and D filled with mercury to prevent the entrance of air.

Oxygen may be delivered from A into any vessel by connecting it to P, exhausting it, t^3 being closed and Q being clamped to prevent the mercury from rising and filling C, and subsequently opening t^3, when the gas will flow from A into the exhausted vessel. If t^3 be well ground it will resist the passage of air sufficiently to permit this to be done.

If a delivery tube be attached to P, all air may be driven from it by flushing it with mercury before proceeding to deliver the oxygen in the usual manner. Thus waste of pure gas is avoided.

The supplementary tap t^1 and mercury trap D are provided in order that accidental breakage of E on the application of heat (when fresh supplies of oxygen are about to be introduced into A) shall not admit air to the stock of oxygen already in A. When A, partly empty, is to be replenished, t^2 is closed, t^1 opened, and heat is applied to E, D being filled with mercury to the level S, through which the gas is permitted to escape. When E is thoroughly heated and a steady evolution of gas has set in, the oxygen is delivered into A. Thus if the replenishment of A be not too long delayed, no loss of time results from accidents to E, which can at any time be replaced and exhausted, whilst the oxygen remaining in A is still available for use, if the taps have been properly ground and are thoroughly lubricated. Of course the trap D, like C, must be closed by filling it with mercury at all times when escape of gas from E is not desired.



When potassium chlorate is used as the source of oxygen, breakages, E, are frequent. Silver oxide is much better, but it is troublesome to obtain it perfectly free from carbon dioxide. This has led us to employ a mixture of the chlorates of sodium[1] and potassium in molecular propor-

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[1] Chlorate of sodium is apt not to be pure; it should be carefully examined before it is used.

tions. We prepare the mixture by thoroughly mixing the recrystallised salts, maintaining the product in a state of fusion for some little while in an open dish, and subsequently powdering the solid produced on cooling. The melting-point of the product is considerably lower than that of either chlorate of potassium or chlorate of sodium; and it gives off its oxygen to about the same extent as chlorate of potassium; that is to say, about one-third of it is easily expelled by a moderate heat.

In conclusion, we are glad to be able to report that we have also constructed most of the rest of the apparatus that will be required in the investigation that is before us. We hope, therefore, to make considerable progress before the next meeting of the Association.

NOTE.—October 10, 1886. Since this report was read we have succeeded in connecting all the parts of the oxygen generator and holder before the blowpipe by a method described by one of us.[1] The only permanent mercury joint which remains is that at F, which is now specially protected against entrance of air. We may, therefore, expect to approach still nearer to the attainment of absolutely pure gases for our experiments.

Report of the Committee, consisting of Professors TILDEN *and* ARMSTRONG (*Secretary*), *appointed for the purpose of investigating Isomeric Naphthalene Derivatives.*

THE study of isomeric naphthalene derivatives acquires importance from a variety of considerations, notably, from the very close relationship of naphthalene to benzene, which finds expression in the use of a simple hexagon to represent the latter hydrocarbon, the first mentioned being symbolised by a double hexagon formed of two benzene hexagons joined so that one side is common to both.

In the case of benzene there are but three possible isomeric di-derivatives, according to the received theory of the constitution of this hydrocarbon; the formation of these di-derivatives is governed by certain very simple 'laws,' the first of which may conveniently be termed the *para*-law, the second the *meta*-law: *i.e.*, mono-derivatives containing a hydrocarbon radicle, one of the halogens, NH_2, or OH invariably yield as *chief* product a para-di-derivative together with the isomeric ortho-di-derivative, the meta-di-derivative being formed, if at all, to but a small extent; whereas mono-derivatives containing NO_2, SO_3H, or COOH yield as chief product the *meta*-di-derivative, the para- and ortho-derivatives being formed in relatively small amount.

Instead of three, naphthalene may give rise to ten isomeric di-derivatives; it might therefore be expected that the laws of substitution for naphthalene would be proportionally less simple than for benzene: thus far, however, this has not been found to be the case, and many of the di-derivatives are to be prepared only by indirect methods. The para-law obtains equally in the case of naphthalene, being applicable to mono-derivatives analogous to those which in the benzene series obey the para-

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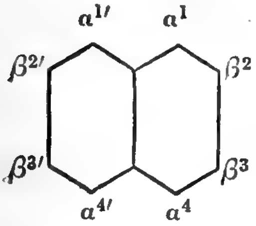
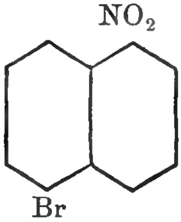
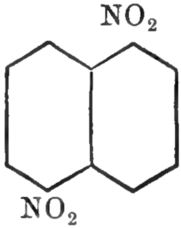
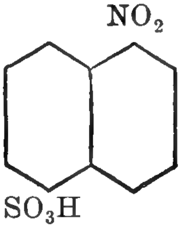
[1] *Methods of Glass-blowing*, pp. 62–3.

law; but an interesting modification of the meta-law, exemplified by the behaviour of nitronaphthalene to bromine, nitric acid, and sulphuric acid, is to be noted: nitrobenzene under such circumstances would yield chiefly the meta-derivative, but in the case of nitronaphthalene the attack becomes shifted to the other nucleus, an α-α-derivative being formed as represented by the formulæ:—









It would appear from our knowledge of the naphthalene derivatives generally that, as a rule, the α-hydrogen atoms (see figure) are those which become displaced, and that the β-atoms are affected only under somewhat exceptional conditions—as in the formation of β-sulphonic acids at high temperatures in presence of an excess of sulphuric acid—and when an amidogen or hydroxyl group is present. Hence the behaviour of nitronaphthalene above referred to—the absence of similarity in the behaviour of the corresponding nitro-derivatives of naphthalene and benzene—is not improbably due to the existence in the case of naphthalene of a higher law, which it may be permitted to term the '*alpha*-law.'

As naphthalene-β-sulphonic acid is the only β-derivative obtainable directly from naphthalene, it appeared to be specially important to study the behaviour of the sulphonic derivatives in order to throw light on the formation of the β-monosulphonic acid; and it was to be expected that their investigation would furnish results of value in determining the laws of substitution in the naphthalene series: moreover the ease with which the sulphonic radicle may be removed by hydrolysis renders the sulphonic derivatives especially suitable subjects of study.

It will suffice to indicate briefly the character of the results hitherto obtained, reserving a full account for one of the chemical journals.

The action of sulphuric acid in excess on naphthalene at a temperature of 160°–180° has been studied by Ebert and Merz, who isolated two distinct acids—an α- and a *β-disulphonic acid*; Armstrong and Graham ('Chem. Soc. Trans.' 1881, p. 133; 'Berichte,' 1882, p. 204) on re-examining the product obtained evidence of the presence of other disulphonic acids, but after numerous trials the attempt to separate these was for the time abandoned, and attention directed to the preparation of disulphonic acids by other methods less likely to give rise to secondary changes, such as readily occur on heating in presence of sulphuric acid. The result has been to establish the existence of two acids isomeric with the α- and β-acid of Ebert and Merz.

γ-Naphthalenedisulphonic Acid.—This appears to be the sole product of the action of chlorosulphonic acid, $ClSO_3H$, on naphthalene in accordance with the equation: $C_{10}H_8+2SO_3HCl = C_{10}H_6(SO_3H)_2 + 2HCl$. On distilling its chloride (m. p. 184°) with phosphorus pentachloride, γ-dichloronaphthalene is produced: therefore it may be concluded that γ-naphthalenedisulphonic acid is an α-α-derivative of the same constitution as the nitronaphthalene derivatives formulated above.

Naphthalene-?-β-disulphonic Acid.—This acid is prepared by acting on naphthalene-β-monosulphonic acid with chlorosulphonic acid, and is certainly the chief product, but it remains to ascertain whether an isomer is not produced simultaneously. It is at once converted by the action of bromine into a dibromo-*mono*sulphonic acid; this behaviour renders it more than probable that the sulphonic radicle introduced by the agency of the SO_3HCl assumes an α- position.

The two acids prepared by Ebert and Merz by the action of sulphuric acid at a high temperature (160°–180°) are in all probability β-β-derivatives; they are both isomeric with the acids obtained by sulphonating naphthalene-α- and β-*mono*sulphonic acids by means of SO_3HCl: and this difference being established between the action of sulphuric acid and that of chlorosulphonic acid, it appeared desirable to ascertain the behaviour with SO_3HCl of the naphthalene derivatives which had previously been converted into sulphonic acids in the ordinary manner. The derivatives taken were α-nitro-, α-bromo-, α-chloro-, and β-chloro-naphthalene: these have all been found to yield the same products when sulphonated by means of SO_3HCl as on treatment with sulphuric acid. It is especially noteworthy, however, that from both α-bromo- and α-chloro-naphthalene an acid has been obtained in small quantity isomeric with the *para*-sulphonic acid previously known, and which forms the chief product; this secondary product is probably also an α-α-derivative like the primary product, but of the same series as the nitro-sulphonic acid formulated above. Two isomeric sulphonic acids also are obtained from β-chloronaphthalene. One, which is the chief product when SO_3HCl is used, has been shown by Arnell to correspond to θ-dichloronaphthalene, while the other corresponds to ε-dichloronaphthalene, and therefore to the β-disulphonic acid of Ebert and Merz, and to Schaefer's betanaphtholsulphonic acid. Probably θ-dichloronaphthalene is the ortho- or 1·2 modification, and it may almost be regarded as established that ε-dichloronaphthalene is a β^2-$\beta^{3'}$-derivative; so that, while α- and β-chloronaphthalene both behave in the manner to be expected from the analogy subsisting between benzene and naphthalene, evidence is afforded by the production of the α^1-$\alpha^{4'}$-derivative from the one and of the β^2-$\beta^{3'}$-derivative from the other of the existence in the naphthalene molecule, in addition to the 'para-plane' of benzene, of two 'planes of symmetry,' as it were, in which an influence is exercised.

The study of the action of bromine on aqueous solutions of the naphthalene-sulphonic acids has also furnished results of interest. It has long been known that when naphthalene-α-sulphonic acid is treated with bromine the sulphonic group is displaced, dibromonaphthalenes being formed, whereas the β-sulphonic acid is converted into a dibromonaphthalene-sulphonic acid, the SO_3H group retaining its place. It now appears that this behaviour of the two acids is fairly typical. Thus the two disulphonic acids of Ebert and Merz—which are doubtless both β-β-derivatives—yield isomeric dibromonaphthaquinone*mono*sulphonates on treatment with bromine in excess—only one of the sulphonic radicles, viz., that which is contained in the C_6 group which is oxidised, being displaced. The isomeric dibromomonosulphonic acids obtained by treating (*a*) naphthalene β-monosulphonic acid and (*b*) the ?-β-disulphonic acid above described with bromine are finally converted by the action of bromine into the same tetrabromonaphthaquinone, the sulphonic radicle being displaced, although in the β-position, in consequence of the oxidation to quinone of the C_6 group in which it is located. The γ-disulphonic acid—which is doubtless an α-α-derivative—readily parts with both its sulphonic radicles, yielding as final products dibromonaphthaquinone and what appears to be a hexabromonaphthalene. A further illustration of the stability of a β-sulphonic radicle is afforded by the behaviour of (Schaefer's) betanaphtholsulphonic acid with bromine, the end product being a bromohydroxyquinone*sulphonate.*

The results thus briefly recorded have been obtained with the assistance of Messrs. F. W. Streatfield, S. Williamson, and W. P. Wynne, B.Sc.

It is anticipated that by the time of the next meeting of the Association the investigation of isomeric naphthalene derivatives will have been carried sufficiently far to render possible a fairly complete statement of the laws of substitution in the naphthalene series in the shape of a final report.

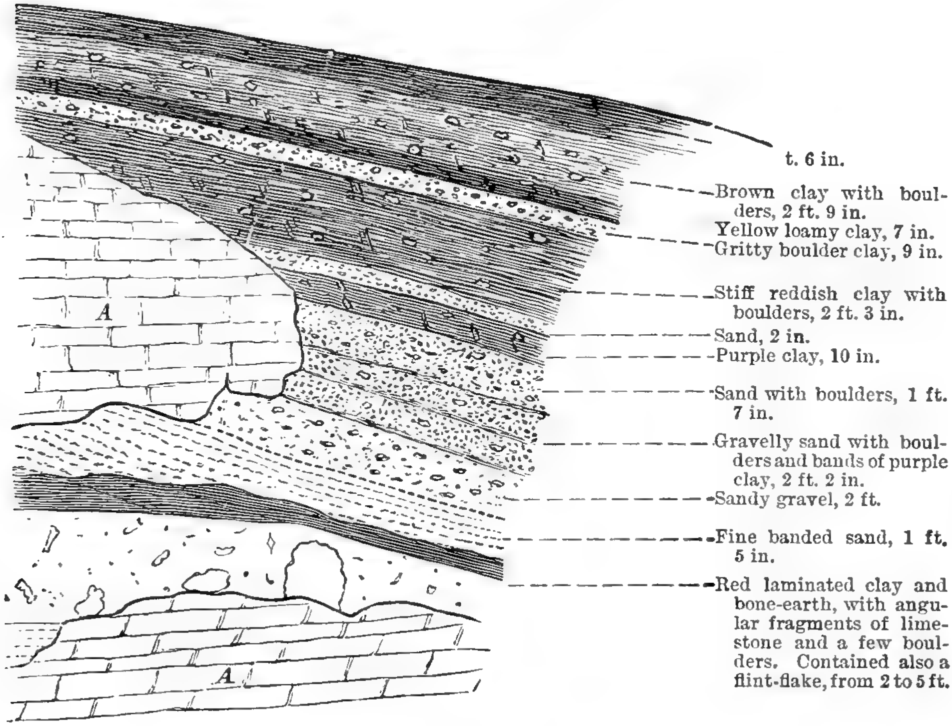
Report of the Committee, consisting of Professor T. McK. HUGHES, Dr. H. HICKS, *and* Messrs. H. WOODWARD, E. B. LUXMOORE, P. P. PENNANT, *and* EDWIN MORGAN, *appointed for the purpose of exploring the Caves of North Wales. Drawn up by* Dr. H. HICKS, *Secretary.*

THE explorations conducted by the Committee have been confined to the caverns of Ffynnon Beuno and Cae Gwyn, in the Vale of Clwyd. These caverns had been explored in preceding years by Dr. H. Hicks and Mr. E. B. Luxmoore, some of the results being given in a paper communicated to the Geological Section of the Association in 1885, but more fully in a paper in the ‘Quart. Jour. Geolog. Soc.,’ Feb. 1886.

Among the remains discovered in these two caverns up to the commencement of the work this year there were over eighty jaws belonging to various animals, and more than 1,300 loose teeth, including about 400 rhinoceros, 15 mammoth, 180 hyæna, and 500 horse teeth. Other bones and fragments of bones occurred also in very great abundance. Several flint implements, including flakes, scrapers, and lance-heads, were found in association with the bones. The most important evidence, however, obtained in the previous researches was that bearing on the physical changes to which the area must have been subjected since the caverns were occupied by the animals. During the excavations it became clear that the bones had been greatly disturbed by water action, that the stalagmite floor, in parts more than a foot in thickness, and massive stalactites had also been broken and thrown about in all positions, and that these had been covered afterwards by clays and sand containing foreign pebbles. This seemed to prove that the caverns, now 400 feet above ordnance datum, must have been submerged subsequently to their occupation by the animals and by man. One of the principal objects, therefore, which the Committee had in view this year was to critically examine those portions of the caverns not previously explored, so as to endeavour to arrive at the true cause of the peculiar conditions observed. Work was commenced at the end of May and carried on during the whole of June and parts of July and August.

Cae Gwyn Cave.

When the explorations were suspended last year it was supposed that we had just reached a chamber of considerable size, but after a few days' work this year it was found that what appeared to be a chamber was a gradual widening of the cavern towards a covered entrance. The position of this entrance greatly surprised us, as hitherto we had believed that we were gradually getting further into the limestone hill. The rise in the field at this point, however, proved to be composed of a considerable thickness of glacial deposits heaped up against a limestone cliff. As the materials covering the bone-earth within and at the entrance were chiefly sands and gravels, it was found necessary to suspend operations in that direction and to ask the landlord (E. Morgan, Esq.) for permission to open a shaft directly over this entrance from the field above. As this necessitated the removal of a considerable surface of land and caused some damage to the field the Committee feel that their special thanks are due to Mr. Morgan for his kindness in so readily acceding to their application. This shaft, as at first opened, was about nine feet across at the surface and over five feet at the bottom. It was subsequently widened at the bottom in consequence of some falls, and the lower part, excepting at one point, had to be carefully faced with timber. The upper part is now much widened and sloped. The shaft was about twenty feet in depth, and the deposits as shown in fig. 1 were made out in it. These were carefully measured by Mr. C. E. De Rance, F.G.S., Mr. Luxmoore, and the writer during the prosecution of the work. Below the soil, for about eight feet, a tolerable stiff boulder clay, containing many ice-scratched



A. Carboniferous limestone. ◊ Position of the flint flake.

FIG. 1.—Section at New Entrance to Cae Gwyn Cave.

boulders and narrow bands and pockets of sand, was found. Below this there were about seven feet of gravel and sand, with here and there bands of red clay, having also many ice-scratched boulders. The next deposit met with was a laminated brown clay, and under this was found the bone-earth, a brown, sandy clay with small pebbles and with angular fragments of limestone, stalagmite, and stalactites. On June 28, in the presence of Mr. G. H. Morton, F.G.S., of Liverpool, and the writer, a small but well-worked flint-flake was dug up from the bone-earth on the south side of the entrance. Its position was about eighteen inches below the lowest bed of sand. Several teeth of hyæna and reindeer, as well as fragments of bone, were also found at the same place, and at other points in the shaft teeth of rhinoceros and a fragment of a mammoth's tooth. One rhinoceros tooth was found at the extreme point examined, about six feet beyond and directly in front of the entrance. It seems clear that the contents of the cavern must have been washed out by marine action during the great submergence in mid-glacial time, and that they were afterwards covered by marine sands and by an upper-boulder clay, identical in character with that found at many points in the Vale of Clwyd and in other places on the North Wales coast. Figs. 2 and 3 explain the order of the deposits as found within the cavern. Fig. 3

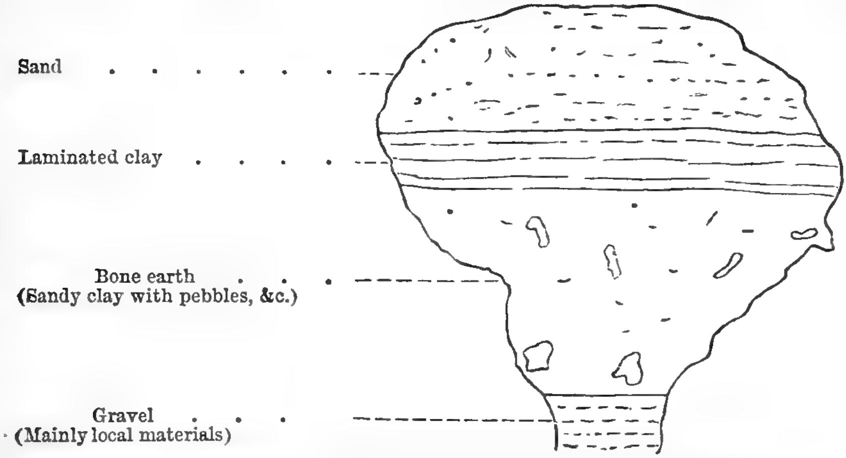


FIG. 2.—Section in Cae Gwyn Cave, near the New Entrance.

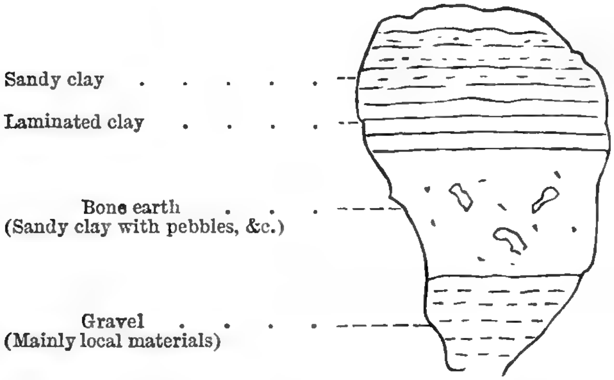


FIG. 3.—Section in Cae Gwyn Cave, about 16 feet from the New Entrance.

was taken at a distance of about sixteen feet from the entrance at the shaft, and fig. 2 just within that entrance. The order in that portion of the cavern examined this year accorded in the main with that found during the previous researches, but within the entrance there was a greater thickness of sand, less of the laminated clay, and more bone-earth than in the other parts of the cavern. The bone-earth seems to diminish in thickness rather rapidly outwards under the glacial deposits, but it was found as far out as the excavations have been made. Here the bone-earth rests directly on the limestone floor, with no local gravel between, as in the cavern.

It would be interesting to know how far the cave earth extends under the glacial deposits, but this could only be ascertained by making a deep cutting through the terrace of glacial deposits, which extends for a considerable distance in a westerly direction. The glacial deposits here are undoubtedly in an entirely undisturbed condition, and are full of smooth and well-scratched boulders, many of them being of considerable size. Among the boulders found are granites, gneiss, quartzites, flint, felsites, diorites, volcanic ash, Silurian rocks, and limestone. Silurian rocks are most abundant. It is clear that we have here rocks from northern sources, along with those from the Welsh hills, and the manner in which the limestone at the entrance to the cavern in the shaft is smoothed from the north would indicate that to be the main direction of the flow. The marine sands and gravels which rest immediately on the bone-earth are probably of the age of the Moel Tryfaen and other high-level sands, and the overlying clay with large boulders and intercalated sands may be considered of the age of the so-called upper-boulder clay of the area. The latter must evidently have been deposited by coast-ice. Whether the caverns were occupied in pre- or only in inter-glacial times it is difficult to decide, but it is certain that they were frequented by pleistocene animals and by man before the characteristic glacial deposits of this area were accumulated. The local gravel found in the caverns, underlying the bone-earth, must have been washed in by streams at an earlier period, probably before the excavation of the rocky floor of the valley to its present depth. From the glacial period up to the present time excavation has taken place only in the glacial deposits, which must have filled the valley up to a level considerably above the entrances to the caverns. The characteristic red boulder clay with erratic blocks from northern sources is found in this area to a height of about 500 feet, and sands and gravels in the mountains to the S.E. to an elevation of about 1,400 feet. The natural conclusion therefore is that the caverns were occupied by an early pleistocene fauna and by man anterior to the great submergence indicated by the high-level marine sands, and therefore also before the deposition of the so-called great upper-boulder clay of this area. As there is no evidence against such a view it may even be legitimately assumed that the ossiferous remains and the flint implements are of an earlier date than any glacial deposits found in this area.

Ffynnon Beuno Cave.

This cavern, which yielded the greatest number of bones in the previous researches, has now been cleared out in all those parts where the deposits appeared to have been undisturbed by man. A considerable addition to the number of bones and teeth has been made this year, but no new forms have to be added to those already mentioned.

The animal remains found in both caves, as defined by Mr. W. Davies, F.G.S., of the British Museum, comprise teeth and bones of eleven genera and sixteen species, as shown by the annexed list:—

Lion (*Felis leo*, var. *spelæa*).
Wild cat (*F. catus ferus*).
Spotted hyæna (*H. crocuta*, var. *spelæa*).
Wolf (*Canis lupus*).
Fox (*C. vulpes*).
Bear (*Ursus*, sp.).
Badger (*Meles taxus*).
Wild boar (*Sus scrofa*).
Bovine (*Bos ? Bison ?*).
Great Irish deer (*Cervus giganteus*).
Red deer (*Cervus elaphus*).
Roebuck (*C. capreolus*).
Reindeer (*C. tarandus*).
Horse (*Equus caballus*).
Woolly rhinoceros (*R. tichorrhinus*).
Mammoth (*Elephas primigenius*).

Fourteenth Report of the Committee, consisting of Professors J. PRESTWICH, W. BOYD DAWKINS, T. MCK. HUGHES, *and* T. G. BONNEY, Dr. H. W. CROSSKEY (*Secretary*), *and* Messrs. C. E. DE RANCE, H. G. FORDHAM, J. E. LEE, D. MACKINTOSH, W. PENGELLY, J. PLANT, *and* R. H. TIDDEMAN, *appointed for the purpose of recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England, Wales, and Ireland, reporting other matters of interest connected with the same, and taking measures for their preservation.*

THE attention of the Committee has been called by Professor Hughes to boulders near Kendal and Settle, which are perched upon pedestals of limestone, and are striated in the direction of the main iceflow of the district, whereas the surface of the surrounding block bears no traces of glaciation.

These boulders appear to have been transported to their present position, and placed upon the bare striated rock under exceptional local conditions, and the pedestals appear to be portions of the surrounding rock protected from denuding agents by the overlying boulder.

The Committee hope to be able to secure the preservation of these boulders.

Mr. Plant reports a remarkable assemblage of blocks in the drift in the valley of the Soar, near Leicester. Excavations to the depth of 30 feet have been made in various parts of the river valley, and after passing through the alluvium the boulder clay has been reached. Thousands of erratics have been found. Half of the erratics were from the Charnwood district, and of the remainder a great many were from the Permian sandstones and Carboniferous rocks of the Ashby coalfield, with blocks of mountain limestone from Staunton, Harold, and Breedon—a distance of fifteen to eighteen miles north-west. The rest are from the east side of the Pennine chain, forty to fifty miles distant north-east.

On a ridge near the Victoria Road, south of Leicester, upwards of 200 erratics have been uncovered. Millstone grit, mountain limestone, and lower oolite blocks, more or less striated, were found mixed with Charnwood syenites. The height of the ridge is 260 feet above the sea, and 110 feet above the present valley of the Soar.

In the drift at Clarendon Park, south-east of Leicester (310 feet), many hundreds of boulders have been exposed during recent excavations. Some of the millstone grit blocks must have travelled forty or fifty miles. Lumps of coal were also found which must have travelled seventeen miles from the north-west.

Dr. Crosskey and Mr. Fred W. Martin record a group of boulders found on the road between Shiffnal and Tong. This group consists of a fine collection of Lake rocks and Criffel granites. They evidently travelled together to their present position. A catalogue of these boulders will be given in the next Report.

The Committee call especial attention to the grouping of the erratics found in different districts, and also to the evidence presented that the Charnwood district was the centre of local ice action.

On the Glacial Phenomena of the Midland District. By Dr. CROSSKEY.

The object of the paper is to indicate some of the problems raised by the glacial phenomena of the Midland district, and point out the typical sections by which they are illustrated.

It is necessary to avoid the confusion caused by the vague use of the term 'boulder clay.' Seven or eight different beds have, in fact, been designated by the term 'boulder clay'; and it has become absolutely necessary to separate the deposits from each other and record their distinct characteristics.

The first question is, What are the lowest deposits of glacial age in the Midlands? What is found at the base of the masses of clay, sand, and gravel scattered over the district? Is there any deposit of the age of the lower boulder clay or Till of Scotland? The lowest of the beds known in the Midlands may be seen at California, near Harborne. It consists of a thick clay filled with angular and striated erratics of Welsh origin, compactly pressed together and intermixed with fragments of rocks from the locality, and is about 480 feet above the sea. This boulder clay is followed by a series of sands and gravels, which are covered by a considerable mass of tenacious 'india-rubber' clay with erratics scattered somewhat sparsely through it; and this upper clay is capped by a second series of sands and gravels, more or less intermixed with clay.

The lower boulder clay is more intensely glacial in character and more analogous to the Scotch Till than any other yet described in the district. Whatever its origin, it belongs to the period of extreme ice action. Of another type of boulder clay an example may be seen at Wolverhampton. This boulder clay contains a mixture of erratics. A large number of its erratics are from the Lakes and some are from Scotland, while flints from the east also occur. In the ordinary Scotch Till, when the trend of the valleys radiating from the central eminences is followed, the course over which the erratics travelled can be traced. But the Wolverhampton boulder clay marks the meeting-place of erratics from various quarters. An example of a third series of beds, possibly belonging to the same age, may be seen in a cutting at Soho, near Birmingham, where clays and sands, containing erratics, are strongly contorted. While the material of these beds is probably lower glacial, the contortions must have been subsequent to its deposition, and indicate the work of another age. How far this series of lower beds may be attributed to the action of land ice or of floating ice is an open question.

The second question is, Are there any Midland glacial beds referable to the period of glacial subsidence? Two series of deposits and of erratics also have to be taken into account—those representing the period of subsidence and those representing the period of re-elevation. During the gradual subsidence of the ice-covered land, erratics would be floated off as its various points became successively immersed, and deposits would also be formed at the sea-bottom. These middle glacial clays, sands, and gravels occur at various points. Fossils have been found near Wellington, Shropshire, Astarte borealis being among them. In beds at Lilleshall, Salop (463 feet), three arctic species occur. The upper boulder clay (worked for bricks through the district) contains erratics, which appear clearly to have fallen into it, and altogether differs from the lower bed. It is a mass accumulated during subsidence.

The third question is, What signs are there of ice action during the re-elevation of the land? During the process of re-elevation the marine clays and sands would be washed and re-sorted by currents, and the sea would be covered by icebergs floating away from our present mountains, which would then be islands in a glacial sea. The Midlands now constitute a table-land. This table-land would at this period be the shallow part of the sea against which icebergs would be stranded. At Icknield Street, Birmingham, the rock has been smashed and a large collection of Welsh erratics flung against it. One of the most marked characteristics of this period would be the distribution of fragments from the present highlands of the Midlands. The present highlands of the Midlands would then be low-lying islands, which would be covered with ice. By the breaking away of the ice-foot around them blocks would be distributed over the sea-bottom in their immediate neighbourhoods. Rowley Hill blocks are found eight or nine miles off. Boulders torn from Charnwood are abundantly spread over many acres for many miles, and must have been carried by local ice. Fragments from the Malvern Hills have been scattered through the plains around.

Erratics from the mountains of Wales, the Lakes, and Scotland also must have been brought by the icebergs travelling from those centres as the mountains became higher and higher. The work done during re-elevation must be distinguished from that done during subsidence.

The surface erratic blocks, so remarkably developed in the Midlands, cannot be roughly explained away in connection with any one portion of the epoch, and present complicated problems. Some erratics now upon the surface may have been originally imbedded in clays and sands, which have been washed away, and have really belonged to the ancient boulder clay. Erratics were dropped by icebergs during the submergence of the land when there was a succession of ever-varying island boundaries. Erratics were also dropped during re-elevation when there was an ever-increasing mountainous area from which they could be derived.

Facts have to be noted in connection with the following points:—

(i.) *The origin of the erratics.*—Some were derived from a distance—*i.e.*, from W. Scotland, the Lakes, and Wales. Others were of local origin and of local range, as from Charnwood, Rowley, and Malvern. Others mark the pushing in of the *débris* derived from chalky boulder clay.

(ii.) *The heights of erratics above the sea.*—Erratics are found in the Midlands on heights extending from comparatively low levels to 900 feet. They could not therefore have been deposited in their present positions at one and the same time. They must indicate a succession of events.

(iii.) *The position of definite groups of erratics in relation to each other.* For example, around Birmingham and Bromsgrove the erratics are chiefly Welsh; but a vast collection of Scotch and Lake erratics lies right across the path the Welsh erratics must have taken.

(iv.) *The distribution of erratics in relation to the physical geography of the district.*—On the table-land north of Wolverhampton, Lake and Scotch rocks are intermixed, the Scotch being abundant. Journeying westward the intermixture becomes more complete. The stream of Welsh erratics crosses the northern stream; then the Welsh erratics become more and more abundant, only a few northern stragglers being found, until at Clent and Bromsgrove not a single erratic of granite has yet been found among thousands of Welsh origin.

Taking a line of country in another direction—between Wolverhampton and Stafford—cretaceous and jurassic *débris* appears. The same *débris* may be noted pushing itself around Coventry.

(v.) *The distribution of erratics in relation to the physical geography of England and Wales.*—The various Midland glacial deposits cannot be understood apart from a careful examination of their relation to the various levels of the plains, highlands, and mountains of the whole of the surrounding country.

Report of the Committee, consisting of Mr. H. BAUERMAN, Mr. F. W. RUDLER, Mr. J. J. H. TEALL, *and* Dr. JOHNSTON-LAVIS, *for the Investigation of the Volcanic Phenomena of Vesuvius and its neighbourhood. Drawn up by* H. J. JOHNSTON-LAVIS, *M.D., F.G.S.* (*Secretary*).

DURING the last twelve months Vesuvius has shown slight variation from the state of activity which it has exhibited during the past few years. Lava has from time to time found fresh openings around the higher parts of the great cone, and has flowed from them one after another, so that the intervals of time during which no fluid rock was issuing were very short. This regularity of action was, however, broken on June 28, when, a lower outlet being formed on the eastern side of the great cone, the consequent depression of the lava level in the main chimney resulted in the crumbling in of the cone of eruption, which before this date had attained very considerable dimensions. During the whole month of July the ash-forming stage prevailed, so that the usual continuous vapour and lava-cake ejections were replaced by intermittent puffs of ash and sand-laden vapour and accompanied by the ejection of stones. The craterial cavity, which is double or bifurcated, which has been excavated within the cone of eruption, is of very considerable size, being about 60 × 80 metres in diameter. The lava that issued during July, on two occasions entirely crossed the Val d'Inferno, and following one of the wooded glens or ravines on the property of the Prince of Ottajano destroyed a considerable number of trees. These different changes will be made apparent by the photographs taken by the reporter and exhibited at the meeting.

In a paper read before the Royal Society the writer has given comparative curves of the activity of Vesuvius, the barometric pressure, and the rainfall, together with the phases of the moon, deduced from observations extending over two years. The method of registering the different degrees of activity[1] is that described in the report of this Committee last year. The results seem to indicate a distinct relationship between barometric pressure and the violence of the explosions, or, in other words, the ebullition of the lava. On the contrary, the rise and fall of lava level within the chimney in relation to tidal action set up within the magma is doubtful, though some coincidences are remarkable. The short time during which observations have been carried on, and the facility with which any true rise and fall of lava may be masked by other causes, necessitates the study of the subject for some years longer. Observations during the past fourteen months go to confirm the conclusions arrived at in the paper above mentioned.

The fourth sheet of the geological map of Monte Somma and Vesuvius has been completed, and is exhibited at the meeting. Although small—a good portion being sea—much patience and time were necessary, owing to the area being thickly inhabited and the ground broken up by numerous small gardens, &c., enclosed within high walls. The geology of the region mapped in this sheet is slightly more difficult to work out than that included in the third sheet (exhibited at the last meeting), and is much more intricate in detail. Sheet 5 is in considerable part mapped, and the reporter had hoped to have completed it for exhibition at the present meeting beside Sheet 4, but he was prevented by a number of family troubles, which forcibly diverted his attention during the spring and early summer. The reporter regrets to announce that the 'Giornale del Vesuvio,' containing a diary of all the observations made during the last four years, and which should have appeared eight months ago, is not yet published. This delay, however, is not the fault of the author. Proofs of nine of the illustrations in phototype are exhibited at the meeting.

The present year is remarkable for the chances it affords for studying the subterranean structure of the Campi Phlegrei and the volcanic region around Naples. The great main drain, which is to convey the sewage of Naples to the Gulf of Gaeta, will traverse the region west of Naples on a line running nearly east and west. Before, however, constructing this sewer a series of five borings have been made to test the ground to be cut through. Observations on the water level, temperature, and presence of volcanic gases were made. Although these borings in themselves have brought no remarkable fact to light, they will, combined with the deep artesian well at Lago Fusaro, form important documents for the study of the structure of such a complicated region.

Five other borings on or near the renowned Starza or foreshore of Pozzuoli, on the works of Sir W. Armstrong, Mitchell, & Co., are interesting as being within a few hundred yards of the celebrated so-called Temple of Serapis. Details of these, two of which are on the beach and the other three at varying distances out to sea, will be published together with others being made. For the present, however, it may be said that these borings fully confirm the opinions generally held as to the oscillations of the ground in this district.

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[1] And not of the quantity of vapour, as erroneously stated in the Abstract, *Proc. Roy. Soc.* No. 243, 1886.

The new Cumana Railway, which is to connect Naples with Baia and Fusaro, in the first part of its course traverses a tunnel of about a mile and a half long, which is cut in the body of the escarpment which constitutes the rocky amphitheatre backing the west end of Naples. Until the present, this was supposed to be composed of a moderately uniform mass of pelagonatised basic marine tuff. Under the middle of the Corso Vitt. Emanuele and the Via Tasso the edge of a trachyte flow was encountered and traversed for a distance of over 70 metres. The rock the reporter has not yet examined microscopically, but it very much resembles a simple non-quartziferous, and more probably a sodalite trachyte. This line of railway will traverse a number of tunnels and cuttings in the Campi Phlegrei, and will have to traverse the hot hill which backs Baia, and will no doubt present various uncommon engineering difficulties, besides giving some useful information bearing on terrestrial physics.

Lastly, a deep well at present being bored at Ponticelli, on the outskirts of Naples towards Vesuvius, has already been carried to a depth of over *a hundred metres*, and during the latter half of this a series of leucitic lava streams were traversed, showing the great distance to which the old flows from Monte Somma reached, and also, that either great depression of land has taken place, or that Monte Somma once formed a volcanic island. As these different works progress they are and will be kept under watch, and all that is interesting will be recorded.

The reporter has partly prepared the first instalment of a study of the ejected blocks of Monte Somma. He has left this subject dormant for two reasons: first, the want of further chemical apparatus for the execution of many analyses required; and, secondly, it was considered necessary to visit the ancient volcanic region of the Fassathal, in the Tyrol, to study some points that could not be worked at in an area covered by thick deposits from recent volcanoes. The striking analogy between the products of volcanic action and the contact metamorphism in the Southern Tyrol and at Vesuvius is so remarkable that many interesting facts will come out of the study of these two regions in relation to each other. The reporter, having had the opportunity this summer of visiting the Tyrol, hopes this winter to be able to study the ejected blocks of Monte Somma, which, from the absence of serpentinisation and other secondary changes, will throw much light on the origin and mutual relations of many varieties of igneous and metamorphic rocks and the genesis of numerous minerals.

The reporter has treated during the past year various questions bearing on Vesuvius and its neighbourhood in papers before the Royal Societies of London and Dublin, the Royal Microscopical Society, the Geologists' Association, and the Accademia Oronzio Costa, besides various articles in 'Nature' and other periodicals. The reporter's 'Monograph of the Earthquakes of Ischia,' after many vicissitudes, was published at the end of 1885.

Fourth Report of the Committee, consisting of Mr. R. ETHERIDGE, Dr. H. WOODWARD, *and* Professor T. RUPERT JONES (*Secretary*), *on the Fossil Phyllopoda of the Palæozoic Rocks.*

Genera and Species.

1. Ceratiocaris leptodactylus (M'Coy).
2. C. Murchisoni (Agass.).
3. C. gigas, Salter.
4. C. valida, nov.
5. C. attenuata, nov. [? tyrannus, Salt.]
6. C. canaliculata, nov.
7. C. Halliana, nov.
8. C. Pardoeana, La Touche.
9. C ludensis, H. W.
10. C. robusta, Salter, C. lata, angusta, and minuta, novv.
11. C. papilio and C. stygia, Salter.
12. C. laxa, nov.
13. C. Salteriana, J. & W.
14. C. cassia, Salter, C. cassioides, nov.
15. C. compta, nov.
16. C. inornata, M'Coy.
17. C. Ruthveniana, nov.

Genera and Species.

18. C. oretonensis and C. truncata, H. W.
19. C. solenoides (M'Coy), and C. gobiiformis, J. & W.
20. Emmelezoe elliptica M'Coy; E. tenuistriata, nov.; E. crassistriata, nov.; E. Maccoyiana, nov.
21. Xiphocaris ensis (Salter).
22. Physocaris vesica, Salter.
23. C. ? spp.
24. C. ? longicauda (D. Sharpe).
25. Ptychocaris simplex and Pt. parvula, Ovák.
26. Cryptozoe problematica, Packard.
27. Geological localities of Mr. J. M. Clarke's fossil Phyllopods.
28. List of British Palæozoic Phyllocarida described in the Third and Fourth Reports.

INTRODUCTION.

Since the publication of the Third Report on Palæozoic Phyllopoda ('Brit. Assoc. Report' for 1885) we have examined many additional specimens in the Museums of the Edinburgh and Glasgow Universities, and in the Braidwood Museum belonging to Dr. J. R. S. Hunter, of Braidwood, near Glasgow. Mr. James Thomson, F.G.S., has given us a quantity of nodules, containing remains of *Ceratiocaris*, from the Lesmahago district; and other friends have lent us several interesting specimens.

We have also again critically examined the fossils enumerated, under 'Ceratiocaris,' in the 'Third Report,' and, having had numerous finished drawings carefully made for illustration of a forthcoming monograph for the Palæontographical Society, we have been able to compare them more perfectly and with more precise results.

Thus we find that—

1. *Ceratiocaris leptodactylus* (M'Coy), see 'Third Rep.' pp. 11–14, as known by its caudal appendages (Cambr. Mus. *a*/923, *a*/924, and a few others), is distinct from *C. Murchisoni*, M'Coy, both as to size and proportions. We have traced two rows of pits (bases of prickles) on *a*/924, as exposed. Some similar caudal appendages, M.P.G. $\frac{17}{14}$, occur in the Lower Wenlock rock of Helm Knot, Dent, Yorkshire.

2. *C. Murchisoni* (Agass.), founded on some specimens figured in 'Sil. Syst.' and 'Siluria,' but unfortunately lost ('Third Rep.' p. 11, &c.), is represented by several analogous fossils, such as Oxford Mus. B and C; Ludlow Mus. C; M.P.G. $\frac{23}{33}$ and $\frac{23}{36}$. We find only one row of pits on the styles, as exposed. We have been unable to determine its carapace; but a fragment lying in the same slab with $\frac{23}{36}$ may belong to it. The carapaces formerly assigned to *C. leptodactylus* and *C. Murchisoni* ('Third Rep.' pp. 12, 15) are now regarded as belonging to distinct species.

3. The caudal appendages of *C. Murchisoni* have a slight curvature; there are others much like them, but straight, and associated with a large ultimate segment, much broader than that in M.P.G. $\frac{23}{36}$. (For

instance, Oxford Mus. F; M.P.G. X $\frac{1}{2}$; Ludlow Mus. T.) One of these (X $\frac{1}{2}$) has been labelled *C. gigas* by Mr. Salter; and therefore we adopt that name.

4. The specimens from the Wenlock beds of Dudley and Kirkby Lonsdale, described and figured in the 'Geol. Mag.', 1866, p. 204, pl. 10, figs. 8 and 9, as belonging to *C. Murchisoni* ('Third Rep.' p. 12), are too thick and strong for that species, and the Dudley example (fig. 8) has different proportions. We propose to distinguish them as *C. valida*.

5. Some abdominal segments (Oxford Mus. E; Ludlow Mus. L; B.M. 39403; M.P.G. $\frac{23}{35}$ and $\frac{23}{36}$; 'Third Rep.' p. 20, &c.), narrow in proportion to those in one other specimen marked $\frac{23}{36}$, and referred to *C. Murchisoni*, and very much narrower and smaller than in *C. gigas*, we separate as a new species, to be called *C. attenuata*. They have straight styles and stylets, much shorter than in either of the foregoing.

6. Two small specimens of crushed telsons (one in Mr. Cocking's collection, and the other M.P.G. X $\frac{1}{28}$, both from the Ludlow series), probably smaller than *C. Murchisoni*, have a fluted or channelled sculpture on their upper part, instead of either wrinkles or leaf-pattern; hence they may be regarded as belonging to a distinct form, for which the name *canaliculata* will be convenient.

7. One fine large carapace (M.P.G. X $\frac{1}{5}$) and others smaller and less definite in some respects (M.P.G. X $\frac{1}{7}$; X $\frac{1}{6}$; X $\frac{1}{9}$; Ludlow Mus. A; Oxford Mus. K & J), and associated with segments and appendages, we regard as distinctive of a new species, though hitherto referred to *C. leptodactylus* ('Third Rep.' pp. 12, 15). The test appears to have been of an unusually solid consistency.

These carapaces in some instances have been much modified by pressure, but we trace a close similarity throughout the series, allowing for probable differences of age. The shape approximates to that of Dr. James Hall's species *C. acuminata* and F. Schmidt's *C. Noetlingi* ('Third Rep.' p. 30). There are marked differences, however, and we intend to designate this form *C. Halliana*, in honour of our old friend, who began working at these Phyllocarida as early as 1852.

A perfect specimen of *C. acuminata*, Hall, has been lately described and figured by Dr. Julius Pohlman in the 'Bulletin of the Buffalo Society of Natural Sciences,' vol. v. No. 1, 1886, pp. 28, 29, pl. 3, fig. 2. Its caudal appendages are much like those of *C. papilio* and *C. stygia*, the style being relatively short, and the stylets broad and blade-like. The appendages in M.P.G. X $\frac{1}{7}$, X $\frac{1}{9}$, and Ludlow Mus. A are different from these, being thinner, tapering slowly, and pitted in at least one row, as exposed.

8. *C. Pardoeana*, La Touche. Two carapaces with segments and parts of appendages from Ludlow (Ludlow Mus. B and D; 'Third Rep.' p. 12) differ from any other form. One of them (B), with a wrong caudal appendage attached to it, in the Ludlow Museum, has been labelled '*C. Pardoensis*,' and as such is referred to in J. D. La Touche's 'Guidebook to the Geology of Shropshire.' We retain this name (altering the termination, as it refers to a person, and not a place) for the two carapaces here referred to. One of them (B) is of special interest as having its *rostrum* still in place.

9. The fine large specimen of *C. ludensis*, H. W. ('Third Report,' p. 16), has been again carefully studied, and we find reason to believe that the caudal appendage which appears longest in the fossil was not

really the longest, or the true telson, but was one of the 'laterals' or stylets. Hence the whole animal was probably much longer than our former estimate made it.

10. *C. robusta*, Salter ('Third Report,' p. 24), being based merely on some small caudal appendages (Cambridge Museum *a*/925 and *a*/926) without carapaces, is troublesome and unsatisfactory to deal with. We find some equivalent styles and broad blade-like stylets, like long scalene triangles, in *C. papilio*, *stygia*, *acuminata*, &c.; but none of these seem small enough for the several little sets of trifid appendages, more or less perfect, which we have met with. *C. robusta* takes in some of these; but Oxford Mus. T is relatively broad, and might be termed *lata*; B.M. 58878, from Muirkirk, has very narrow members (*angusta*); and one set in the Owens College is so neat, symmetrical, and small that it might be called *minuta*.

11. The specimens Ludlow Mus. S. and M.P.G. $X\frac{1}{17}{}^{2}$ have each a long style and a strong stylet attached to a broken ultimate segment, and were regarded as var. *longa* in the 'Third Report,' p. 25. Although not showing the lattice-pattern so often seen on the segments of *C. papilio* and *C. stygia*, they may well belong to one of those species, and the ornament may have flaked off from the ultimate segment. The study of *C. papilio* and *stygia* ('Third Report,' pp. 16–20) we have not yet exhausted by any means. We know, however, that the abdominal segments were delicately sculptured with leaf-like or lattice-pattern ornament, the points of the triangles pointing upwards, or rather backwards, towards the carapace, and one limb of the triangle, where free, running downwards and outwards in the other direction. These oblique lines are often visible when the triangles have disappeared from wear or decomposition. Among many others the segments M.P.G. $X\frac{1}{17}{}^{1}$; B.M. 41900: Oxford Mus. A and H exhibit fine examples of this leaf-like ornament; and it is visible in several more complete individuals in those collections. In the Braidwood and Glasgow Museums numerous specimens show it well. See also 'Third Report,' p. 31.

12. A small and very delicate specimen, B.M. 59648, has a thin subovate carapace, with excessively fine parallel longitudinal striæ, and shows 14 or 15 segments, some within and five outside the carapace, ending with a neat trifid set of appendages. This differs from any other form we know; and probably some small loose bodies, of numerous segments, occurring in the Lesmahago shales ('Third Report,' p. 20) may be of the same species. Its looseness of structure would suggest the name *laxa*.

13. Of *C. Salteriana*, noticed as a new species in the 'Third Report,' p. 23, we have not yet seen any additional specimens.

14. The specimens which we referred to in the 'Third Report,' pp. 23 and 24, as *C. cassia*, Salter, are separable into two forms. *C. cassia* proper is recognised on an interesting slab, of which one counterpart is in the Ludlow Museum (E and F) and the other in the Museum of Practical Geology at Jermyn Street, London ($X\frac{1}{1}$). The other somewhat similar, but larger and otherwise different, specimens are not unlike in the characters of the carapace, but they have more abdominal segments exposed and proportionally longer caudal appendages—M.P.G. $X\frac{1}{26}$; B.M. 39400; Ludlow Mus. K; Oxford Museum L and Q. These might be conveniently named *C. cassioides*.

In all the specimens of both kinds the carapace has been apparently thin and tough, so as to allow of their being crumpled very much. This condition and the presence of harder parts of their internal organs beneath give rise to various tubercular irregularities of the surface, in some cases simulating ocular tubercules. There are, however, no real eye-spots. There may have been irregularities of the surface, due to the attachment of the muscles of the jaws within the body.

15. An ovate carapace, represented by a mere film, and five abdominal segments, with a neat trifid tail, all flattened but very distinct, have no close ally among the known forms. The segments are delicately striate, with oblique lines on each side, suggesting the name *compta*, which we propose for this specimen—Ludlow Museum, E.

To *C. inornata*, M'Coy ('Third Report,' pp. 20, 21), we have nothing to add, except that some large specimens (so named, Cambridge Mus., *b*/35) have a greater proportional depth (height) at the ventral border than smaller individuals, and yet have the same general outline and posterior slope, as well as the longitudinal lineate ornament. The presence of this sculpturing is not in accordance with the trivial name. These large specimens may belong to *C. stygia*.

In the Cambridge Museum is a specimen (*b*/36) of two abdominal segments, with a style and a stylet in good preservation, being convex and not injured by pressure. The penultimate segment is smooth, but shows faint traces of oblique lines; the ultimate is quite smooth and cylindrical; the telson (style) is attached by an apparently rounded joint; and the two uropods much resemble some of those referred to *C. robusta*. This specimen is from Benson Knot, and is labelled *C. inornata*; but the evidence of its specific relationship is supported only by its having been found in the same rock, and by its size suiting the large form of *C. inornata?* (*b*/35). It belongs possibly to *C. stygia*.

17. From the list for *C. inornata*, given in the 'Third Report,' we have to remove one of the specimens found at Benson Knot, and marked '44342' in the British Museum, being decidedly different in outline (more ovate), though similarly marked with longitudinal striæ. It might well be named *C. Ruthveniana*, in memory of the old geological collector who laboured for very many years in the Kendal district for Professor Sedgwick and others.

18. *C. oretonensis* and *truncata*, H.W. ('Third Report,' pp. 21, 22), though near to *C. inornata* in shape, hold their distinct places as species.

19. Of *C. solenoides* and *C. gobiiformis* ('Third Report,' p. 22) there is nothing new to be stated.

20. As intimated in the 'Third Report,' pp. 27, 28, the presence of the ocular tubercle has an important signification, showing that the animal must have had an organ equivalent to the eye sufficiently developed to affect the external covering, whether it was adapted for clear vision or not. It may be a family distinction; at all events, the oculate carapaces have to be removed from *Ceratiocaris*, and we propose that M'Coy's *C. elliptica* be referred to a new genus under the name *Emmelezoe*.[1]

E. elliptica, M'Coy, is described in the 'Third Report,' p. 27, as represented by the type, Cambridge Mus. *b*/15; but Ludlow Mus. G., and M.P.G. X $\frac{1}{10}$ and $\frac{23}{32}$ differ from it considerably. The first of these is shorter and broader (higher), nearly semicircular in outline, with an acute and projecting postero-dorsal angle; and its surface has a fine, almost

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[1] 'Εμμελής, elegant; ζωή, life (a termination common in some of M. Barrande's genera).

silky, linear ornament. As a new species this might be known as *E. tenuistriata.* The specimen X $\frac{1}{10}$ is subovate, larger than either of the other two, and is coarsely striate, with longitudinal anastomosing wrinklets, and might be named *E. crassistriata.* M.P.G. $\frac{23}{32}$ is smaller than any of the foregoing, somewhat boat-shaped, between the last and *elliptica* in shape, but not identical with either; and it is rather coarsely striate longitudinally. To this form we propose to give the name *E. Maccoyiana*, in honour of the first describer of any member of this genus.

21. At page 26 of the 'Third Report,' we described Salter's *Ceratiocaris? ensis*, and now we are still more confirmed in the opinion that it belonged to a distinct genus. Its large size, its curvature, and the serration on both the upper and the lower edge, and the profuse spination (as shown by pits) on the latter distinguish it from other telsons; and more particularly its lozenge-shaped sectional area, of an unequal rhombic form, blunter at the outer (upper) and convex edge than on the other, the ridge along the sides not being quite on the medial line, but nearer the outer than the inner edge. We propose the name *Xiphocaris*[1] for this rare genus.

M. Barrande's *Ceratiocaris primula* ('Third Report,' p. 32) has a style (or stylet?) with lozenge- or diamond-shaped section; but this uropod, though curved, is of different dimensions, and is pitted all over.

22. *Physocaris vesica*, Salter ('Third Report,' p. 28), we consider as having had its abdominal segments shifted from below upwards, and turned over on their axis, after death; and therefore as having been figured upside down.

23. Of *C.? lata, insperata,* and *perornata* we have no further evidence at present.

24. *Ceratiocaris? longicauda*, D. Sharpe ('Third Report,' p. 29), a foreign (Portuguese) form within our reach, has been studied in the Geological Society's Museum, Burlington House, and shows some interesting features. Its scientific name was given under the supposition that the fossil was a *Dithyrocaris*, with a longer abdomen than usual; but its cylindrical ultimate segment, its somewhat bayonet-shaped style, and blade-like stylets clearly remove it from that genus, as intimated in our former notice. It is probably distinct also from *Ceratiocaris*; it has some analogy with the Devonian *Elymocaris*; but at present we cannot fix its generic place.

25. In the 'Sitzungsb. K. böhm. Ges. Wiss.' 1885, M. Ottamar Novák, Keeper of the Barrande Collection at Prague, has described a new Phyllocaridal genus from the *étage* F, f 2, in Bohemia, as *Ptychocaris*, with two species *Pt. simplex* and *Pt. parvula*, characterised by a strong and obliquely longitudinal ridge or sharp fold on each valve, and by an anterior group of three small nodules, an ocular tubercle behind them, and some larger but less distinct swellings further back, but still in the antero-dorsal region. M. Novák supplies also a Table of the vertical distribution of the *Phyllocarida* in Bohemia.

In the Annales XIII. Soc. Géol. du Nord, 3me Livr. April 1886, p. 146, M. E. Canu gives a *résumé* of the results of M. O. Novák's researches in the *Phyllocarida*, with some woodcuts of *Aristozoe regina, Bactropus longipes,* and *Ceratiocaris debilis* (see 'Third Report,' pp. 32–34), and of *Ptychocaris simplex* (see above).

26. Dr. A. S. Packard, junior, has described and figured some

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[1] Ξίφος, a sword; καρίς, a shrimp.

peculiar appearances on an internal cast of a Carboniferous Phyllopodous carapace from Illinois, as traces of four pairs of lamellate limbs (thoracic feet), probably 'the homologues of the exopodites of *Nebalia.*' He has defined the genus and species as *Cryptozoe problematica* ('American Naturalist,' Extra, Feb. 1886, p. 156; and 'Proceed. Americ. Philosoph. Soc.' vol. xxiii. No. 123, pp. 380–383).

27. In a Geological Report, Assembly Document, No. 161, 1885 (or 1886), Mr. J. M. Clarke has defined the localities and geological succession in Ontario County and New York, where the Phyllopods which he previously described (see 'Second Report,' 1884, pp. 80–86, and 'Third Report,' p. 3) have occurred with or without Goniatites.

28. A list of the British Palæozoic Phyllocarida described in the Third and Fourth Reports.

—	Carboniferous Limestone; Oreton	Ludlow Beds					Wenlock Beds			Upper Llandovery; Onny River	Tremadoc Slates; Portmadoc
		Upper Ludlow; Ludlow	Upper Ludlow; Benson Knot, Kendal	Upper Ludlow; Lesmahago and Muirkirk	Lower Ludlow; at and near Ludlow	Upper Shale = Lower Ludlow	Lower Shale = Wenlock	Wenlock; Kirkby-Lonsdale	Lower Wenlock; Helm Knot, Dent		
						Dudley					
1. Ceratiocaris leptodactylus	—	—	—	—	+	—	—	—	+		
2. C. Murchisoni	—	×	—	—	×						
3. C. gigas	—	—	—	—	× & Knighton						
4. C. valida	—	—	—	—	—	—	×	×			
5. C. attenuata (tyrannus?)	—	—	—	—	×						
6. C. canaliculata	—	×									
7. C. Halliana	—	—	—	—	×						
8. C. Pardoeana	—	—	—	—	×						
9. C. ludensis	—	—	—	—	×						
10. C. robusta	—	×	—	—	×						
11. C. lata	—	—	—	—	×						
12. C. angusta	—	—	—	×							
13. C. minuta	—	—	—	—	×						
14. C. papilio	—	—	?	×	×						
15. C. stygia	—	—	?	×							
16. C. laxa	—	—	—	×							
17. C. Salteriana	—	—	—	—	×	×					
18. C. cassia	—	—	—	—	×						
19. C. cassioides	—	—	—	—	×						
20. C. compta	—	—	—	—	×						
21. C. decora	—	—	—	—	Fresh-water, Pembrokeshire						
22. C. oretonensis	×										
23. C. truncata	×										
24. C. inornata	—	—	×								
25. C. Ruthveniana	—	—	×								
26. C. solenoides	—	—	×								
27. C. gobiiformis	—	—	×								
28. C. perornata	—	—	×								
29. C. ? lata	—	—	—	—	—	—	—	—	—	—	×
30. C. ? insperata	—	—	—	—	—	—	—	—	—	—	×
31. C. ? sp.	—	—	—	—	—	—	—	—	—	×	
32. Physocaris vesica	—	—	—	—	×						
33. Xiphocaris ensis	—	—	—	—	×						
34. Emmelezoe elliptica	—	—	×								
35. E. tenuistriata	—	—	—	—	×						
36. E. crassistriata	—	Presteign									
37. E. Maccoyiana	—	—	—	—	×						

Twelfth Report of the Committee, consisting of Professor E. HULL, Dr. H. W. CROSSKEY, Captain DOUGLAS GALTON, Professors J. PRESTWICH *and* G. A. LEBOUR, *and* Messrs. JAMES GLAISHER, E. B. MARTEN, G. H. MORTON, JAMES PARKER, W. PENGELLY, JAMES PLANT, I. ROBERTS, FOX STRANGWAYS, T. S. STOOKE, G. J. SYMONS, W. TOPLEY, TYLDEN-WRIGHT, E. WETHERED, W. WHITAKER, *and* C. E. DE RANCE (*Secretary*), *appointed for the purpose of investigating the Circulation of Underground Waters in the Permeable Formations of England and Wales, and the Quantity and Character of the Water supplied to various Towns and Districts from these Formations. Drawn up by* C. E. DE RANCE.

YOUR Committee have not been able to include in the present report information which would be of considerable value in drawing up a final report on the result of their thirteen years' labour. They therefore consider they will best carry out the instructions given them in 1874 by continuing their investigations for at least a year.

It had been hoped by the Committee that the details of the sections passed through, and the character and quantity of several important wells and borings now in progress in the Midland counties, might have been laid before this meeting, but they are still incomplete.

Northamptonshire.—At Kingsthorpe, 2½ miles north-east of Northampton, a trial for coal was made in 1830, against the advice of Dr. William Smith, F.R.S., and Mr. Richardson, of the British Museum. This shaft was described by Dr. Buckland, and later by the late Mr. S. Sharp ('Geol. Mag.,' vol. viii.). It passed through 120 feet of Oolites, 760 feet of Lias, and 60 feet of sandstone, 12 feet of marls, and 15 feet of conglomerates, referred at the time by Dr. Smith to the New Red series. The Middle Lias (or marlstone) appears to have produced 36,000 gallons per hour at a depth of 210 feet from the surface, and the New Red a like quantity of brackish water from a depth of 880 feet. The work was stopped at 967 feet, after costing 30,000*l.*

In 1846 the London and North-Western Railway bored for water in Northampton, and, on reaching 650 feet, tapped a salt-water spring, containing chloride of sodium, carbonate of soda, sulphates of magnesia and lime, the spring occurring in a 4-feet bed of magnesian limestone, lying under 50 feet of variegated sandstone and marls.

In 1879 a boring was made by the water company at Kettering Road, one mile north-east of Northampton, to a depth of 851 feet. In this boring the Lias rested on an eroded surface of crystalline conglomerates and sandstone, 67½ feet in thickness, which are somewhat doubtful in age, no fossils having been discovered, but overlie 45 feet of carboniferous dolomitic limestone with fossils, which is believed to have yielded the 200,000 gallons of saline water met with in this boring, containing 1,200 grains of mineral salts per gallon.

The second trial of the Northampton Waterworks Company was at Gayton, two miles north-west of Blisworth Station, and five south-west of Northampton. The details are given by Mr. H. J. Eunson (Range of the Palæozoic Rocks beneath Northampton, 'Q. J. G. S.,' vol. xl. part III. p. 485). The Lias, White Lias, and Rhætic continued to 617 feet from the surface, the latter resting on a slightly eroded series of marl, followed by variegated sandstone 60 feet in thickness, which are referred to the Trias. At 676½ feet occurred carboniferous sandstone with fossils, which, with the underlying marls and limestones are regarded as a local littoral deposit, lying on the true carboniferous limestone occurring at 699 feet. The beds beneath are very remarkable, but do not affect the present inquiry. The total depth reached was 994 feet. As in the other boring, the water was saline, containing 1,500 grains of mineral salts to the gallon, the quantity being only 100,000 gallons per day. The water stood 20 feet higher than at Kettering Road, giving a gradient ($\frac{20}{6}$) of 3⅓ feet per mile to the north-east.

In the boring lately carried out for Mr. J. Fleming (of Newcastle-on-Tyne), at Orton, five miles west of Kettering, and twelve miles to the N.E. of Northampton, the Triassic beds were absent, and the beds of doubtful age were 24 feet, the underlying carboniferous beds were absent, and a quartz-felzite 74 feet thick still persisted when the boring was abandoned at 789 feet.

Details of Wells and Borings, Cheshire. Collected by Mr. G. H. Morton, F.G.S., from Mr. H. Aston Hill, C.E.

1. The Wallasey Waterworks, Great Float, near Birkenhead. **1*a*.** No. 1 well, 1861. Borehole enlarged to 13 inches, and deepened to 400 feet from surface in 1876. No. 2 well 1874; not deepened since. **2.** 23 feet. **3.** No. 1 shaft, 7 feet diameter, 90 feet from surface. Borehole 13″ diameter, 400 feet from surface. No. 2 shaft, 7 feet diameter, 90 feet from surface. Borehole 18″ diameter, 400 feet from surface. **3*a*.** **4.** The pumping is almost continuous, and the working level of water is about 40 feet from surface. After stopping four hours the water rises to 24 feet from surface. **4*a*.** When No. 1 well was sunk in 1861, the water rose to within 9 feet of the surface. Cannot tell how high it would rise now, being unable to stop pumping for a sufficiently long period. **5.** 1,250,000. **6.** No. No. **7.** No. Do not stop pumping sufficiently long to see what height water would rise to; but as a rule our working level is about 17 feet below mean level of the Birkenhead Docks. **8.** Not had an analysis made recently. Water is considered of excellent quality, and does not possess any marked peculiarity.

		ft.		ft.
9.	Red marl	78	Red rock	56
	Sand and marl	9	Grey rock	12
	Marl	6	Hard red rock	22
	Clay, stones, and sand	3	Soft red rock	48
	White rock	12		

Total . . . 246 ft. from surface, in 1861.

10. Probably. **11.** Yes. **12.** It is believed so. **13.** No. **14.** No. **15.** Don't know of any deep wells having been discontinued; but several shallow ones have been, in consequence, no doubt, of surface contamination.

Northamptonshire.

Section of Boring at Hambledon. Collected by Mr. W. Whitaker.

		ft.	in.
Inferior Oolite (Northampton sand)		10	6
Upper Lias		176	0
Middle Lias	Marlstone rock	15	0
	Clay	3	0
	Rock	1	0
	Clay	12	0
	Rock	1	0
	Clay	16	0
	Rock	1	0
	Clay	+	

Boring ceased 240 feet from the surface. Water was found in the lower part of the marlstone, but not in great quantity. An increased quantity was found in each of the three bands of rock subsequently perforated. The water-level stands in the bore about 6 feet above the bottom of the marlstone.

Shropshire.

Collected by Mr. T. S. Stooke, C.E.

1. At Sunderton, near Shrewsbury. **1*a*.** 1884. No. **2.** 205 feet. **3.** No well. Bore-hole 76 feet in depth, 5 inches diameter. **3*a*.** **4.** Normal surface of water 11 feet. **4*a*.** 4½ feet; 11 feet. **5.** The full yielding power of bore-hole has not been tested. The yield is considerable. **6.** Not known to vary. **7.** Not known to be affected about 5 feet above an adjoining stream. **8.** By Mr. Thomas Blunt, M.A.

Total solid contents	50·00	grains to gallon
Chlorine in chlorides	8·50	„ „
Nitrogen in nitrates	0·00	„ „
Oxygen absorbed	0·012	„ „
Temporary hardness, Clarke's scale	25½°	
Permanent „ (after boiling for some time)	9½°	

The water is pronounced wholesome, but somewhat hard for drinking and domestic use.

		ft.
9.	Soil and clay	6
	Red sand	1
	Clay with stones	20
	Red sand	2
	Clay	5
	New red sandstone	38
	Marl	4
	Total depth	76

9*a*. New red sandstone. **10.** Yes. **11.** Yes. **12.** No. **13.** No. **14.** No. **15.** No. **16.**

Collected by Mr. Thos. S. Stooke, C.E.

1. Atcham workhouse well, near Shrewsbury. **1*a*.** A bore-hole was put down in 1884. **2.** 206 feet. **3.** 60 feet in depth; 4 feet in diameter; 181 feet; cased with 4-inch tubes. **3*a*.** No driftway. **4.** 54 feet; the water level is only reduced about 6 inches in affording the supply required. The ordinary water level is quickly restored. **4*a*.** The water stands about 12 inches higher in well since the bore-hole was put down. **5.** The average quantity pumped is about 10,000 gallons daily. The full yielding power of the well and bore-hole has not been tested. **6.** Water level does not vary since bore-hole was put down. **7.** Not affected by local rains. About 15 feet higher than the normal summer level of Severn, which is situated about ½ mile from the site of well. **8.** Water of very good quality; no recent analysis has been taken. **9.** No record of strata pierced by the well.

Section of Boring.

60 to 80 feet—sand.
80 to 124 „ —sand and gravel.
124 to 152 „ —coarse gravel sand with flint.
152 to 210 „ —grey sand and gravel.
210 to 214 „ —red sandstone.
214 to 230 „ —marl.

9*a*. Sand and gravel beds. **10.** **11.** The well is cased with brickwork throughout. **12.** No. **13.** No. **14.** No. **15.** No. **16.** The bore-hole was carried through 2½″ tubes placed within the 4″ tubes to the depth of 230 feet. The inner tubes were withdrawn, as an ample supply was obtained at the depth of 181 feet.

Collected by Mr. C. E. De Rance from Mr. William Blackshaw, Borough Surveyor, Stafford.

Stafford Corporation Waterworks Pumping Shaft and Trial Boring at Ensonmoor.

Particulars of Strata passed through.

ft.	in.	
1	0	Soil.
16	6	Clay.
7	6	Loamy sand.
14	0	Gravel yielding 400,000 gallons of water per 24 hours.
35	0	Red marl.
4	0	Sand.
0	9	Light friable sandstone.
46	7	Blue and red rock marl with veins of gypsum yielding 800,000 gallons of water per 24 hours.
356	0	Blue and red rock marl with veins of gypsum but no water.
369	0	Red and grey sandstone.
850	4	

June 3, 1886.—Water overflowing at the rate of 44,000 gallons per 24 hours.

South Staffordshire.—In districts of Old Hill and Tipton many of the coal mines are waterlogged, and are underwatered by a pumping commission, appointed in 1873, with powers to levy rates of 9*d.* per ton on coal, ironstone, and slack, and 3*d.* a ton on fireclay and limestone. In Tipton in 1873 there were 77 pumping stations; in 1885 these were reduced to 10. The principal pumping stations over an area of 50 square miles are Bradley Station (near Moxley, G. W. R.), which can raise four million gallons from a depth of 126 yards, the Moat, and the Stoneheath Stations.

APPENDIX I.

Memoranda for Mr. De Rance, Reporter to the Underground Water Committee of the British Association, Birmingham Meeting, 1886. *By* Mr. E. B. MARTEN, *of Pedmore, Stourbridge.*

The Committee have investigated chiefly the Triassic Rocks, and with a view to trace the flow of potable water, with a few illustrations from other geological formations.

The drainage of the South Staffordshire and East Worcestershire coalfield being taken up by a commission under the South Staffordshire Mines Drainage Act, 1873, information has been obtained of the state of the underground water, and many a puzzle has presented itself as to how far the effects of any one pumping station will reach, as it depended not only on the natural porosity of the strata, but also on the extent to which the natural barriers had been pierced or weakened by mining operations.

It was found that although naturally the underground water would level itself and flow out at the nearest surface stream, as if all the coalfields were one homogeneous rock, it was far from the case when attempts were made to pump the whole sufficiently for mining purposes. It was then found that the part dealt with by the Act divided itself into the two sides east and west of the Sedgley, Dudley, and Rowley Hills; and the east side again into four smaller areas, Bentley, Bilston, Tipton, and Oldbury; and in the west Kingsaricford and Old Hill, any one of which could be pumped separately. These smaller districts were again divided into smaller pounds, each separated when the water was pumped down below the broken barriers.

These are readily seen in the sketch map of area under the Act with five large districts, each having the smaller pound-boundaries marked in different colours.

It was soon found that Bilston and Tipton were so far one that when Tipton was pumped Bilston water flowed down and nearly swamped Tipton, so that some of the largest pumps in the kingdom have been put down on the lower side of the boundary between those districts, and the most difficult operation in mining successfully carried out, of driving under the Bilston water and tapping it.

To each pumping station the water flows, but the district which it will drain depends on the 'faults' and workings.

A few examples may be of interest, especially as compared with the behaviour of the water in the more homogeneous strata under the investigation of the Committee, and will be given in the next report.

APPENDIX II.

By MR. E. B. MARTEN.

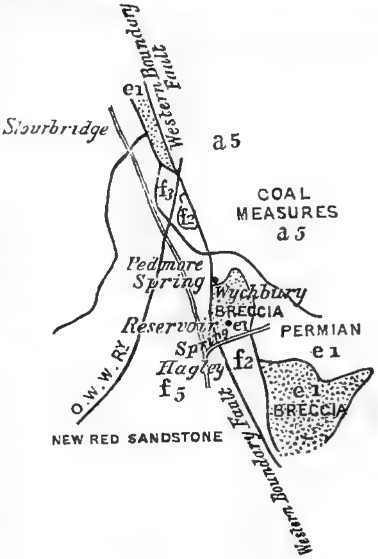
Although the records are, I believe, closed, I send you particulars of four springs yielding extremely good water and sufficient for supplying the village of Pedmore, just upon the borders of the great western boundary fault of the coalfield as it passes away south under the Clent Hills and Hagley.

Wychbury Camp Hill, like Clent, Walton, Woodbury, and other hills of Permian formation, is capped by the Breccia described by Professor Jukes, which receives the rainfall and holds it like a sponge on the somewhat denser rock below, springs showing themselves all around 500 feet above sea-level at the base of the Breccia at Pedmore and Hagley, and forming the heads of rivulets.

Within the last few weeks the water has been analysed by Dr. Bostock Hill, and found to be very good as follows:—Parts per 100,000: total solid impurity, 20·0; organic ammonia, 0·002; free ammonia, 0·001; chlorine, 2·5; temporary hardness, 5·43; permanent hardness, 9·57: total hardness, 15·00.

On the west side of the fault the New Red sandstones abut against the Permian, and being far more porous the rainfall sinks away, so that at Hagley the few wells are 70 feet deep, and at Pedmore there are no deep wells, and the few that are shallow easily get contaminated. The general level of the water in the New Red sandstone is about 250 feet above the sea, the river Stour being the lowest outlet about one mile below the Wollaston Pumping Station, described by me on page 7, 1882 (Eighth Report), is about 200 feet above sea-level.

In excavating for a small reservoir, about three years ago, one side slipped in, the whole coming off like half a peg-top, point downwards, leaving a smooth, polished, 'slickenside' surface, so that we were evidently exactly on the great western boundary fault.



APPENDIX III.

Weekly Readings of Height of Water in Messrs. S. Courtauld & Co.'s Well, Bocking, Essex. Datum is 137·07 Feet above Sea-level.

Date	Above Datum in Inches	Date	Above Datum in Inches	Date	Above Datum in Inches
Aug. 20, 1883	11½	Aug. 11, 1884	54	Aug. 4, 1885	38½
„ 27 „	11½	„ 18 „	53½	„ 10 „	39½
Sept. 3 „	14½	„ 25 „	51½	„ 17 „	36
„ 10 „	10	Sept. 1 „	52½	„ 24 „	35½
„ 17 „	9	„ 8 „	49½	„ 31 „	35
„ 24 „	11	„ 15 „	48½	Sept. 7 „	37½
Oct. 1 „	12½	„ 22 „	50	„ 14 „	35
„ 8 „	8	„ 29 „	45½	„ 21 „	36
„ 15 „	12½	Oct. 6 „	42	„ 28 „	36
„ 22 „	10½	„ 13 „	44	Oct. 5 „	38½
„ 29 „	10	„ 20 „	42	„ 12 „	38
Nov. 5 „	12½	„ 27 „	44	„ 19 „	35
„ 12 „	12½	Nov. 3 „	42½	„ 26 „	41
„ 19 „	11½	„ 10 „	39½	Nov. 2 „	35
„ 26 „	16	„ 17 „	40	„ 9 „	32
Dec. 3 „	12	„ 24 „	40½	„ 16 „	31
„ 10 „	11	Dec. 1 „	42	„ 23 „	34
„ 17 „	10	„ 8 „	42	„ 30 „	34
„ 24 „	8	„ 15 „	42	Dec. 7 „	30
„ 31 „	9½	„ 22 „	40	„ 14 „	29
Jan. 7, 1884	12	„ 29 „	43	„ 21 „	31
„ 14 „	9½	Jan. 5, 1885	42	„ 28 „	33
„ 21 „	9½	„ 12 „	43½	Jan. 4, 1886	33
„ 28 „	16½	„ 19 „	39½	„ 11 „	33
Feb. 4 „	11	„ 26 „	41	„ 18 „	37½
„ 11 „	15	Feb. 2 „	44	„ 25 „	36
„ 18 „	13	„ 9 „	43	Feb. 1 „	37
„ 25 „	13½	„ 16 „	45	„ 8 „	35
Mar. 3 „	13	„ 23 „	42½	„ 15 „	32½
„ 10 „	16½	Mar. 2 „	41½	„ 22 „	30
„ 17 „	12	„ 9 „	41½	Mar. 1 „	33
„ 24 „	11½	„ 16 „	40	„ 8 „	31
„ 31 „	14½	„ 23 „	39½	„ 15 „	31
April 7 „	15	„ 30 „	42	„ 22 „	32
„ 14 „	12½	April 7 „	46	„ 29 „	34
„ 21 „	12	„ 13 „	42½	April 5 „	33
„ 28[1] „	31½	„ 20 „	40½	„ 12 „	32½
May 5 „	42	„ 27 „	44	„ 19 „	33½
„ 12 „	44	May 4 „	44½	„ 27 „	33½
„ 19 „	49	„ 11 „	41½	May 3 „	29½
„ 26 „	49	„ 18 „	42	„ 10 „	31½
June 3 „	57	„ 26 „	42	„ 17 „	32
„ 9 „	56½	June 1 „	40	„ 24 „	32
„ 16 „	55	„ 8 „	39½	„ 31 „	31
„ 23 „	57	„ 15 „	40	June 7 „	31
„ 30 „	58	„ 22 „	39½	„ 15 „	31½
July 7 „	58½[2]	„ 29 „	41	„ 21 „	29
„ 14 „	58½[2]	July 6 „	38½	„ 28 „	27½
„ 21 „	57½	„ 13 „	40	July 5 „	26½[3]
„ 28 „	56	„ 20 „	39½	„ 12 „	27
Aug. 5 „	54	„ 27 „	37	„ 19 „	29

[1] Essex earthquake, April 22, 1884.

[2] Highest recorded since earthquake.

[3] Lowest recorded since earthquake.

APPENDIX IV.

List of Questions Circulated.

1. *Position* of well or shafts with which you are acquainted?

1a. State *date* at which the well or shaft was originally sunk. Has it been deepened since by sinking or boring? and when?

2. Approximate *height* of the surface of the ground above Ordnance Datum (mean sea-level)?

3. *Depth* from surface to bottom of shaft or well, with diameter. *Depth* from surface to bottom of borehole, with diameter?

3a. *Depth* from the surface to the horizontal drift-ways, if any? What is their length and number?

4. *Height* below the surface, at which water stands *before* and *after* pumping. Number of hours elapsing before ordinary level is restored after pumping?

4a. *Height* below the surface, at which the water stood when the well was first sunk, and height at which it stands now when not pumped?

5. *Quantity* capable of being pumped in gallons per day of 24 hours? Average quantity daily pumped?

6. Does the *water level* vary at different seasons of the year, and to what extent? Has it diminished during the last ten years?

7. Is the ordinary *water level* ever affected by local rains, and, if so, in how short a time? And how does it stand in regard to the level of the water in the neighbouring streams, or sea?

8. *Analysis* of the water, if any. Does the water possess any marked *peculiarity*?

9. *Section* with nature of the rock passed through, including cover of Drift, if any, with *thickness*?

9a. In which of the above rocks were springs of water intercepted?

10. Does the cover of Drift over the rock contain *surface springs*?

11. If so, are these *land springs* kept entirely *out* of the well?

12. Are any large *faults* known to exist close to the well?

13. Were any *brine springs* passed through in making the well?

14. Are there any *salt springs* in the neighbourhood?

15. Have any wells or borings been discontinued in your neighbourhood in consequence of the water being more or less *brackish*? If so, please give section in reply to query No. **9.**

16. Kindly give any further information you can.

Second Report of the Committee, consisting of Mr. W. T BLANFORD, Professor J. W. JUDD, *and* Messrs. W. CARRUTHERS, H. WOODWARD, *and* J. S. GARDNER (*Secretary*), *appointed for the purpose of reporting on the Fossil Plants of the Tertiary and Secondary Beds of the United Kingdom.*

[PLATE VII.]

OUR attention has been devoted exclusively this year to the fossil flowering or phanerogamous plants.

The results of our researches point to the conclusion that while that section known as Gymnospermous, to which the Coniferæ belong, is of the highest antiquity, being almost coeval with the first definite remains of plants in the Palæozoic age, there are no Angiospermous plants in British rocks of greater antiquity than the Secondary period, if we except the problematic plant known as *Spirangium.* Even down to so late as the Lias we have been unable to ascertain that any indisputable Angiosperm has been discovered within our area, for we are led to the conclusion that the supposed Monocotyledons from the Rhætics, near Bristol, hitherto referred to the family of Pond-weeds under the name *Najadita*, are really cryptogamic plants of the moss tribe, closely allied to the river moss *Fontinalis.* This group had not previously been found fossil, and, so far as it goes, would indicate rather a temperate climate. It is important to notice that these conclusions are shared by such high authorities on fossil plants as Prof. Williamson, Mr. Carruthers, and all botanists who have examined them, as well as by Mr. Brodie, the possessor of the specimens. The *Lilia*, *Bensonia*, and other supposed Monocotyledons of similar age are very imperfectly preserved, and doubtless referable to Cycads, a family which then abounded.

We have examined a large number of specimens of the anomalous Jurassic plant described by Carruthers as *Williamsonia.* It is well known that Prof. Williamson, in whose possession or charge a number of the finest specimens remain, has devoted a considerable amount of attention to them, without, however, feeling justified in coming to any very definite conclusion as to their true position in the vegetable world. De Saporta, on the other hand, has found more perfectly preserved specimens in France, and has no hesitation whatever in referring them to the group of *Pandanaceæ.* Though there are still many difficulties in the way, our own examination of the specimens in London, Manchester, Cambridge, and elsewhere tends to confirm Saporta's view so far as that there do appear to be vestiges, in some cases at least, of lignitic structure which may represent the areolæ or carpels. These rather minute cavities and the lignitic matter surrounding them fall away on exposure to the air, and only traces of them are visible. Should Saporta's contention be upheld, *Williamsonia* will be by far the most perfectly known of the secondary Angiosperms, since all the organs of fructification and even of foliation are more or less known.

A still more definite Monocotyledon is the *Podocarya*, from the Inferior Oolite, originally figured by Buckland, and redescribed by Carruthers. Its resemblance to the fruit of *Williamsonia*, as interpreted by Saporta, is extremely striking, and on suggesting this to that author, he replied that he was in the act of preparing an important work on the very subject. The same work is to include an illustration of the most recent member of the group, obtained from the Grey Chalk of Dover, and which we thought advisable to communicate to him.

Next in point of age, among English Monocotyledons, to the *Podocarya* is the *Kaidacarpum*, from the Great Oolite, also described by Carruthers, and by him referred to the *Pandaneæ.* We have been able to ascertain that a second species, hitherto supposed to be of Cretaceous age from the Potton Sands, is a derived fossil, and undoubtedly Jurassic. A third species was originally figured, without any reference in the letterpress as to its age or locality, by Lindley and Hutton as *Strobilites Bucklandi*, in their 'Fossil Flora,' vol. ii. pl. 129, published between 1833–35, from a drawing made by Miss E. Bennett for Dr. Buckland. In the first edition of Morris's 'Catalogue,' 1843, it is set down as from 'Gr. S. Wilts,' which cannot mean either Lower or Upper Greensand, the abbreviations for which are 'L. G. S.' and 'U. G. S.,' but which certainly looks like a misprint for 'Gr. O.,' the sign for Great Oolite. In the second edition of Morris, 1854, the locality is corrected to 'U. G. S. Wiltshire,' but it appears likely that the correction may have been made without ascertaining the facts *de novo*, for the only entry occurring in Miss Bennett's 'Catalogue of the Organic Remains of Wiltshire,' published in

1831, that could possibly refer to this fossil, is a '*Cycadeoidea?*' from the Portland Beds, which occurs under the heading 'Woods' on p. 9. A journey to Newcastle with the object of examining the Hutton collection of fossil plants, where it seemed probable the specimen might be found, has been unsuccessful, and its present whereabouts is still unknown. We think it, however, far more likely to prove a Jurassic than a Cretaceous fossil if found, and the genus should not be included in lists of plants of the latter age.

The oldest Monocotyledons thus appear to be referable to the Pandaneæ, a group of plants distributed in widely distant and remote oceanic islands, and whose fruits are still met with at sea in drifts of vegetable matter.

Next to these in antiquity are two very monocotyledonous-looking fragments from the Jurassic of Yorkshire, which have been fully described in the 'Geological Magazine' for May and August. The one is apparently an unopened palm-like spathe, and the other a jointed cane-like stem. Mr. Brodie possesses an undoubtedly monocotyledonous leaf fragment from the Purbeck of Swindon.

The *Aroïdeæ* have long been supposed to be a group of very high antiquity, but there are good reasons for believing that the supposed remains of aroïdeous plants from beneath the Tertiaries are, without exception, referable to other groups, and actually there are no known traces of them earlier than the Middle Eocene, when they become by no means uncommon.

In a similar manner the fruits once supposed to represent *palms* in the Palæozoic and Mesozoic rocks have been gradually removed or suppressed, and, unless the fragments of palm-like wood in the gault at Folkestone are taken into account, there are no traces of palms in any of our Secondary strata. They, however, appear as low down in our Eocene as the Woolwich series.

We are not yet able to speak with certainty regarding the supposed liliaceous or *Dracæna*-like stems from the Wealden, so frequently mentioned by Mantell, and now in the British Museum, since they have not yet been thoroughly examined; but it is very probable that they are liliaceous, and, if so, of the highest interest. The Wealden has so far yielded no other trace of any more highly organised plants than ferns and Gymnosperms, and this, when we remember that Monocotyledons were undoubtedly in existence, is a fact that should be of great significance to speculative geologists. The sediments must represent the deposits of the drainage system of a large area, for they are of vast extent and thickness, varied in character, and abounding in remains of trunks and stems, fruits and foliage of plants. In them, therefore, if anywhere, we might reasonably expect to find at least the traces of reed and rush, but the swamps seem to have been tenanted only by Equisetum and ferns, and the forests mainly by Cycads and Conifers.

The same absence of Angiosperms, so far as British rocks are concerned, is continuous throughout the Neocomian and Gault, and it is only in the White Chalk that we meet with any indications of them, and these only take the form of a more than suspicious impression of a net-veined leaf, in the Jermyn Street Museum, and of some structureless bodies which were apparently some kind of fruit.

When, however, we turn to the gymnospermous section of Phanerogams the records are very different. To refer here to the earlier Secondary

Coniferæ and Cycadeæ would be quite beyond our province, and it is only those of the Cretaceous, as the last discoverable ancestors in our area of the Eocene flora, that are of immediate interest. These belong, excluding Cycads, chiefly to the newest section of the Coniferæ, the Pine family. We are able to make the following contribution to our knowledge of these:—

Pinites Andræi, Coemans. 'Flore fossile du Terrain Crétacé du Hainault,' 1866, p. 13, pl. v. fig. 1. Gault, Folkestone, fig. 1.

This specimen measures 5 centimetres in length and nearly 3c. in breadth, though something should be perhaps deducted for the compression undergone. When perfect it was probably composed of 50 to 60 imbricated leathery scales, about half that number being visible on the exposed face. The substance of the scale seems to have been considerable, though the edges are thin; they are smooth even without striæ, and with the upper margin round to obtusely pointed. They are apparently variable in size.

The cone is of the same general type as *P. Andræi*, Coem., from the Gault of La Louvière, Hainault, though somewhat shorter, more oval, and with thinner and rounder scales. The form and general consistence of the scales, as well as their size, the number composing each whorl, and their disposition are, however, so similar that we think it better, in the case of so imperfect a specimen, to unite it rather than claim specific rank on account of distinctions that might largely disappear with more perfect specimens. If the assimilation is correct the apex of the cone, as well as the base, would have been somewhat pointed. The cones are very abundant at La Louvière, more than 100 specimens having been collected; and they are stated to have been frequently curved and highly resinous. The specimen from Folkestone was found by us, being unique from that locality, and is now in the British Museum.

Pinites Valdensis, sp. nov. figs. 4 and 5. Wealden, Brook Point, Isle of Wight.

This fragment shows the presence in the Wealden flora of a Pine of the section *Strobus* with a cone composed of scales as numerous and thin as in any recent species. The cone was long, cylindrical, and tapering, the scales very numerous, permanent, imbricated, leathery, pointed, and lightly thickened at the apex, with entire margin, striated, and slightly keeled. It somewhat resembles *P. Dunkeri*, Carr., also of the Wealden, but is probably a distinct species. The specimen, fig. 5, is from the York Museum, and 4, in which all the scales are mutilated, from the Woodwardian Museum. Both these, with several others, are from the Wealden of Brook, so that it appears to be by no means rare there. It is associated with *Cycadostrobus elegans*, Carr.,[1] a representation of which is given for comparison in fig. 8.

Pinites Carruthersi, sp. nov. Fig. 6. Wealden, Brook Point, Isle of Wight.

The fragment figured represents another long cylindrical cone with very numerous persistent leathery imbricated scales. It tapers like the one last described towards the base, the scales being much thicker, though thin at the edge, smooth, without keel, and with entire rounded margins. It resembles the Gault species *P. Andræi* in texture, but there were at least twice as many scales in each whorl, and these are much more imbricated. It also is quite distinct from *P. Dunkeri*, Carr.

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[1] *Journ. of Bot.* vol. iv. pl. lvii. fig. 9.

It resembles *Cedrus Lennieri*, 'Sap. Veg. foss. de la Craie inférieure des Environs du Hâvre,' *Mém. de la Soc. Géol. de Normandie*, 1877, but is not apparently the same species.

Pinites cylindroides, sp. nov. Lower Greensand, Potton. Figs. 2 and 2a.

This is an almost perfectly cylindrical specimen, being very slightly thickened towards the base, 7 centimetres in length and 22 millim. in diameter, composed of about 96 scales, arranged in 12 rows from left to right, and 8 rows from right to left, the arrangement thus being $\frac{8}{12}$. The scales are short and at right angles to the axis, with a smooth flat half-moon-shaped apophysis or scale-head, now gaping, but evidently imbricated before the seeds were shed. The scales become very small towards the base. The summit is abraded, exposing the end of a somewhat slender axis, fig. 2a. Certain grooved lines on the sandy matrix between the scales show that the cone was furnished with foliaceous bracts, and the marks of a boring insect are visible. The specimen, which is quite distinct from any other fossil or recent cone, is singularly elongated and cylindrical, scarcely tapering at all from the base upward. It is fortunately in excellent condition, certainly not derived from any older bed, like so many of the Potton fossils, and is well cared for in the Woodwardian Museum.

Pinites Pottoniensis, sp. nov. Fig. 3. Lower Greensand, Potton.

The fragment figured, though much mutilated, fortunately shows the characteristically winged seeds of *Pinus* in the most perfect manner, entirely removing any lingering doubt as to the occurrence of representatives of true *Pinus* as low down as the Neocomian. The scales were set at an acute angle with slightly thickened recurved apophyses, the form of which cannot clearly be made out, though they appear to have been narrow, keeled, and mucronate. It nearly resembles a type very common in the Eocene, and is of great interest in many ways. It also is in the Woodwardian Museum, and was obtained from the same formation.

The specimen, fig. 7, evidently represents a third species from the Wealden of Brook, with scales very closely resembling a common Barton and Bracklesham type, but its fragmentary condition scarcely renders it advisable to attach any specific name to it.

The accompanying list comprises all the British Cretaceous Coniferæ previously known, up to the present date, though there is no doubt that many new and undescribed forms must exist in collections.

List of British Cretaceous Coniferæ previously described.

Pinites Fittoni, Carr., Purbeck, 'A Cone,' Fitton, 'Geol. Trans.' 2nd ser. vol. iv. p. 230, pl. xxii. fig. 9. Dammarites, 'Ung. G. et spec. Plant. foss.' p. 384. Pinites, 'Geol. Mag.' vol. iii. p. 543.

P. Mantellii, Carr., 'Geol. I. of W.' 2nd ed. p. 452, 3rd ed. p. 337, pl. xlii.; and Carr. 'Gym. Fruits,' 'Geol. Mag.' vol. iii. p. 543, pl. xxi. fig. 3, Tilgate.

P. patens, Carr. id. p. 543, pl. xxi. fig. 4, Tilgate.

P. Dunkeri, Carr. id. p. 542, pl. xxi. figs. 1, 2, Brook. Abietites, Mant. 'Geol. I. of Wight,' 2nd ed. p. 542.

P. Sussexsiensis, Carr. Zamia, Mant. 'Quart. Journ. Geol. Soc.' vol. ii. p. 51, pl. ii. fig. 1; Zamites, Morris Cat.; Zamiostrobus, Goepp. 'Ueber Schless. Gesellsch.' 1844, p. 129; Pinites, Carr. 'Geol. Mag.' vol. iii. p. 541, pl. xx. figs. 5, 6.

P. elongatus, Endl. 'Synop. Conif.' p. 286; Strobilites, Lind. and Hutton, 'Foss. Flora,' vol. ii. p. 23, pl. xxix.

P. Leckenbyi, Carr. Pinites, 'Geol. Mag.' vol. vi. p. 2, pl. i. figs. 1–5, Shanklin.

Abietites Benstedi, Goepp. Abies, Mant. 'Quart. Journ. Geol. Soc.' vol. ii. p. 51, pl. ii. fig. 2, 1846. Pinites, Carr. 'Journ. Bot.' Jan. 1867; 'Geol. Mag.' vol. iii. p. 541; Abietites, Goepp. 'Foss. Conif.' p. 207.

A. oblongus, Goepp. Abies oblonga, Lind. and Hutt. vol. ii. p. 155, pl. cxxxvii. Supposed to be from Greensand, near Lyme Regis; described by a misprint as from 'Dresent,' instead of 'present' shore. Elate, Unger, 'Syn.' p. 199. Abietites, Goepp. 'Foss. Conif.' p. 207. Pinites, Endl. 'Synop. Conif.' p. 283; Carr. 'Geol. Mag.' vol. iii. p. 541. (Professor Williamson is describing a magnificent specimen of this or an allied form.)

Pinites gracilis, Carr. Gault, Folkestone, 'Geol. Mag.' vol. vi. p. 2, pl. i. fig. 9.

P. hexagonus, Carr. id.[1] vol. viii. p. 540, pl. xv.

Sequoiites Gardneri, Carr. id. vol. vi. p. 2, pl. i.

Sequoiites ovalis, Carr. id. vol. viii. p. 542.

Sequoiites Woodwardii, Carr. id. vol. iii. p. 544, pl. xxi. figs. 11–16, Blackdown.

We have now dealt with the more highly organised of our Mesozoic plants, and pass on to those of the Eocene.

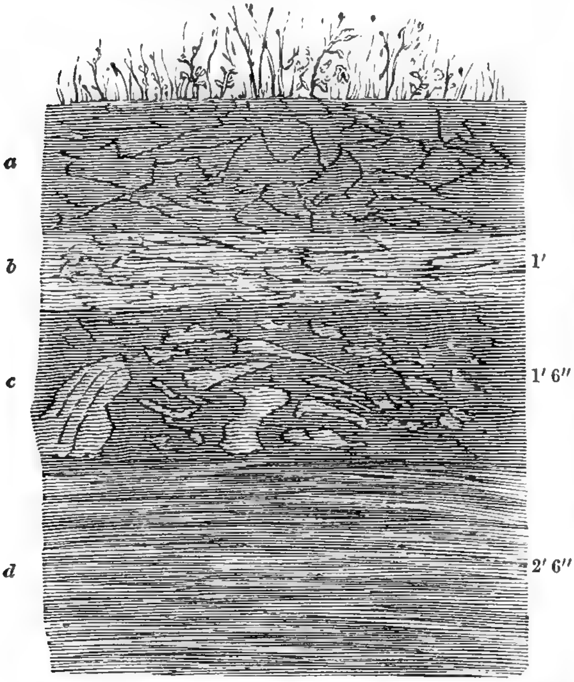

FIG. 1.—Section at Colden Common, near Winchester.

London Clay (3 feet).—*a.* Very sandy clay, mottled yellowish and pale drab.

Reading Beds (5 feet).—*b.* Very plastic clay, of pale drab colour. *c.* Ferruginous sand with sea shells,[2] occasional pebbles, enclosing rolled fragments of pale drab clay with fossil leaves. *d.* Imperfectly stratified grey loamy sand.

Among the most interesting of recent discoveries is that of plant-remains in a small sand-pit at Colden Common, between Bishopstoke and Winchester, the first locality in the Hampshire basin that has yielded any of Woolwich and Reading age. This was first communicated to us by Mr. Whitaker, who thought the leaves might prove to be of London Clay age. They are, in fact, actually included in its basement bed, and mingled with casts of marine shells and sharks' teeth, but the blocks of clay with leaves are derived, though other unfossiliferous clay-seams are *in situ*. If not of London Clay age, however, they are much nearer to it than the Reading flora,

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[1] Far larger specimens than that originally described, one 8 inches long by $1\frac{3}{4}$ inch in diameter, have since been found.

[2] *Cardium Laytoni, Panopæa, Cytherea, Pecten, Thracia? Trigonocœlia, Natica?* Sharks' teeth.

which occurs below the great mass of mottled clay, whilst these lie above it as shown in the accompanying sections. The plants show in the main, as might be anticipated, an approach to the Alum Bay flora, which is still higher and above the London Clay; but whether these leaves are connected in any closer degree with the fruits of Sheppey than are those from Woolwich, Croydon, or Bromley is a question which we have not as yet the data for answering. There are, at all events, no remains of Palms among them, and this, so far as it goes, is against the connection; but on the

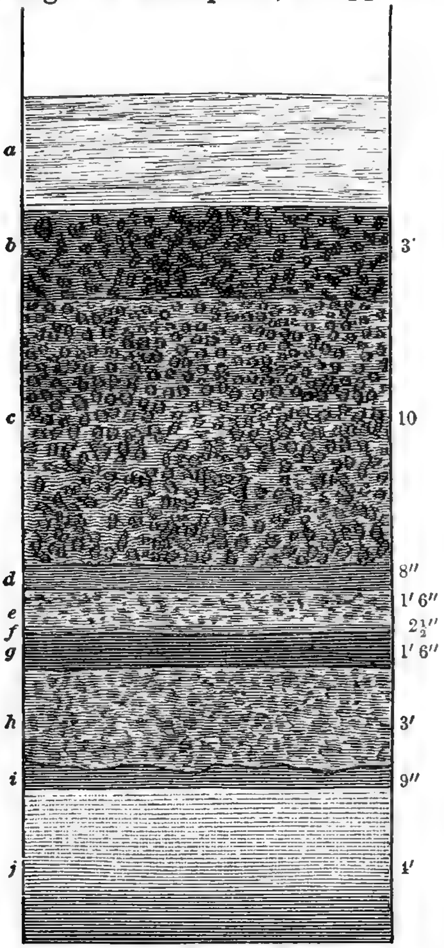

FIG. 2.—Section at Katesgrove, Reading.

London Clay.—*a.* Unctuous laminated clay, whitish, slightly mottled orange with well-defined base. There is only about 3 feet exposed here, but it becomes very fossiliferous nearer Reading, containing *Ostrea*, *Pectunculus*, *Cytherea*, *Natica*, *Voluta*, &c.

Reading Beds.—*b.* Stiff clay, mottled slate and chocolate colours, 3 feet. *c.* The same with the addition of crimson, 10 feet. *d.* Dark greenish-grey clay, about 8 inches. *e.* Stiff clay, mottled bright pink and drab, 1 foot 6 inches. *f.* Same as *d*, 2½ inches. *g.* Ditto of dark crimson colour, about 18 inches. *h.* Yellow and drab mottled clay with traces of red, 3 feet. *i.* Clayey sand, warm grey colour, about 9 inches. *j.* Ditto, of greenish yellow passing into buff sand, becoming mottled greenish at base, about 4 feet exposed. The leaf bed is a little below this.

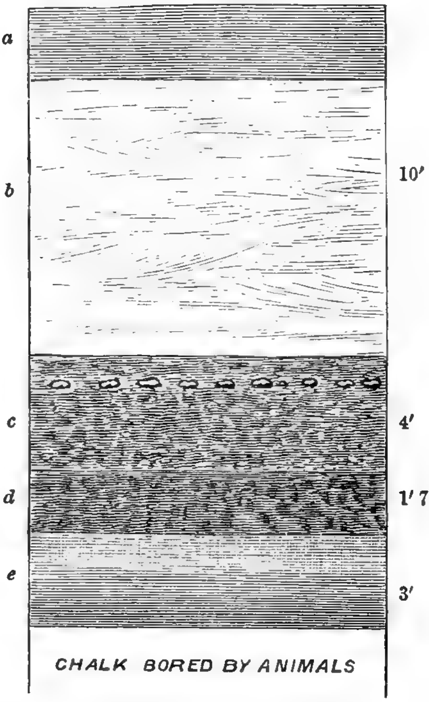

FIG. 3.—Section at Coley Hill, Reading.

Reading Beds.—*a.* Mottled clay.[1] *b.* Current-bedded sand, white to buff, with occasional galls and lenticular patches of clay, in some of which indistinct willow-like leaves occur.

Thanet Beds.—*c.* Clayey sand, greenish in colour, with layer of irony concretions, 4 feet. *d.* Dark slate-coloured clay, piped with ochreous sand, 1 foot 7 inches. *e.* The oyster bed, at first stiff dark clay with strong line of oysters, and sub-angular pebbles, then the same clay with bore-holes of green sand, becoming sandy at base with green-coated flints.

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[1] This in places is dovetailed into the sand, which sometimes thins considerably, though the mottled clay never rests directly on the Thanet beds.

other hand the fruits of an *Alnus*, like that from Swale Cliff, abound. There is no large variety among the leaves, the majority being large and simple, but with highly serrate margins, and the species will not be found to exceed 12 or 14 in number, including *Platanus*, which is rare.

Though we have continued to collect the Reading, we have been unable so far to determine any new species. The assemblage of fruits at Sheppey on the other hand becomes of increasing interest, and has proved unexpectedly rich in Palms, many of them apparently identical with existing species which are now found growing in the remotest regions.

Besides the large variety of Nipas, which are still met with in enormous abundance among the seed-vessels of the New Guinea drift, we have seeds indistinguishable from *Verschaffeltia splendida*, endemic to the Seychelles, from *Sabal Blackburniana* of the Bermudas, from a *Desmoncus*, an *Areca*, a *Monodora*, and probably of many, certainly of some other Palms. When we consider that probably many of the kinds of Palm fruits would sink at once, we realise how great an assemblage of this magnificent family is indicated by the Sheppey drift.

The difficulties we fear of determining anything but a fraction of the Sheppey fruits must prove insurmountable. Their outer coats are for the most part destroyed, and some part of their inner structure, nearly always quite different in form from that which is external, is revealed. Botanists have been able to determine but few of the drifted fruits brought home by the *Challenger*, though these are more perfect and of living species belonging to definite and known floras.

The Bournemouth cliffs continue to furnish fresh forms, though the leaf-beds are becoming more and more difficult of access. We have especially enriched the series of *Smilaceæ*, and a complete account of them has been presented to the Linnean Society. The series now obtained falls little short of a hundred specimens, and is by far the richest of fossil Smilaceæ, perhaps of any family, ever brought together. Such a material has enabled us to reduce the number of distinct species to no more than five, most of which are represented by foliage in all stages of development, from the largest leaves measuring several inches, down to quite minute leaves from near the extreme growing points. The necessity for such extensive series when dealing with fossil leaves may not at once be apparent, but the President of the Linnean Society expressed the opinion at the meeting that out of less material not five but five-and-twenty species might have been made.

The leaves of Smilaceæ are highly characteristic, and can be determined with a large degree of certainty; but it is quite improbable that such will be the case with very many of the families of Dicotyledons. There is indeed little hope that more than a very few can be determined with anything like the precision required for botanical purposes, unless we can call in aid the fruits or some other organs. Thus if we may base a conclusion upon the large number of the characteristic bracts, which envelope the seed in a section of *Flemingia* that are met with in the Bournemouth flora, the leaves of that genus should be far from uncommon, and they should also be found in the Swiss Oligocene, yet no species of Flemingia has ever been recorded from the Tertiaries. The leaves, however, may perhaps be sought for among the species of *Populus* and *Carpinus*.

Fortunately fruits and even flowers are comparatively abundant at Bournemouth, and we consequently anticipate little difficulty in determining leaves belonging to such easily distinguishable fruits as *Alnus*, *Tilia*, *Acer*, *Carpinus*, the *Leguminosœ*, and many others, but the residuum with indeterminable fruits, or fruits that will not float, may be very large. We are thus brought to the question, whether any value beyond that of mere landmarks, or aids to the correlation of rocks, can be attached to the determinations of fossil dicotyledonous leaves arrived at when fruits are absent. Nearly every Tertiary and even many Cretaceous floras are said to comprise *Quercus*, *Fagus*, and *Corylus*, to select these as typical examples. Now, we very much doubt whether the fruits of these genera have been met with in any strata older than the Upper Miocene, we might almost say the Pliocene; whilst in the latter the fruits of at least two of them are very far from uncommon. Fossil hazel-nuts are well known to abound in forest beds such as the one at Brook, in the Isle of Wight, and at Carrickfergus. It does appear to us that it would have been wiser and more consistent, when arriving at these determinations, to have taken the absence of fruits into account, when these were such as would naturally have been preserved. The large proportion of fossil dicotyledonous leaves that have been referred without any hesitation to living genera must strike everyone, in comparison with the relatively few associated fruits that have been determined otherwise than as Carpolithes—a name which is a confession of failure. It will thus be seen that in our opinion the fossil Dicotyledons of our own Eocene must be dealt with in a manner different from that pursued by the majority of foreign writers on kindred subjects, and that a revision of much of their work is urgently needed.

To resume our immediate subject, we have nothing new to record of the Bracklesham flora except that Mr. Elwes, in excavating in the New Forest, met with Nipadites in some abundance, and a specimen he still has proves the species to be the same as that from Bracklesham Bay, and entirely different from that which forms a conspicuous zone in the marine series of the Bournemouth group.

At Barton, on the other hand, we have been able to procure nearly a dozen pine-cones, hitherto a great desideratum, from the Highcliff beds, which go far to prove that there is only one variety there, indistinguishable from the *Pinus Dixoni* of Bracklesham. Along with these we have branches of apparently the Bournemouth *Araucaria*, and an important and entirely new fruit, fortunately represented by many specimens, which permit us to examine the details of their structure. These consist of twigs on which are seated in some profusion clusters of numerous sessile woody pericarps with deeply laciniate margin, giving the fruit when closed the appearance of a large burr. These enclose a nut or seed, rather smaller, but otherwise resembling that of a cucumber. There has not yet been time to make the researches necessary to come to a conclusion regarding it, and Mr. Carruthers and other botanists who have seen the specimens are unable offhand to pronounce upon its affinities. A rather large fossil plant from the same locality has recently been lent us by the Council of the Hartley Institute, and altogether the plants from this horizon, hitherto very meagrely represented, bid fair to take an important position. On the other hand, the Hordwell end of the same section, though twice visited since our last report, has furnished nothing new.

We have fortunately met with a few very distinctly marked leaves from the Middle Headon of Headon Hill, preserved in the York Museum, which with those previously obtained from the Lower Headon of Hordwell, help to bridge over one of the few gaps in our really surprisingly complete succession of Eocene floras.

We have continued to investigate the great series of plant remains so assiduously collected by Mr. A'Court Smith, and with this object have visited Gurnet Bay, as well as receiving several packages of fossils from that place. While lamenting that they are of so fragmentary a nature, we cannot overlook their importance as almost the last representatives of the great series of floras which maintained themselves in our area throughout the Eocene time. As an illustration of their value we may instance the fact that while anything like true grasses seem to be wholly wanting in the previous floras, there are many more or less definite indications of them in this. We have reason to hope that renewed working in the still younger beds of Hempstead may lead to further discoveries, for, besides the better known plants described by Heer, pine-cones and a fine aroïdeous fruit have been obtained from them.

EXPLANATION OF PLATE.

1. *Pinites Andræi*, Coemans, from the Gault, Folkestone (British Museum).
2. *P. cylindroides*, sp. nov., from the Lower Greensand, Potton (Woodwardian Museum).

2*a*. End of axis, with scales of same.

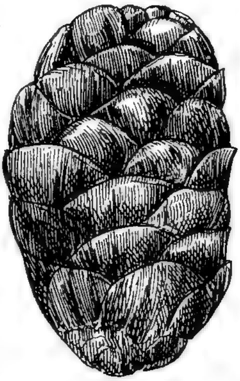
3. *P. Pottoniensis*, sp. nov., from the same (Woodwardian Museum).
4. *P. Valdensis*, sp. nov., from the Wealden of Brook Point (Woodwardian Museum).
5. Another specimen (York Museum).
6. *P. Carruthersi*, sp. nov., from the Wealden of Brook Point (Woodwardian Museum).
7. *Pinites*, from the Wealden of Brook Point (Woodwardian Museum).
8. *Cycadostrobus elegans*, Carr., from the Wealden of Brook Point (Woodwardian Museum).

The figures are about two-thirds the natural size.

Report of the Committee, consisting of Professor McKENDRICK, Professor CLELAND, *and* Dr. McGREGOR-ROBERTSON (*Secretary*), *appointed for the purpose of investigating the Mechanism of the Secretion of Urine.*

YOUR Committee have to report as follows:—A method of procedure, and various points to be determined as to the proportion of the several constituents of the urine in different states of the kidney and under the influence of drugs, have been decided on, and the microscopical examination of the kidney after certain experiments has been undertaken; but the progress of the investigation was hindered by unavoidable circumstances. Your Committee therefore respectfully request to be reappointed.

British Cretaceous Cones.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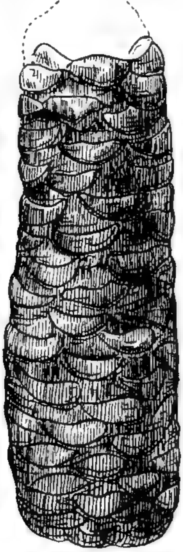
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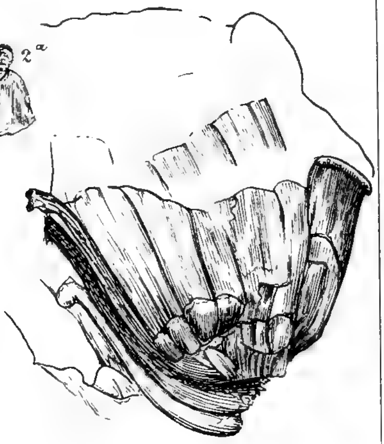
2a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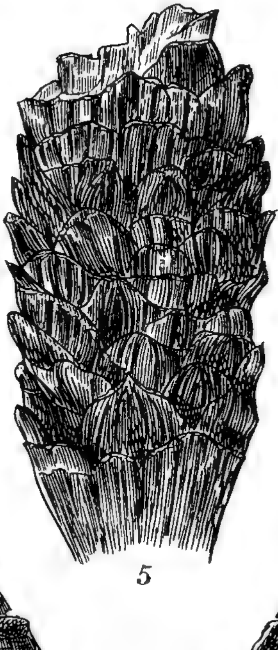
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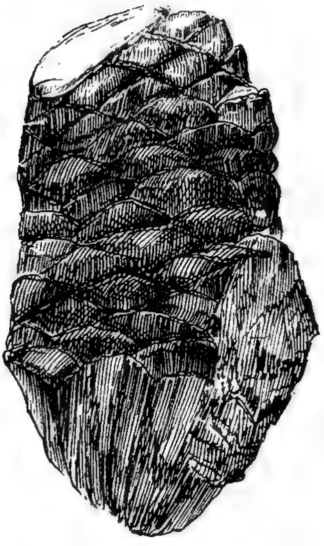
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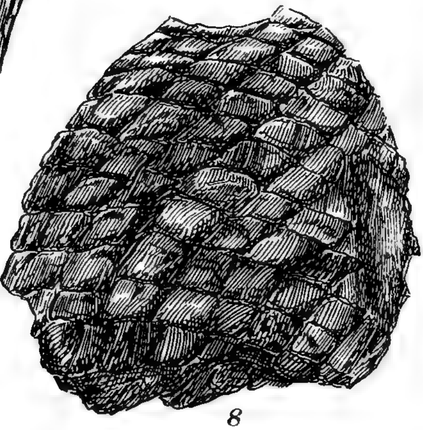
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Illustrating the Second Report on the Fossil Plants of the Tertiary and Secondary Beds of the United Kingdom.

Report of the Committee, consisting of Professor McKendrick, Professor Struthers, Professor Young, Professor McIntosh, Professor Alleyne Nicholson, Professor Cossar Ewart, *and* Mr. John Murray (*Secretary*), *appointed for the purpose of promoting the establishment of a Marine Biological Station at Granton, Scotland.*

The Committee report that the sum of 75*l.* placed at their disposal has been used to aid in defraying the expenses of carrying on the work of the Scottish Marine Station at Granton. Two reports on the work of the institution during the past year are given below; they have been sent in to the Secretary by Mr. J. T. Cunningham, the Superintendent, who has charge of the zoological investigations; and Dr. Hugh Robert Mill, who is responsible for the physical work:—

The Biological work of the Station falls into three principal divisions: (1) Embryology and Morphology, (2) Faunology, (3) the accommodation of students and investigators.

(1) Efforts to elucidate some facts bearing on the reproduction and development of Myxine formed the principal part of the work under this head during the autumn and winter. In the summer the aquarium had been arranged, and a large tank was specially devoted to the purpose of keeping specimens of the animal in confinement. After careful attention to the matter it was found that the creatures refused entirely to feed while in captivity; they lived several months, but no signs of reproductive activity appeared, with one exception noted below. It was then determined to continue the examination of large numbers of specimens every month in the year in order to find if the ova were shed at any limited season. As almost nothing accurate was known on the whole subject, the first problem was to obtain ripe males and females. In November the testis in its immature condition was recognised, and it was subsequently found that with few exceptions all very immature specimens were hermaphrodite, containing immature testicular tissue at the posterior end of the generative organ. Microscopic examination of the largest ova obtained showed that the well-known polar threads belonged to the vitelline membrane, and were developed in tubular depressions of the follicular epithelium. In December, January, February, and March females were obtained which had just discharged their ova, the collapsed capsules, still quite large, being present in the ovary. At the end of January two females were obtained in which the polar threads were so far developed as to form projections at the ends of the enclosing follicle. One specimen with eggs in this condition was taken from the aquarium. No perfectly ripe ova were ever obtained. In February moving spermatozoa were discovered in hermaphrodite specimens, but the total quantity of milt present was quite insignificant. The greater number of the specimens examined were obtained from fishermen's lines baited for haddock; some were taken by baited traps. In March dredging was carried on off St. Abb's Head, with a view to obtain deposited fertilised eggs of Myxine, but none were found. It has thus been shown that Myxine deposits its eggs in the months of December to March, and that the females are taken on the hook immediately after the eggs have been shed. But no method has been dis-

covered of obtaining adults in the ripe condition, or of obtaining the fertilised ova and embryos. The research and its results are described in a paper in the 'Proceedings of the Royal Society of Edinburgh,' and more fully in a paper which will appear in the next number of the 'Quarterly Journal of Microscopical Science.'

At the beginning of the present year the systematic examination of the ova of all species of fish which could be obtained was commenced. The pelagic ova of the cod, haddock, whiting, and gurnard had been examined in the previous spring, and those of a large number of additional species have now been figured and described at successive stages of development. The results of this work are now being published in full by the Royal Society of Edinburgh, and will appear as a memoir in the Society's 'Transactions.'

(2) The Faunological investigations have been carried on as time permitted since the opening of the Station, and have, since June last, been receiving particular attention. A report on the Chætopoda, in the preparation of which Mr. G. A. Ramage is giving his assistance, will appear in the coming autumn; a report on the Sponges is being prepared by Mr. J. Arthur Thomson; and miscellaneous notes on other classes will be incorporated with these special reports.

(3) The following is a list of those who have carried on studies at the Station:—

	Name	Began	Left	Subjects
1885.	Dr. Kelso, Edinburgh . .	August .	September 26 .	Teleostean ova.
	And. D. Sloan, Edinburgh .	August 8 .	April 1886 .	Cœlenterates.
	A. H. W. Macdonald, Edinburgh	October 5 .	November 1885	General.
	G. L. Gulland, Edinburgh .	October 6 .	November 1885	Crustacea.
1886.	G. A. Ramage, Edinburgh .	June 3 .	—	Chætopoda, &c.
	J. M. M. Kay, Edinburgh .	July 24 .	—	General.
	Miss Macomish, London .	August 2 .	—	Mollusca.
	J. Arthur Thomson, Edinburgh	August 9 .	—	Sponges, &c.

The yacht is kept up in the same condition as at the opening of the station, and the number of men is unaltered. The ark at Millport is again in use this summer, and is in the charge of Mr. David Robertson. Mr. Cunningham worked there for one week in June, having found at Millport a particularly favourable opportunity for the study of Teleostean ova. Many other naturalists have taken part in the *Medusa's* dredgings in the Clyde district during the present summer. The services of Alex. Turbyne, the keeper of the Station, in making excursions in trawlers to procure fish ova, have been most valuable. All those interested in the Station are greatly indebted to Mr. Robert Irvine, of Royston, for the friendly assistance which he has always been ready to afford on every occasion.

Preserved specimens of marine animals and plants are still sent out to applicants, and some attention is being paid to the question of oyster cultivation in the Firth of Forth.

J. T. CUNNINGHAM, B.A., F.R.S.E.

Physical marine research has from the commencement formed one of the distinctive features of the Scottish Marine Station. During last year work has been carried on in this direction by Dr. H. R. Mill and Mr. J. T. Morrison; other gentlemen have occasionally made use of the facilities of the Station.

Regular meteorological observations are continued twice daily, and include the temperature at surface and bottom of the water. An elaborate set of experiments with Mr. John Aitkin's new forms of thermometer screen were completed last year by Mr. H. N. Dickson. Experiments with various anemometers are still in progress.

Atmospheric dust is being collected on several islands in the Firth of Forth by means of large funnels and carboys, which are periodically emptied and the contents forwarded to Mr. Murray for examination.

Monthly trips along the Firth of Forth for the observation of temperature and salinity have taken place regularly from river to sea; preliminary results have been communicated to the Royal Society of Edinburgh from time to time, and a complete discussion of salinity is nearly ready for publication. It shows remarkable relationships between salinity and configuration, which have suggested new definitions of the words *river*, *estuary*, and *firth*. Special attention has been devoted to the relation of salinity and temperature to tide in the estuary of the Forth. Besides the observations of the scientific staff of the Station, thermometer readings are taken by volunteer observers at different parts of the Forth river-system and in the adjacent parts of the North Sea.

The *Medusa* has made regular trips on the Clyde since April last at intervals of two months. Temperature and salinity observations are made in all parts of the estuary and firth from Dumbarton to the North Channel, and in all the connected lochs. These trips have yielded results of great interest and novelty. They are communicated in several papers to various sections of the present meeting.

The temperature of two deep fresh-water lakes—Loch Lomond and Loch Katrine—has been observed at all depths once a month since November 1885, in continuation of Mr. J. Y. Buchanan's work.

Daily temperature observations have been established on a number of rivers and at several points on some. The Station has charge of observations on the Thurso, in the north of Scotland, the Forth and Teith, and the Tweed; and it has also been the means of inducing independent observers to undertake similar work on the Tummel (a tributary of the Tay), the Tay, and the Derwent, in Cumberland. These are all salmon rivers, and the observers being interested in fishing have already succeeded in showing some connection between temperature and the movements of salmon.

In consequence of experience gained in physical marine investigations the apparatus used for the purpose has been progressively modified and improved—the Scottish thermometer-frame and water-bottle may be pointed to as special instances.

The Station has, since September 1885, been able to advise and assist several public bodies in starting observations of temperature and salinity, the National Fish Culture Association of England, the Dundee Harbour Trust, and the Fishery Board for Scotland being amongst the number. Thermometers have been lent to several naturalists for use on short scientific voyages.

The collection of all existing records of sea and river temperature round the coast of Scotland is proceeding, and promises when completed to be of great value in showing the different sea-climates of the east and west coasts—a question of much importance in relation to the distribution of marine species.

HUGH ROBERT MILL, D.Sc., F.R.S.E.

The Committee beg to recommend that a grant of 100*l.* be made for the maintenance of the Station during the ensuing year.

Report of the Committee, consisting of Professor RAY LANKESTER, Mr. P. L. SCLATER, Professor M. FOSTER, Mr. A. SEDGWICK, Professor A. M. MARSHALL, Professor A. C. HADDON, Professor MOSELEY, *and* Mr. PERCY SLADEN (*Secretary*), *appointed for the purpose of arranging for the occupation of a Table at the Zoological Station at Naples.*

YOUR Committee regret to report that, in consequence of the insufficient grant voted for their use at the Aberdeen meeting of the British Association, they have been placed, during the past year, in a very difficult and undesirable position. Indeed, if they had not been met in the most generous spirit by Professor Dohrn, the Committee would have been unable to carry out the purpose for which they have been appointed during a number of successive years.

The following are the facts of the case. Tables in the Zoological Station at Naples are let to foreign Governments and scientific bodies for periods of not less than one year, and at a fixed annual rental, which has for some time been established at 100*l.* The table previously at the disposal of the Committee had been hired on these terms. At the Aberdeen meeting of the Association, held last year, the sum of only 50*l.* was entrusted to your Committee, and they were consequently unable to hire a table in the usual way. Several informal communications passed between the Committee and Professor Dohrn, and culminated in the two letters subjoined, which your Committee submit for the consideration of the Council.

'Ewell, Surrey: *November* 28, 1885.

'DEAR SIR,—I am directed, as Secretary of the Committee for arranging for the occupation of a table at the Zoological Station at Naples, to acquaint you with the fact that the Committee have been entrusted only with 50*l.* this year by the British Association, which they much regret.

'They are aware that it is impossible that you should depart from the principle of the Institution which you have founded, and that you would compromise its interests by letting a table for less than a year, or for less than the regularly established sum of 100*l.* They therefore propose to present the sum of 50*l.* to the Direction of the Zoological Station of Naples without any stipulation; but I am instructed to add that they hope, should a naturalist approved by the Committee desire to visit Naples during the year, that you will be able to receive him as a guest for such period as may be convenient to your arrangements.

'In the meantime the Committee desire me to assure you that they will use their best efforts to obtain next year the usual grant, which will enable them to lease a table at the Naples Station in the usual way. They further beg you to be assured that the project of the Marine Biological Association for erecting a laboratory at Plymouth has not been the cause of the insufficient grant made by the British Association at Aberdeen, since no grant was applied for or assigned to the Plymouth enterprise this year.

'I am, dear Sir,
'Yours very faithfully,
'W. Percy Sladen,
'*Sec. to the Committee.*

'Prof. Anton Dohrn.'

'Naples: *December* 5, 1885.

'Dear Sir,—In acknowledging the receipt of your communication, dated November 28, on behalf of the Committee for arranging for the occupation of a table at the Zoological Station at Naples, I find it difficult not to begin with the expression of the sincerest gratitude both for the grant of 50*l.* and for the tenor of the communication which informs me of the condition under which the grant is tendered to me. I cannot but consent at once to the propositions the Committee makes therein; and I shall be doubly pleased if you should have to announce to me at the earliest possible date the arrival at Naples of a naturalist whom the Committee desires to see installed at the table, and who will be sure to receive the full share of the advantages which the Zoological Station, its staff, and myself may be able to give him for his scientific work.

'It is a great satisfaction to me to be assured by the Committee that they will use their influence to continue the table in the usual way. Indeed, as you say, it is essential for the existence of the Zoological Station that the regulations hitherto observed should be maintained. The system of letting tables to different Governments or scientific bodies has been introduced as the best possible means to guarantee the existence of an institution which it would have been difficult to create in any other way on so large a scale.

'It seems to me beyond doubt that in creating and continuously strengthening one great central institution, a greater good to science is secured than by promiscuously attempting to establish smaller laboratories on different points of the European coast, without carefully weighing whether such laboratories offer any special advantage, and can be carried to a state of really efficient working order. If available funds existed, every university—nay, every zoologist—might establish a seaside laboratory for his own private use, and thus pursue with all possible advantage his favourite lines of research. But, as it is, such funds are not ready, and nobody, I dare to say without presumption, can judge better about the difficulties of making them forthcoming than the writer of these lines. The Zoological Station of Naples represents up to this date a capital of 20,000*l.*, and has to provide for a yearly budget of 6,000*l.* to 7,000*l.* The efforts it has cost to secure these sums have been considerable. I may be permitted to state that it took seven or eight years of persevering effort to add the recently acquired 4,000*l.* for the creation of the new physiological laboratory now in course of construction, and I look forward to considerable effort being needed to secure adequate annual sums for working it. It would take more than double the amount of money to create the same facilities for physiological research at any other seaside place, and a much greater annual outlay to carry it to the perfection which may be readily attained by the establishment of this new physiological laboratory as part of the already extensive Naples Zoological Station.

'In stating that the proposed Marine Laboratory at Plymouth did not cause the diminution of the grant for the Naples Station, the Committee seems to place itself on the same principle which I am advocating, viz., that whatever may be the advantages of a greater number of local zoological stations, they can hardly supersede the importance of having access to the greatest and most effective establishment of the kind; and by giving that access to British naturalists also secure the welfare and ever-increasing efficiency of this central biological institution, which to conduct to its highest level will always remain the chief duty of

'Yours sincerely,
'Prof. Dr. ANTON DOHRN.

'W. PERCY SLADEN, Esq.,
'*Secretary to the Committee of the British Association.*'

Your Committee beg to direct the attention of the Council to the liberal manner in which Professor Dohrn has assisted them by generously placing at their disposal the resources of the station as unreservedly as if a table had been hired in the usual way and the customary contribution had been paid.

Your Committee trust that the Council will not again leave them with a sum insufficient for the hire of the Naples table, and desire to state that they would not be able again to propose such terms to Professor Dohrn as they have done this year.

The Committee would suggest that all sums granted by the Association for the prosecution of marine biology should be assigned in the first instance to the present Committee, and voted in one sum. And they would propose now a grant of 200*l.*, of which 100*l.* should be appropriated for the hire of a table in the Zoological Station at Naples, and 100*l.* for the Plymouth laboratory of the Marine Biological Association.

The General Collections.—The extensive series of marine organisms collected by officers of the Italian navy, mentioned in the last Report, have been placed in the hands of specialists for investigation. The distribution of the collections was undertaken by a Committee appointed by the R. Accademia dei Lincei of Rome, by whom the material has been confided to about sixty naturalists in Belgium, Denmark, Germany, England, Holland, Italy, Austria, Hungary, Russia, and Switzerland. Very few specimens now remain undistributed. The Committee placed no restrictions of any kind upon the use of the material, requesting only the return of specimens not needed for investigation.

The Publications of the Station.—The progress of the various works undertaken by the station is here summarised:—

(1) Of the 'Fauna und Flora des Golfes von Neapel' the following monograph has been published since the last Report:—XIII. Karl Brandt, Koloniebildende Radiolarien (*Sphærozoëa*) (276 pp., 9 plates).

The following works are in the press:—J. Fraipont, 'Polygordius'; H. Eisig, 'Capitellidæ.'

Monographs by G. von Koch on 'Gorgoniidæ,' by P. Falkenberg on 'Rhodomeleæ,' and by J. W. Spengel on 'Balanoglossus' will subsequently appear, the plates being now in the press.

(2) Of the 'Mittheilungen aus der Zoologischen Station zu Neapel' vol. vi. is completed (756 pp., 32 plates).

(3) The 'Zoologischer Jahresbericht' for 1884 (1499 pp.) is published. The editors and the general arrangement of the sections are the same as in the preceding year. The 'Bericht' for 1885 is in the press. The index (register) will be given in greater detail than in previous years.

(4) Of the Guide to the Aquarium (printed in German, English, Italian, and French) a second Italian edition has been published.

Extracts from the General Report of the Zoological Station.—The officers of the station have courteously furnished lists (1) of the naturalists who have occupied tables since the last Report, (2) of the works published during 1885 by naturalists who have worked at the Zoological Station, (3) of the specimens sent out by the station during the past year. These details, which will be found at the end of this Report, are the strongest evidence of the activity and efficiency of the institution.

The British Association Table.—During the past year Dr. Robert Scharff, who had been nominated by your Committee, has been kindly allowed by Professor Dohrn to occupy a table for a period of nearly six months (December to May), in accordance with the generous undertaking contained in his letter already quoted. Dr. Scharff has been engaged in several important investigations, the results of which he hopes to publish during the coming winter. His report on the occupation of the table is appended.

I. *Report on the Occupation of the Table, by* Dr. ROBERT SCHARFF.

I commenced my studies at the Zoological Station by taking up the small group of the Chlorhæmidæ. Several species of this group of marine Annelids are pretty abundant in the bay, such as *Siphonostoma diplochætum* and *Stylarioides monilifer.* I examined a number of them anatomically, but before I had quite concluded my researches my attention was drawn by Professor Dohrn to a more interesting field of study, namely, the gills of Elasmobranch fishes.

Since the publication of the series of articles on the origin of Vertebrates by Professor Dohrn, anything regarding the development and structure of the gills of fishes has been received with much greater interest by scientists than formerly. Several organs having now quite a different function are stated by Dohrn to have been merely gill-clefts in the ancestral vertebrate. Thus the mouth was primitively a pair of gill-clefts which have coalesced and come to open in front. The organ of smell is also supposed to represent a gill-cleft. With regard to the mouth, strong additional support is given to Dohrn's theory by Beard's researches on the 'Branchial Sense-organs in Ichthyopsida.' On the other hand, Blaue's as well as Beard's discoveries do not lend any support to the view of the nose having been a gill-cleft.

I merely mentioned these facts, without going into further details, in order to show the importance of having an exact knowledge of the histological structure of the gills in order to be able to compare it with that of the other organs mentioned.

In the investigation I carried on at Naples during several months the gills of the following Elasmobranch fishes were examined, both fresh and preserved:—

Scyllium catulus.
— *canicula.*
Trygon violaceus.
Raja asterias.
— *clavata.*
Torpedo ocellata.
— *marmorata.*
Squatina angelus.
Mustelus lævis.
— *vulgaris.*

The general structure and anatomy of the gills are of course well known, and have been the subject of several important papers.

The gills of sharks and rays are easily distinguished from the corresponding organs of Ganoids and Teleosteans. While the rows of branchial leaflets, which are placed upon the branchial arches in the latter two groups project freely into a common cavity covered by the operculum, in the Elasmobranchii they are distributed in separate branchial sacs. Every one of these sacs also has its own opening to the exterior. As in Teleosteans, the branchial leaflets are provided with secondary folds at their sides, in which the true branchial capillaries are to be found, and thus form the principal respiratory surface.

The whole branchial leaflet has the form of the blade of a knife. The base is taken up by the artery, the free margin by the vein. The triangular shape of the cross-section is somewhat interfered with by the above-mentioned lateral folds, which are placed upon the sides at right angles. They appear as semicircular flaps. The gills, as well as the gill-clefts, contain a large number of mucous cells in their outer cellular layers. As far as I have been able to make out, there are no special cells having a sensory function. In adult gills there are no ciliated cells; in the fully grown embryo of *Mustelus*, however, the cells covering the lateral flaps of the branchial leaflets were ciliated. At the margin of the gill-cleft I also observed ciliated cells.

One of my principal objects in studying the gills of Elasmobranch fishes was to find out the nature of the nerve-endings. I regret that, although I tried a large number of different methods, and much time was spent over it, I was not successful. For general purposes, however, I can recommend the following method of staining with chloride of gold, which did me more good service in tracing nerves than Ranvier's or any of the other methods:—

'Place the small object in a watch-glass-full of $\frac{1}{2}$ per cent. chloride of gold, and add one drop of hydrochloric acid. Leave this in the dark for about half an hour; then, after washing out with water, put the object in a mixture of one part formic acid to four parts water, and expose to light until a violet colour appears.'

A more detailed account of the innervation, as well as the structure of the mucous and other cells composing the cellular layers of the gill-cleft and the branchial leaflets, will be published during the course of next winter. I can only give this very short *résumé* at present, having to complete many of my observations by a series of sections which I purpose making shortly.

II. *A List of Naturalists who have worked at the Station, from the end of June* 1885 *to the end of June* 1886.

Number on List	Naturalist's Name	State or University whose Table was made use of	Duration of Occupancy	
			Arrival	Departure
322	Prof. Albini . .	Italy	Jan. 26, 1885	Aug. 22, 1885
323	Lieut. N. Asbeleff .	Russia	July 23, ,,	,, 12, ,,
324	Stud. E. Bornand .	Switzerland . .	Aug. 18, ,,	June 10, 1886
325	Dr. J. H. Wakker .	Holland . . .	Sept. 3, ,,	Dec. 1, 1885
326	Dr. O. Hamann . .	Prussia . . .	,, 24, ,,	Oct. 20, ,,
327	Dr. E. de Daday .	Hungary . . .	Oct. 5, ,,	May 15, 1886
328	Dr. A. Ostroumoff .	Russia	,, 8, ,,	Mar. 10, ,,
329	Prof. W. Krause .	Berlin Academy .	,, 24, ,,	Dec. 31, 1885
330	,, . .	Prussia . . .	Jan. 1, 1886	Mar. 6, 1886
331	Dr. Monticelli . .	Province of Naples .	Nov. 1, 1885	—
332	Dr. T. Balsamo . .	,, .	,, 1, ,,	—
333	Lieut. A. Colombo .	Italy	,, 17, ,,	April 5, 1886
334	Dr. R. Semon . .	Prussia	,, 21, ,,	—
335	Dr. O. Geise . . .	Saxony . . .	,, 25, ,,	June 7, ,,
336	Dr. F. Zschokke .	Switzerland . .	Dec. 4, ,,	,, 8, ,,
337	Dr. A. Tichomiroff .	Russia	,, 11, ,,	May 16, ,,
338	Dr. R. Scharff . .	British Association .	,, 14, ,,	,, 3, ,,
339	Prof. A. della Valle .	Italy	,, 21, ,,	Jan. 17, ,,
340	Prof. W. Preyer. .	Prussia	,, 29, ,,	April 21, ,,
341	Dr. G. Jatta . .	Italy	Jan. 1, 1886	—
342	Dr. J. Raffaele . .	,, ...	,, 1, ,,	—
343	Dr. M. de Davidoff .	Bavaria	,, 7, ,,	April 2, 1886
344	Prof. G. von Koch .	Hesse . . .	Feb. 2, ,,	Mar. 16, ,,
345	Dr. G. Karsten . .	Prussia . . .	Mar. 10, ,,	May 1, ,,
346	Dr L. Will . .	Hamburg . . .	,, 10, ,,	April 24, ,,
347	Prof. W. His . .	Saxony . . .	,, 13, ,,	,, 7, ,,
348	Prof. Kollmann. .	Switzerland . .	,, 15, ,,	May 1, ,,
349	Dr. J. Steiner . .	Baden . . .	,, 20, ,,	June 5, ,,
350	Dr. L. Plate . .	Bavaria . . .	,, 20, ,,	May 6, ,,
351	Prof. C. Chun . .	Prussia . . .	,, 27, ,,	,, 1 ,,
352	Cand. J. Dobberke .	Holland . . .	April 6, ,,	July 9, ,,
353	Mr. W. Heape . .	Cambridge . .	,, 15, ,,	June 1, ,,
354	Prof A. della Valle .	Italy	,, 16, ,,	May 5, ,,
355	Dr. Onodi . . .	Hungary . . .	,, 18, ,,	June 9, ,,
356	Dr. F Nansen . .	Stazione Zoologica .	,, 21, ,,	,, 7, ,,
357	Dr. F. Schwinck .	Bavaria . . .	May 4, ,,	—
358	Prof. A. della Valle .	Italy	June 18, ,,	—

III. *A List of Papers which have been published in the year* 1885 *by the Naturalists who have occupied Tables at the Zoological Station.*

Dr. von Sehlen . . .	Zur Aetiologie der Alopecia areata. Virchow's 'Archiv,' Bd. xcix. 1885.
Dr. J. Frenzel. . . .	Ueber einige in Seethieren lebende Gregarinen. 'Archiv f. mikr. Anatomie,' Bd. xxiv. 1885.
,, ...	Ueber die Mitteldarmdrüse (Leber) der Mollusken. *Ibid.* Bd. xxv. 1885.
,, ...	Temperaturmaxima für Seethiere. Pflüger's 'Archiv f. d. ges. Physiologie,' Bd. xxxvi. 1885.
,, ...	Ueber den Darmcanal der Crustaceen nebst Bemerkungen zur Epithelregeneration. 'Archiv f. mikr. Anatomie.' Bd. xxv. 1885.

Prof. N. Wagner . .	Sur quelques points de l'organisation de l'Anchynie. 'Archives de Zool. Expér.' t. iii. 2e Série, 1885.
Mr. W. Ransom . .	On the Cardiac Rhythm of Invertebrata. 'Journal of Physiology,' vol. v. 1885.
Dr. W. Kükenthal . .	Ueber die lymphoiden Zellen der Anneliden. 'Jenaische Zeitschr. f. Naturw.,' Bd. xviii. 1885.
Mr. Sidney F. Harmer .	On the Structure and Development of Loxosoma. 'Quart. Journ. Micr. Science,' 1885.
Prof. C. Chun . .	Ueber die cyclische Entwickelung der Siphonophoren. 'Sitzungsb. K. Preuss. Acad. Wiss.' 1885.
„ . .	Ueber die cyclische Entwickelung der Siphonophoren. Zweite Mittheil. *Ibid.*
Dr. L. Örley . . .	Die Entozoen der Haie und Rochen. 'Természetrajzi Füzetek,' vol. ix. 1885.
„ . . .	A Czápáknak és Rájaknak Belférgei. *Ibid.*
„	Zur Physiologie der Haiembryonen. *Ibid.*
Dr. J. Walther . .	Die gesteinbildenden Kalkalgen des Golfs von Neapel und die Entstehung structurloser Kalke. 'Zeitschr. der deutschen geolog. Gesellschaft,' 1885.
Prof. G. Albini . .	Sui movimenti dei cromatofori nei Cefalopodi. 'Rendiconto Accad. Scienze Fis. e Mat., Napoli,' Anno 24, 1885.
M. M. Jaquet . . .	Recherches sur le Système vasculaire des Annélides. 'Mittheil. Zool. Station Neapel,' Bd. vi. 1885.
J. M. de Castellarnan .	La Estacion de Nápoles y sus Procedimientos para el esamen microscópico, Madrid, 1885.
Mr. A. G. Bourne . .	On the supposed communication of the vascular system with the exterior in Pleurobranchus. 'Quart. Journ. Micr. Science,' vol. xxv. 1885.
Prof. A. Swaen . .	Étude sur le développement des Feuillets, &c. dans le blastoderme de la Torpille. 'Extr. Bull. Acad. Roy. Belgique,' 3e Série, t. 9, 1885.
Dr. E. Rohde . . .	Die Musculatur der Chaetopoden (Nachtrag). 'Zool. Beiträge,' herausgeg. von Dr. A. Schneider, Breslau, Bd. i. 1885.
Dr. A. Gravis . . .	Sur les Travaux Botaniques pendant son séjour au Laboratoire de la Station Zoologique de Naples (Extr. Belgique Horticole, 1884).
„ . . .	Procédés Techniques usités à la Station Zool. de Naples en 1883 (Extr. du procès-verb. Soc. belg. de Microscopie, 1884).
Prof. C. Emery . .	Contribuzioni all' Ittiologia. 'Mittheil. Zool Station Neapel,' Bd. vi. 1885.
Dr. J. T. van Bemmelen .	Ueber vermuthliche rudimentäre Kiemenspalten bei Elasmobranchiern. 'Mittheil. Zool. Station Neapel,' Bd. vi. 1885.
Prof. G. Entz . . .	Zur näheren Kenntnis der Tintinnoden. *Ibid.*
A. Colombo . . .	Raccolte Zoologiche eseguite dal R. piroscafo Washington nella Campagna abissale talassografica dell' anno 1885. 'Rivista Marittima,' Aprile 1885.
G. Chierchia . . .	Collezioni per studi di scienze naturali fatte nel viaggio intorno al mondo dalla R. corvetta 'Vettor Pisani,' 1882-3-4-5, con 12 tavole e 2 grandi carte zootalassografiche (Estratto dalla 'Rivista Marittima,' Settembre, Ottobre, Novembre, 1885), Roma, 1885.

IV. *A List of Naturalists to whom Specimens have been sent from the end of June* 1885 *to the end of June* 1886.

					Lire c.
1885.	July	4	Prof. C. Claus, Vienna . .	Various . . .	125·55
	„	6	Prof. P. Pavesi, Pavia . .	Annelida . . .	49·15
	„	„	Landwirthsschaftsschule, Weilburg	Cœlenterata . .	34·4

					Lire c.
1885.	July	7	Dr. F. Blochmann, Heidelberg .	Various	99·90
	,,	,,	Prof. Askenasy, Heidelberg .	Algæ	6·40
	,,	8	Mr. E. G. Stocker, London .	Various	26·65
	,,	,,	Mr. V. Frič, Prague . . .	Various	43·80
	,,	10	Dr. Th. Barrois, Lille . .	Mactra	6·05
	,,	11	Mr. Ch. Jefferys, Tenby . .	Mollusca	153·90
	,,	15	University, St. Petersburg .	Siphonophora . .	66·65
	,,	18	Mr. A. Kreidl, Prague . .	Collection	107·35
	,,	25	H.R.H. Prince Rupprecht of Bavaria	Mollusca	82·90
	,,	29	Mr. Pernoletti, Beziers . .	Octopus	76·
	,,	31	Mr. W. E. Hoyle, Edinburgh .	Mollusca	143·85
	,,	,,	Marchese Diana, Naples . .	Various	41·10
	Aug.	8	Prof. Giglioli, Florence . .	Fishes	70·45
	,,	12	Dr. L. Edinger, Frankfort-on-Maine	Brains of fish . .	14·45
	,,	15	Mr. H. Reichelt, Leipzig . .	Mollusca	9·85
	,,	16	K. Zool. Sammlung, Munich .	Collection	417·55
	,,	20	Mr. A. Eloffe, Paris . . .	Collection	275·10
	,,	24	Prof. Paladino, Naples . .	Ovaries of Squatina .	12·45
	Sept.	4	Prof. D'A. W. Thompson, Dundee	Collection	250·30
	,,	9	Mr. V. Frič, Prague . . .	Cœlenterata . .	106·10
	,,	,,	Obergymnasium, Sarajevo .	Various	60·95
	,,	15	Baron R. von Drasche, Vienna .	Various	17·95
	,,	,,	Mr. A. Kreidl, Prague . .	Various	12·
	,,	16	Mr. E. Marie, Paris . . .	Various	47·40
	,,	19	Prof. E. Haeckel, Jena . .	Collection	538·15
	,,	20	Admiral de Kasnakoff . .	Collection	20·
	,,	23	Dr. Bolau, Aquarium, Hamburg	Living animals . .	—
	,,	25	Prof. Richiardi, Pisa . . .	Collection	246·35
	,,	,,	Mr. A. Eloffe, Paris . . .	Various	69·70
	,,	28	Dr. John Beard, Manchester .	Embryos of Torpedo .	27·65
	,,	,,	Prof. C. Chun, Königsberg .	Siphonophora . .	10·30
	Oct.	5	Prof. C. Vogt, Geneva . .	Chimæra monstrosa .	13·
	,,	18	Prof. Mohr, Lahr . . .	Collection	179·40
	,,	20	Dr. H. J. Veth, Rotterdam .	Collection	207·85
	,,	,,	Dr. E. Everts, Hague . .	Collection	90·15
	,,	,,	Prof. C. Chun, Königsberg .	Embryos of Torpedo .	17·25
	,,	21	Mr. J. Puls, Ghent . . .	Collection	176·55
	,,	23	Dr. O. Hamann, Göttingen .	Spatangus	37·50
	,,	24	Zoolog. Institut, Berlin .	Collection	437·50
	,,	,,	Mr. E. Marie, Paris . . .	Various	102·20
	,,	,,	Prof. C. K. Hoffmann, Leyden .	Engraulis	3·35
	,,	28	Prof. G. Frizzi, Perugia . .	Mollusca	63·95
	,,	,,	K.K. Geol. Reichsanstalt, Vienna	Corallinea	6·90
	,,	,,	Prof. Hubrecht, Utrecht . .	Various	52·85
	,,	29	Prof. Bogdanoff, Moscow . .	Ascidiæ, Hydromedusæ	317·75
	,,	,,	Dr. Rabl-Rückhard, Berlin .	Amphioxus	9·20
	Nov.	11	Prof. A. della Valle, Modena .	Collection	524·90
	,,	,,	Prof. Emery, Bologna . .	Various	143·60
	,,	,,	Prof. Ehlers, Göttingen . .	Various	75·35
	,,	13	Dr. Th. Barrois, Lille . .	Dentalium	3·60
	,,	15	Musée d'Histoire Nat., Geneva .	Various	115·05
	,,	16	Dr. Zograf, Zool. Mus., Moscow	Aplysia, Hippocampus	37·75
	,,	17	Mr. R. Damon, Weymouth .	Collection	103·05
	,,	24	Rev. A. M. Norman . . .	Collection	335·30
	,,	,,	Dr. P. Pelseneer, Brussels . .	Cymbulia	9·85
	,,	28	Mr. Pedro Antigo, Barcelona .	Crustacea	77·10
	,,	,,	Mason College, Birmingham .	Collection	142·10
	,,	,,	Höhere Bürgerschule, Hamburg	Collection	250·
	,,	29	Prof. Newton Parker, Cardiff .	Collection	205·35
	Dec.	11	University, Warsaw . . .	Collection	451·35
	,,	,,	Prof. M. Marshall, Manchester .	Antedon	38·15

					Lire c.
1885.	Dec.	11	Dr. Simroth, Leipzig	Collection	100·
	„	12	Prof. Gezá Entz, Klausenburg	Collection	169·
	„	14	Prof. D'A. W. Thompson, Dundee	Collection	62·55
	„	16	Dr. A. Toth, Szegedin	Pelagia	5·75
	„	„	Dr. N. Ormandy, Szegedin	Collection	121·50
	„	„	Prof. Salensky, Odessa	Collection	237·10
	„	17	Zool. Institut, Munich	Pecten	5·95
	„	20	Laboratoire de Zoologie, Dijon	Collection	460·95
	„	„	Mr. F. Rüse, Copenhagen	Mollusca	42·35
1886.	Jan.	3	Prof. Wiedersheim, Heidelberg	Heads of Dogfish	50·
	„	5	Mr. E. Marie, Paris	Torpedo, Octopus	60·45
	„	10	Prof. Sabatier, Montpelier	Collection	410·75
	„	11	Zool. Museum, St. Petersburg	Cœlenterata	88·10
	„	12	Dr. E. Voges, Heisede	Collection	125·
	„	16	Zool. Institut, Berlin	Collection	425·15
	„	„	Mr. E. Marie, Paris	Various	34·25
	„	„	Laboratoire de Zoologie, Lille	Various	25·85
	„	22	Prof. Ludwig, Giessen	Collection	625·
	„	„	Mr. J. Tempère, Paris	Various	22·60
	„	„	Mr. R. Damon, Weymouth	Various	139·15
	Feb.	8	Mr. J. Beck, London	Various	125·
	„	„	Dr. von Hanstein, Göttingen	Various	70·
	„	9	Prof. Hertwig, Munich	Various	182·95
	„	„	Prof. A. Andres, Milan	Strongylocentrotus	46·50
	„	„	Dr. L. Eger, Vienna	Various	95·15
	„	10	Mr. R. Vallentin, Leytonstone	Echinodermata	13·80
	„	„	Prof. A. Batelli, Perugia	Fishes	63·65
	„	15	Mr. J. B. Jeaffreson, London	Pycnogonida	6·85
	„	„	Dr. O. Hamann, Göttingen	Echini	4·45
	„	19	Mr. L. Dreyfus, Wiesbaden	Collection	952·
	„	„	„ „ „	Collection	298·
	„	„	Inst. de Zoologie, Lille	Various	62·30
	„	„	Mr. H. Putze, Hamburg	Argonauta	22·85
	„	„	Dr. J. Früh, S. Gall	Corallinea	1·
	„	21	Mr. H. Knorr, Munich	Various	72·85
	„	22	Morphol. Laboratory, Cambridge	Animals for Dissection	578·50
	„	„	Dr. A. Pauly, Munich	Eyes of Pecten	6·75
	„	„	Mr. E. Simon, Paris	Crustacea	21·95
	„	24	Dr. Mendelsohn, Posen	Various	55·
	„	„	Prof. H. Blanc, Lausanne	Various	93·90
	„	„	Dr. Ed. Pergens, Louvain	Bryozoa	24·90
	March	3	Mr. E. Marie, Paris	Pyrosoma, Nemertina	32·35
	„	4	Zool. Institut, Göttingen	Echinodermata	136·05
	„	6	Mr. H. Putze, Hamburg	Argonauta	22·75
	„	10	Mr. Kymmel, Riga	Various	162·90
	„	11	Mr. A. Kreidl, Prague	Various	64·05
	„	„	Prof. Fritsch, Berlin	Torpedo	13·75
	„	12	Prof. A. Goette, Rostock	Cœlenterata	6·55
	„	13	Mr. V. Frič, Prague	Callianassa	1·85
	„	16	Mr. J. Tempère, Paris	Various	31·25
	„	24	Prof. G. von Koch, Darmstadt	Collection	625·
	„	27	Dr. Hering, Frankfort-on-Maine	Various	79·40
	„	„	Mr. Pfeiffer, Ehrenfeld	Various	71·40
	April	3	Lab. de Zool., Vimereux	Various	228·45
	„	8	Veterinär Högskole, Copenhagen	Various	128·65
	„	„	Morphol. Lab., Cambridge	Amphioxus	97·35
	„	14	Senckenbergisches Mus., Frankfort-on-Maine	Collection	1250·
	„	„	Polytechnicum, Zurich	Lepidopus	32·
	„	„	Lab. de Zool., Neuchatel	Collection	244·35
	„	16	Dr. I. Felix, Leipzig	Various	29·15
	„	19	Prof. C. Vogt, Geneva	Brachiopoda	30·70
	„	21	Dr. L. Eger, Vienna	Corallium	47·30

					Lire c.
1886.	April	22	Dr. G. Riem, Halle-on-Saale	Various	64·10
	,,	23	Prof. Hofrath Preyer, Jena	Echinodermata	113·05
	,,	28	Oberstaatsanwalt, Hamm, Cologne	Collection	69·50
	,,	,,	Prof. Frizzi, Perugia	Various	8·45
	May	2	Dr. Bolau, Hamburg	Living Specimens	25·
	,,	3	Dr. Pancritius, Königsberg	Intestines	29·95
	,,	,,	University, Columbia, Missouri	Collection	436·
	,,	,,	Dr. Müller, Berlin	Collection	260·85
	,,	,,	Zool. Museum, Berlin	Collection	78·55
	,,	6	Dr. Moesch, Zürich	Various	57·65
	,,	,,	Prof. Frizzi, Perugia	Petromyzon	8·75
	,,	,,	Dr. G. Gilson, Louvain	Testicoli	4·80
	,,	10	Mr. Jaquet, Jena	Scymnus	12·55
	,,	13	Realgymnasium, Zwickau	Collection	105·75
	,,	17	Mr. H. W. Gwatkin, Cambridge	Various	75·
	,,	,,	Dr. Karsch, Berlin	Myzostomum	6·40
	,,	19	Musée d'Hist. Nat., Brussels	Fishes	136·30
	,,	20	Prof. Gabor de Baczó, Zilah	Collection	150·
	,,	22	Mr. J. T. Hillier, Ramsgate	Various	38·
	,,	24	Mr. H. Putze, Hamburg	Various	31·70
	,,	,,	Dr. Rückert, Munich	Embryos of Dogfish	—
	,,	27	Prof. Kupfer, Munich	Petromyzon	50·
	,,	29	Zool. Institut, Heidelberg	Collection	271·60
	,,	31	Prof. Chun, Königsberg	Various	151·95
	June	1	Count Peracca, Turin	Lacerta muralis	10·
	,,	8	Zool. Institut, Würzburg	Cardium	8·85
	,,	11	Prof. D'A.W. Thompson, Dundee	Collection	161·15
	,,	,,	Mr. J. Tempère, Paris	Various	28·40
	,,	13	Mr. P. Antigo, Barcelona	Various	84·95
	,,	16	Prof. W. His, Leipzig	Embryos of Dogfish	19·25
	,,	,,	Prof. Rabl, Prague	,, ,,	27·35
	,,	,,	Prof. Ray Lankester, London	Thysanoteuthis, &c.	86·
	,,	21	K. Obergymnasium, Szatmar	Collection	125·
	,,	22	,, ,, Tyrnan	Collection	62·50
	,,	,,	Dr. F. Zschokke, Aaran	Collection	44·45
	,,	26	Istituto Pontano, Naples	Collection	45·
	,,	29	Mr. Gustav Schneider, Basle	Rhizostoma, Corallium	33·95
	,,	30	Mr. F. Hermann, Naples	Xiphias	15·
					19,781·05

V. *A List of Naturalists to whom Microscopic Preparations have been sent from the end of June* 1885 *to the end of June* 1886.

						Lire c.
1885.	Oct.	23	Zool. Inst., University, Berlin	52	preparations	105·
	Nov.	27	Dr. O. S. Jensen, Christiania	23	,,	50·
	,,	29	Prof. W. Newton Parker, Cardiff	13	,,	31·
	Dec.	12	University, Warsaw	14	,,	25·
1886.	May	31	Miss Garland, Winchester	3	,,	6·25
						217·25

Report of the Committee, consisting of Mr. JOHN CORDEAUX (*Secretary*), Professor A. NEWTON, Mr. J. A. HARVIE-BROWN, Mr. WILLIAM EAGLE CLARKE, Mr. R. M. BARRINGTON, *and* Mr. A. G. MORE, *appointed for the purpose of obtaining (with the consent of the Master and Brethren of the Trinity House and the Commissioners of Northern and Irish Lights) observations on the Migration of Birds at Lighthouses and Lightvessels, and of reporting on the same.*

THE General Report of the Committee, of which this is an abstract, is comprised in a pamphlet of 173 pages,[1] and includes observations taken at lighthouses and lightvessels, as well as at several land stations, on the coasts of Great Britain and Ireland and the outlying islands.

The best thanks of the Committee are due to their numerous observers for their assistance. Much good work has been rendered by those amongst them who have taken the trouble to forward a leg and wing of such specimens as have been killed against the lanterns, and which they have themselves not been able to identify. This has already led to the determination of several rare birds, which otherwise would have escaped notice. It is evident that unless the birds can be correctly named the value of this inquiry is materially diminished, and ornithologists may justly refuse to accept the accuracy of the statements. It is intended, in order to facilitate the sending of wings, to supply the light-keepers with large linen-lined envelopes, ready stamped, and enclosing labels for dates and other particulars.

The best thanks of the Committee are also tendered to Mr. H. Gätke for the increased interest he has given to their report by forwarding a daily record of the migration of birds as observed at Heligoland between January 1 and December 31, with the concurrent meteorological conditions under which the various phenomena occurred.

Altogether 187 stations were supplied with printed schedules for registering the observations, and returns have been sent in from 125. About 267 separate schedules have been sent in to your reporters. The general results, as far as the special object of the inquiry, have been very satisfactory, and much information has also been accumulated respecting the breeding habits of seafowl on the outlying islands and skerries on the Scotch and Irish coasts, and altogether a great mass of facts and valuable data obtained which cannot fail to be of value to future inquirers.

A special point of interest in the report is the large arrival, with a north-east wind, of Pied Flycatchers in the first week in May 1885, observed at Spurn Point, Flamborough Head, the Isle of May, and Pentland Skerries. At Flamborough Head the Flycatchers were accompanied by male Redstarts in large numbers, both species swarming for two or three days. The immigration at this period was not exclusively confined to these two species. Mr. Agnew, writing from the Isle of May, at the entrance of the Firth of Forth, says, under date of May 3rd—'An extraordinary rush of migrants to-day; have never seen anything like it

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[1] 'Report on the Migration of Birds in the Spring and Autumn of 1885.' McFarlane and Erskine, 19 St. James's Square, Edinburgh.

in spring. To attempt to give numbers is simply useless. I will just give you the names in succession: Fieldfares, Redwings, Ring Ouzels, Blackbirds, Lapwings, Dotterels, Rock-pigeons, Hawk, Meadow Pipits, Redstarts, Whinchats, Tree Sparrows, Yellow Wagtails, Ortolan (obtained), Robins, Chiff-chaffs, Wood-warbler, Blackcap-warbler, Marsh Tit, Whitethroats, and Pied Flycatchers.' And on the 4th: 'Still increasing in numbers, but wind shifted this morning to E. for S.E.'

A noteworthy incident also of the vernal migration was the great rush of Wheatears observed at the Bahama Bank vessel off the Isle of Man, and at Langness on the night of April 13, when many perished and were captured. On the same night Wheatears were killed at the Coningbeg and Rathlin Island lighthouses, on the Irish coast On the 12th and 13th the rush was very heavy at stations on the west coast of Scotland. No corresponding movement was observed on the east coast of Great Britain on the same night; but at Hanois L. H., Guernsey, on the 10th of May, at night at the north light, and on the Lincolnshire coast and Farn Islands on the 10th and 11th. These entries are sufficient to show the immense area covered by the migration of this species at or about the same period. On the east coast of England the first Wheatears were observed at the Farn Islands on February 22.

The autumnal migration is first indicated at Heligoland on July 6, and was continued with slight intermissions up to the end of the year. A similar movement affected the whole of the east coast of Great Britain during the same period, but was apparently less constant and persistent than at Heligoland.

It has been remarked in previous reports that the migration of a species extends over many weeks, and in some cases is extended for months. Yet it is observable that, at least on the east coast of England, year by year, the bulk or main body of the birds come in two enormous and almost continuous rushes during the second and third weeks in October and the corresponding weeks in November.

In the autumn of 1885 it is again observable that the chief general movements which usually characterise the southward autumnal passage were two in number, and affected the stations over the whole coast line both east and west of Great Britain. The first of these commenced about the 11th ot October, and was continued to the 20th. The second from the 8th to the 12th of November. It is worthy of notice that these two chief movements of the autumn were ushered in by and were concurrent with anti-cyclonic conditions, preceded by and ceasing with cyclonic depressions, affecting, more or less, the whole of the British isles. From this it appears not unlikely that birds await the approach of favourable meteorological conditions, of which perhaps their more acute senses give them timely warning to migrate in mass. Whatever may be the cause which impels these enormous rushes, often continuous for days, it is one which operates over an immense area at one and the same time.

The October rush reached its maximum on the 16th, at which date almost all the stations report extraordinary numbers of various species on the wing. As one out of many we quote from the journal of Mr. James Jack, principal of the Bell Rock lighthouse: 'Birds began to arrive at 7.30 P.M., striking lightly and flying off again; numbers went on increasing till midnight, when it seemed that a vast flock had arrived, as they now swarmed in the rays of light, and, striking hard, fell dead on balcony or rebounded into the sea. At 3 A.M. another flock seemed to have arrived, as the numbers now increased in density; at the same time all kinds crowded on to the lantern windows, trying to force their way to the light. The noise they made shrieking and battering the windows baffles description. The birds were now apparently in thousands; nothing ever seen here like it by us keepers. Wherever there was a light visible in the building they tried to force their way to it. The bedroom windows being open as usual for air all night, they got in and put the lights out. All birds went off at 6 A.M., going W.S.W. Redwings were most in number; Starlings next; Blackbirds, Fieldfares, and Larks.' The rush in November chiefly took place in the night; at the Bell Rock the movement ceased at midnight of the 12th, and at the Longstone Lighthouse, on the Farn Islands, a little earlier—at 10.30 P.M., when the wind became strong from S.W.

From each succeeding year's statistics we have come to almost similar conclusions regarding the lines of flight—regular and periodically used routes where the migratory hosts are focussed into solid streams. Three salient lines on the east coast of Scotland are invariably shown, viz., (1) by the entrance of the Firth of Forth, and as far north as Bell Rock, both coming in autumn and leaving in spring; (2) by the Pentland Firth and Pentland Skerries, likewise in spring and autumn; and (3) by the insular groups of Orkney and Shetland, which perhaps may be looked upon as part of No. 2. On the other hand, three great areas of coast line, including many favourably lighted stations, almost invariably, save in occasionally protracted easterly winds, and even then but rarely, send in no returns, or schedules of the very scantiest description. These areas are Berwickshire, the whole of the east coast south of the Moray Firth, and Caithness and East Sutherland. Each and all of these areas possess high and precipitous coast lines, if we except the minor estuaries of the rivers Tay and Dee, and a small portion of the lower coast line of Sutherland, which face towards the east.

On the east coast of England these highways are less clearly demonstrated. The Farn Islands, Flamborough Head, and the Spurn are well established points of arrival and departure; but south of the Humber as far as the South Foreland the stream appears continuous along the whole coast line, and to no single locality can any certain and definite route be assigned. It cannot be said that the southerly flow of autumn migrants is equally distributed along the entire west coast of England. On the contrary, the schedules afford unmistakable evidence that the great majority of these migrants, so far as the English and Welsh coasts are concerned, are observed at stations south of Anglesey. But while the north-west section of the coast is thus less favoured than the rest, such is not the case with the Isle of Man, which comes in for an important share of the west coast migratory movement. The fact has already been alluded to, that large masses of immigrants from Southern Europe pass through the Pentland Firth, and, along with migrants from Faröe, Iceland, and Greenland, pass down the west coast of Scotland, whence many cross to Ireland, and it seems most probable that the remainder leave Scotland at some point on the Wigtown coast, and pass by way of the Isle of Man to the west coast of Wales, and thus avoid the English shore of the Irish Sea. The schedules sent in from the coasts of Flint, Cheshire, Lancashire, and Cumberland show that in 1884–85 comparatively few migrants were observed, and that the great general movement did not affect them in any general degree. These remarks do not apply to migrants among the waders and ducks and geese, which, as a rule, closely follow coast lines, and which are abundantly represented on the Solway and coasts of Cumberland and Lancashire. There is a much used bird route along the north coast of the Bristol Channel, and thence, from the Pembroke coast, across to Wexford, passing the Tuskar Rock, the best Irish station.

The fact of a double migration or passage of birds, identical in species, across the North Sea in the spring and autumn both towards the E. and S.E. and to the W. and N.W., is again very clearly shown in the present report. This phenomenon of a cross migration to and from the Continent, proceeding at one and the same time, is regularly recorded on the whole of the east coast of England, but is specially observable at those lightvessels which are stationed in the south-east district; at the same time, it is invariably persistent and regular year by year.

Our most interesting stations are those on small islands or rocks, or lightvessels at a considerable distance from shore, and the regular occurrence of so many land birds, apparently of weak power of flight, around these lanterns is a matter of surprise to those unacquainted with the facts of migration. No clear indication of the migration of the Redbreast has yet been shown on the Irish coast; the records of its occurrences are few and scattered. The Black Redstart was recorded at several stations in the southern half of Ireland; specimens were forwarded from Mine Head, The Skelligs, and Rockabill. It is apparently a regular winter visitant to The Skelligs and Tearaght, generally appearing in October and November. The occurrences so far recorded by the Committee of the Black Redstart on the east coast of Great Britain, in the autumn, range between October 23 and November 3.

In the spring of the present year Mr. G. Hunt, under date of March 20, reports an extraordinary flight of Rooks at Somerton, on the Norfolk coast, which he observed from 10.30 A.M. to 6 P.M. He says: 'I observed them flying just above the sand-hills, going due south, and as far as the eye could see both before and behind there was nothing but Rooks. There could never for one moment of the day be less than a thousand in sight at one time; they kept in a thin wavering line. The coast line here runs due north and south.' Mr. J. H. Gurney reports: 'I saw the Rooks and Grey Crows on the same day in much smaller numbers as were seen at Somerton, which is fifteen miles further south. I again saw them on the 21st, 22nd, 25th, 26th, and 29th, but none after this date; with us, however, Grey Crows preponderated: the direction was to S.E. An enormous migration of these and many others is recorded from Heligoland, also from Hanover between March 19 and 25.'

In conclusion your Committee wish to thank H.R.H. the Master and the Elder Brethren of the Trinity House, the Commissioners of Northern Lights, and the Commissioners of Irish Lights for their ready co-operation and assistance, through their intelligent officers and men, in this inquiry.

The Committee respectfully request their reappointment.

Report of the Committee, consisting of Professor CLELAND, Professor McKENDRICK, Professor EWART, Professor STIRLING, Professor BOWER, Dr. CLEGHORN, *and* Professor McINTOSH (*Secretary*), *appointed for the purpose of continuing the Researches on Food-Fishes and Invertebrates at the St. Andrews Marine Laboratory.*

THE Committee beg to report that the sum of 75*l*., placed at their disposal, has for the most part been expended in the purchase of instruments and books permanently useful in the Laboratory, only a limited proportion having been disbursed for skilled assistance.

Since the meeting of the Association at Aberdeen last year several structural improvements in the wooden hospital, now converted into the Laboratory, have been completed, and others are being carried out by the Fishery Board for Scotland. These changes will render the temporary building much more suitable for work. A small yawl of about 21 feet in length has also been added to the apparatus by the Fishery Board. The desiderata now are an increase in the number of good microscopes and other expensive instruments, and an addition to the nucleus of books which workers require always at hand. In this respect the Laboratory has been much indebted to the Earl of Dalhousie, who forwarded a complete set of Fishery Blue Books, and to the Trustees of the British Museum, who sent their publications relating to marine zoology. Collections of papers have also been forwarded by many observers, amongst whom Professor Flower, the late Dr. Gwyn Jeffreys, and Professor Alexander Agassiz are conspicuous. Most of the Continental and American workers in marine zoology and cognate subjects, as well as those of our own country, are indeed represented.

The first work of the year was the examination of a fine male Tunny, 9 feet in length, caught in a beam-trawl net near the mouth of the Forth, and the skeleton of which is now being prepared for the University Museum. Various interesting anatomical features came under notice, and its perfect condition enabled a more correct figure of its external appearance to be made (*vide* 'Ann. Nat. Hist.' April and May 1866 and 'Fourth Report of the Fishery Board for Scotland,' plate viii.) The examination of various food- and other fishes in their adult and young conditions was systematically carried out, and notes on the following species will be found in the 'Annals of Natural History,' and the 'Report of the Fishery Board':—Weever (greater and lesser), shanny, sand-eel, halibut, salmon, common trout, herring, sprat, conger, ballan-wasse, shagreen-ray, piked dog-fish, and porbeagle-shark. Special attention was also given to the 'Mode of Capture of Food-Fishes by Liners,' 'Injuries to Baited Hooks and to Fishes on the Lines,' 'Shrimp-Trawling in the Thames,' 'Sprat-Fishing,' and to the 'Eggs and Young of Food- and other Fishes,' 'Diseases of Fishes,' the 'Effect of Storms on the Marine Fauna,' and 'Remarks on Invertebrates, including Forms used as Bait.'[1]

The active work in connection with the development of fishes for the season may be dated from the middle of January, when one of the local trawlers captured a large mass of the ova of one of the food-fishes, viz., the catfish (*Anarrhichas lupus*, L.). The embryos in these eggs (which are the size of the salmon's) were well advanced, so that with the excep-

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[1] *Vide* 'Fourth Report of the Fishery Board for Scotland,' 1886.

tion of a few unimpregnated ova observed during the trawling experiments of 1884, the earlier stages have yet to be examined. The large size of the embryos of the catfish permitted a satisfactory comparison to be instituted between them and the salmon, which had formerly been under examination, and the results, with drawings of both forms, are nearly completed, and will be communicated to one of the Societies during the winter.

The first pelagic ova, viz., those of the haddock, made their appearance during the very cold weather in the beginning of February, and the examination of these, together with those of the cod and common flounder—both of which were unusually late—enabled Mr. E. E. Prince and the Secretary to extend considerably the observations of last year. Moreover, for the first time, the ova of the ling (*Molva vulgaris*) were examined, and the development followed to a fairly advanced stage. These were procured by a long-line fisherman of Cellardyke (who with others was supplied with suitable earthenware jars[1] and encouraged by a visit to the Laboratory), fertilised about 100 miles off the Island of May, and safely brought, after a considerable land-journey, to St. Andrews. The fertilised ova of the plaice and lemon-dab were similarly brought by Captain Burn, late of the Hussars, from the Moray Frith; for the Laboratory had then no boat suited for procuring a supply nearer home. No fish, however, has been more useful to the workers this season than the gurnard (*Trigla gurnardus*), the spawning period of which seems to have been somewhat later than usual. The first ova were procured about the middle of May, and the embryos of the last hatching (middle of August) still swarm in the vessels. Further observations were also made on the ova and young of the lumpsucker, Montagu's sucker, shanny, stickleback, sand-eel, *Cottus*, &c. Amongst others the nearly ripe ovum of *Ammodytes tobianus* has been examined. It is colourless, translucent, and has a beautifully reticulated capsule. Mr. Prince is of opinion that, as suggested in the 'Report of H.M. Trawling Commission,' it resembles a pelagic egg.

Moreover, the information necessary for filling up the gaps between the very early stages of the young food-fishes near the surface and their appearance off the shore as shoals of young forms more or less easily recognisable specifically has been considerably increased. Much of this knowledge has been obtained by the aid of a huge tow-net of coarse gauze—upwards of twenty feet in length—attached to a triangle of wood, ten feet each way, sunk by a heavy weight and kept steadily at the required depth in fathoms by a galvanised iron float, such as is used for the ends of herring-nets. Since the completion of the net, however, the services of the Fishery Board tender *Garland* have only once been available, and the yawl has been at our disposal only a few weeks. In these brief opportunities, however, the young of various fishes have been obtained at stages hitherto unknown, and some rare invertebrates and a remarkable Medusa have been captured. Enough, in short, has been seen to indicate the value of this apparatus, and of certain modifications of the ordinary beam-trawl for work on the bottom.

The hatching and rearing of the embryos of the common food-fishes have been attended with much greater success than last year or the

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[1] Containing about a gallon. These were partially filled with pure sea-water then containing fertilised ova, and simply tied over with porous cheese-cloth.

previous one, and a large series of microscopic preparations (chiefly sections with the Caldwell and rocking microtomes) has been made chiefly by Mr. E. E. Prince, embracing the entire development of the food-fishes from the early ovum to a late larval stage. The study of these preparations is now being proceeded with; but in traversing a field so extensive as the embryology of these important Teleosteans a great expenditure of time and labour is required. It is hoped, however, that the results will be completed during the winter.[1]

Since the beginning of June Dr. Scharff has been occupied with the investigation of the intra-ovarian egg of a number of Teleosteans. Among the ovaries examined were those of *Trigla gurnardus*, *Gadus virens* and *G. luscus*, *Gadus merlangus*, *Anarrhichas lupus*, *Conger vulgaris*, *Blennius pholis*, *Lophius piscatorius*, and *Salmo salar*. The researches were made on fresh ovaries and on spirit-specimens. Most of those reserved for section-cutting were previously treated either with picrosulphuric or weak chromic acid. Special attention was paid to the structural changes in the growing nucleus. The origin of the follicular layer surrounding the egg, as well as the origin and development of the yolk, will be dealt with in a paper to be published shortly.

Considerable advancement has been made in the study of the development of the common mussel by Mr. John Wilson. Some of the very early larvæ are described in the Report of last year, along with an account of the artificial methods employed. This year embryos were developed for forty days in vessels suitable for microscopic manipulation. Normal growth continued during the first fourteen days. At the end of this period the largest embryos had shell-valves ·128 mm. in length. They are transparent and almost semicircular, the dorsal (hinge-) line being nearly straight. The powerful velum could be wholly withdrawn within the valves. The alimentary system was conspicuously developed. In the beginning of June great numbers of young mussels were found swimming actively on the very surface of the sea close to the shore, and measuring ·134 mm. They differed from the most advanced of those artificially reared only in their being more robust, the stage reached being the same in both. At various periods somewhat later in the season many older, though still microscopic, mussels were captured with the tow-net in St. Andrews Bay from the shore seaward for four miles. Besides the careful study of their development, Mr. Wilson has also been engaged with the histology of the mussel (especially that of the generative organs) at various stages, up to the adult condition.

The Committee beg to recommend a renewal of the grant (100*l.*) for the ensuing year.

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[1] *Vide* for other observations the *Annals of Natural History* for April, May, June, and August 1886; *Nature*, June 1886, &c.

Report of the Committee, consisting of General J. T. WALKER, General Sir J. H. LEFROY, Professor Sir W. THOMSON, Mr. ALEX. BUCHAN, Mr. J. Y. BUCHANAN, Mr. JOHN MURRAY, Dr. J. RAE, Mr. H. W. BATES (*Secretary*), Captain W. J. DAWSON, Dr. A. SELWYN, *and* Mr. C. CARPMAEL, *appointed to organise a Systematic Investigation of the Depth of the Permanently Frozen Soil in the Polar Regions, its Geographical Limits and Relation to the present Pole of greatest cold.*

THE inquiry referred to the Committee necessitated reference to residents in many distant regions, and time must elapse before any large harvest of observations can be hoped for; nevertheless, the Committee are in a position to quote several valuable communications, especially one from Mr. Andrew Flett, adding materially to what was previously known on the subject of the extension of permanently frozen soil, or ground ice, in America.

It will be convenient to arrange the data now available in their order of latitude.

1. Lat. 71° 18′ N., long. 156° 24′ W.—At the wintering station of the United States expedition of 1881–2, under Lieutenant P. H. Ray, United States America, that officer found the temperature of the soil 12° F. at 28 feet from the surface, and the same at 38 feet.

2. Lat. 68° N., long. 135° W.—At Fort Macpherson, on Peel River, Mr. Andrew Flett, who passed 12 years there, reports:—'The greatest depth of thawed-out earth I came across round that post was $3\frac{1}{2}$ feet, October 10, 1865. The greatest depth of frozen ground was 52 feet 3 inches, September 27, 1867, near the mouth of Peel River. The bank had fallen in; at the bottom the perpendicular cliff, which I tried with a boat pole, was frozen as hard as a rock. A black sandy soil. The surface was not above two feet thawed out. The cliff was measured with the tracking line.' This account leaves it doubtful whether the frost may not have entered the soil from the face of the cliff. On the other hand it is evident that it extended to a greater depth from the surface than was measured.

3. Lat. 67° N., long. 142° W. on the Youcon.—The same gentleman writes:—'I spent 12 years on the Pelly or Youcon River, on the west side of the Rocky Mountains. Round old Fort Youcon ground ice is found at 6 feet; this I have seen in the river banks in September where they had caved in; but no particular notice has been taken as far as I know by anyone, unless it be Chief Factor Robert Campbell, now residing in Merchiston, Strathclair, P.O., Manitoba.'

4. Lat. 65° N., long. 120° W.—On the Mackenzie River, about ten miles above the mouth of Bear River.—The same gentleman writes:—'I have seen many landslips on the Mackenzie, which more frequently takes place in rainy weather; July, August, and sometimes September; but I never examined them particularly excepting one, which we came near being buried by in camp. This was about August 15, 1876. By a pole, I found the bottom of the slide frozen hard, a grey clay and gravel mixed, *from where the earth broke off was not over* 6 *feet.* The surface soil sandy. Some way back from the river bank the country is muskeg more or less, and by removing the moss by hand we came to hard frozen ground in August.' The sentence printed in *italic* is somewhat ambiguous. It

is understood to mean that the bank was not much more than 6 feet high, and was hard frozen at that depth; the depth to which the frost extended is therefore unknown.

5. Lat. 64° 20′ N., long. 124° 15′ W.—On Mackenzie River.—The face of a cliff from which a recent land-slide had occurred was measured by the present reporter in June 1844. The soil was frozen to a depth of 45 feet from the surface (see 'Magnetic Survey,' p. 161).

6. Lat. 62° 39′ N., long. 115° 44′ W.—At Fort Rae, on Great Slave Lake.—Captain Dawson, B.A., observed the temperature of the soil monthly at his station of circumpolar observation, 1882–3. The following table contains his results:—

Months	In Degrees Fahr.			
	1 Foot	2 Feet	3 Feet	4 Feet
1882.				
September	40°·6	37°·9	36°·1	34°·5
October	32·5	32·7	32·5	32·3
November	23·9	29·1	30·9	31·3
December.	15·8	24·6	28·8	30·8
1883.				
January	8·3	19·9	25·7	28·5
February	11·1	21·2	24·5	26·3
March	9·5	20·8	22·7	24·8
April	18·9	25·2	24·3	25·3
May.	34·0	32·0	33·8	30·5
June	43·5	36·5	32·4	31·5
July.	48·0	41·0	37·0	34·5
August	47·3	41·9	38·5	36·5

The mean temperature of the air at 5 feet 10 inches above the surface, in the same months, was as follows:—

1882.	
September	44·40° Fahr.
October	32·59° „
November	9·30° „
December	−15·20° „
1883.	
January	−26·80° „
February	−10·41° Fahr.
March	−7·71° „
April	19·30° „
May	96·30° „
June	51·49° „
July	61·11° „
August	56·50° „

We learn from this table that the soil is frozen at a depth of 4 feet from November to June inclusive, and is at the lowest temperature at that depth in March. It further shows that, like the waters of the Scottish lakes, as proved by the observations of Mr. J. Y. Buchanan and Mr. J. F. Morrison in Loch Lomond and Loch Katrine last winter, the mean temperature of the soil reaches its minimum about the time of the vernal equinox. The rise of earth temperature in February above that recorded in either January or March is remarkable. It does not appear from the convergence of the lines when projected that temperatures below 32° F. extend lower than 11 or 12 feet. Captain Dawson writes: 'There are two reasons why these earth temperatures are above what is probably the average in that latitude. (1) The ground had a slope of $\frac{1}{16}$ to the S.W.; and (2) it was fully exposed to the rays of the sun; now in most places, the ground is either covered with thick moss or shaded by brushwood, and its surface temperature in the hottest day is not likely to exceed 70° F., whereas earth exposed to the rays of the sun may easily reach a temperature of 120° F.' Fort Rae is situated on a long arm or inlet of Great Slave, having a depth of 10 or 12 feet of water.

7. Lat. 62°, long. 129° 40′.—Jakutsk, Siberia.—The great depth of permanently frozen soil in this part of the valley of the Lena has long been well known; but the following extract translated from a recent paper by Doctor Alex. Woeikof, of St. Petersburg, entitled 'Klima von Ost-Siberien,' contains information on the influence of local conditions which will make it of value to observers, and we therefore reproduce it.

'The further north,' he remarks, 'the longer is the duration of cold in valleys in comparison with that on higher ground. The effect extends to a part of autumn and spring, and is observable in the mean temperature of the year.'

The following observations of earth temperatures are a proof:—

	At Depth				Limit of Frozen Soil
	20 ft.	50 ft.	300 ft.	381 ft.	
Jakutsk[1] .	. 13·6°	17·1°	25·0°	26·6° Fahr.	620 feet
Mangan mine	. 22·1°	25·2°	...	...	269 „
Schelou mine	. 22·1°	25·7°	...	...	298 „

Thus, on heights in the vicinity of Jakutsk the earth temperature is from 8·1° to 8·6° F. higher than it is in the town and valley at the same depth, and it is even lower at 300 feet in the former than at 50 feet in the latter locality. The total depth of frozen soil is, according to Middendorf,[2] more than twice as great in the valley as it is on the heights; and observe that these lesser heights are in winter relatively colder than higher isolated mountains. Middendorf also states that no frozen soil was found at 60 metres above the level of the river at the mouth of the Maja, in Aldan, but that it was found about four miles and a quarter up the stream at three metres above the level of the river, and that about 28 miles further, in the mountains, there is a deep hollow from which aqueous vapour is constantly rising.

Kuppfer asserts that in Bergrivier Nertschinsk, in the Trech Swjatitilei mine, frozen soil was found at a depth of 174 feet, but that in Wossdwischenst mine, which lies 230 feet higher, the frozen soil ceased at 50 feet. Even in Altai it is acknowledged that many valleys are colder than the neighbouring heights.

Dr. Woeikof sums up a number of observations in the following sentences, which apply to the greater part of East Siberia, but more particularly to the north-east portion:—

(1) As the greater cold coincides with calms and light winds, the valleys and lower grounds are colder than the heights.

(2) The temperature of isolated mountains is relatively higher than that of lesser elevations.

(3) The lowering of temperature in the valleys is so lasting and considerable that the mean of the year is also lowered, as is proved by the observations of earth temperature.

(4) The depth of the frozen soil is greater in valleys than on the neighbouring heights, probably also than it is on the higher mountains.

(5) In the Tundras of the far north (answering to the Barren grounds

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[1] M. Schergin's shaft.

[2] *Sibirische Reise*, Bd. i.

and Muskegs of the North-West Territory of Canada) the winter is warmer than in the valleys of the Forest-zone. Probably because the stronger currents of the air do not permit the cold stratum to remain so long stagnant.

7A. Lat. 61° 53′ 30″ N., long. 6° 46′ 30″ E. Faleide, Nordfjord, in Norway.—The following memorandum, supplied by a recent tourist in Norway as the result of numerous inquiries on the Nordfjord in about lat. 61° 53′, shows, as we should expect, a remarkable difference in the penetration of frost in a high European latitude. 'The ground at Faleide (on the Nordfjord) is frozen from one to two and a half feet deep about the Fjord in winter, but this depends upon how soon the snow falls. Higher up the mountains the ground is scarcely frozen at all, owing to the snow falling sooner, and, in fact, if the snow falls very early lower down it is scarcely frozen to any depth.'

8. Lat. 61° 51′, long. 125° 25′, Fort Simpson, on Mackenzie's River.—The summer's heat was found in October 1837 to have thawed the soil to a depth of 11 feet, below which was 6 feet of ground ice (Richardson), making the depth of descent of the frost 17 feet. The result is anomalous; at other posts in the same region the summer thaw is much more superficial. Thus, it will be observed above that in the month of October, at Fort Rae, the soil was at a nearly uniform temperature, but slightly above the freezing point, from the depth of 1 foot to 4 feet. Franklin found a summer thaw of only 22 inches at Great Bear Lake, and the writer was informed that it was only 14 inches at Fort Norman (lat. 64° 41′). Fort Simpson is situated on an island of deep alluvial soil, bearing timber of large size, and possessing an exceptional climate.

9. Lat. 57°, long. 92° 26′, York Factory, Hudson's Bay.—Sir J. Richardson has stated that the soil was found frozen to a depth of 19 feet 10 inches in October 1835, the surface being thawed to a depth of 2 feet 4 inches.

10. Lat. 55° 57′, long. 107° 24′. Lake à la Crosse.—It is stated that no frozen soil was found in sinking a pit to a depth of 25 feet in 1837, and that the earth was only frozen to a depth of 3 feet in the winter of 1841. Both records are anomalous, and call for verification.

11. Lat. 53° 40′, long. 113° 35′. At Prince Albert, on the Saskatchewan.—Mr. W. E. Traill, who was in charge of this post in 1872, reports that a settler in the neighbourhood came to frozen ground at a depth of 17 feet, but did not learn whether they passed through the frozen strata, or, if such was the case, what was the thickness of it. The same gentleman, writing from Lesser Slave Lake (lat. 55° 33′), remarks that he has never come across any indication of perpetual ice during the twenty-two years he has passed in the North-west Territory.

13. Mr. Andrew Flett, writing from Prince Albert, April 21, 1886, says:—'Hundreds of wells have been sunk in this settlement; one I had sunk myself, beginning of July 1881, 27 feet deep; saw no frozen earth. As far as I have noticed on this prairie land, when there is a good fall of snow when the winter sets in, the frost does not penetrate so deep as when there is no snow till late, and in some years very light snow. I had a pit opened on the 9th inst. (April); the surface was thawed 3 inches; we got through the frozen earth at 4 feet 7 inches. On the 11th inst. I saw a grave dug in the churchyard at Emmanuel College, one mile from my place, 5 feet deep, and had not got through the frost. My place is on higher ground, loam soil.'

14. Mr. W. Ramsay settled on the South Saskatchewan, 35 miles from here, sunk a well 40 feet, May 27, 1884; no frost.

15. Mr. Jos. Finlayson, 3 miles from here, sunk a well beginning of July 1882, 46 feet. He saw no frost.

16. Mr. J. D. Mackay, on the same section as the above, sunk a well 27 feet, July 15, 1884, found particles of frozen earth at 7 feet deep.

17. Mr. W. C. Mackay, my next neighbour half a mile west of this, sunk a well about June 20, 1884; found particles of frozen earth at 5½ feet.

18. Lat. 53° 32′, long. 113° 30′. Fort Edmonton, on the Saskatchewan, 2,400 feet above the sea. Dr. James Hector, on March 5, 1858, found the soil frozen to a depth of 7 feet 6 inches.[1]

19. Lat. 51° 14′, long. 102° 24′. At Yorkton Mr. J. Riaman, when digging a well last summer (1885), found the frost at a depth of 19 and 20 feet, and continuing for a depth of 30 inches. In this case, therefore, the total depth to which frost descended was about 22 feet. Mr. J. Tarbolton, of Yorkton, in communicating the last observation, remarks:—'The depth to which frost penetrates during the winter varies, I find, with the character of the winter itself, and with the nature of the locality. I made observations in an open unprotected spot, where there was little or no snow, and found frost to the depth of 5 feet 9 inches. This occurred last July, and the frost was then about 2 feet deep (*i.e.*, had descended to 7 feet 9 inches). But in the bluffs near my house I dug a cellar, at the same time, going down between 8 and 9 feet, encountering no frost at all.

'This year, however, when digging another well in April, in almost the same place, I encountered frost at 2 feet, and the ground continued solid until I had gone down from 4½ to 5 feet from the surface. From this, and from the information I obtained from others, I am safe in saying that the frost penetrates here to an average of 5 feet, except when we have had a great depth of snow in the beginning of winter, in which case it does not penetrate nearly so far. The bluffs referred to are groves of poplar from 3 to 6 inches in diameter, on the edge of an open plain.'

Mr. Charles Carpmael, Director of the Meteorological Service of Canada, to whom most of the above reports were addressed, remarks:—'We can easily imagine that at a depth of 17 feet at Prince Albert, there might be no frost at all in winter, but owing to the slow travelling downward of the wave of cold, it might have reached a depth of 17 feet in the early summer.

'It is easily seen that the annual mean temperature of the air might be considerably below the freezing point without the occurrence of permanently frozen soil, for in winter the soil is often covered deep in snow, so that the temperature of the soil might be but little below 32°, although the temperature of the air were 30° or 40° F. below zero. Again, the heat which had entered the soil in summer would only be removed by slow conduction, whereas the summer heat would not only travel downwards by conduction, but be carried into the soil by percolation of the warm water through the surface.'

20. Lat. 50° 30′, long. 103° 30′. The Bell farm, near Indian Head.—Frozen soil is said to have been met with in the summer of 1884 at a depth of 12½ feet; details are wanting.

21. Lat. 49° 53′, long. 97° 15′. City of Winnipeg and the neighbour-

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[1] *Journal R. G. S.* vol. xxx. p. 277.

hood.—Mr. Ch. N. Bell reports that frozen soil has been found as under in various cemeteries:—

Brookside Cemetery on the open prairie close to the city, soil rich black loam, varying in depth from one to two feet; subsoil heavy grey clay.

		On the Higher Ground		On the Lower Ground	
		ft.	in.	ft.	in.
December 23, 1884	Frozen to	0	10	2	2
January 3, 1885		1	0	3	0
March 21 „		1	4	3	6
May 6 „		4	4	5	0
June 25 „	None down to	6	0	6	0
January 14, 1886		0	10	1	6

A further communication of June 1, 1886, states that the frost only descended 3 feet 6 inches on the higher ground in the winter of 1885–6, and had at that date disappeared. It descended 5 feet in the lower ground, but had almost disappeared.

At St. John's Cemetery in the city.—'I am advised by the clergyman,' says Mr. Bell, 'that frost has been found at from five to eight feet depth;' careful investigation will be made there this year.

St. Boniface, a suburb of Winnipeg to the east.—The frost penetrates from five to eight feet, according to the season, varying locally under the conditions of the exposure, tillage, dryness, and heat or frost cracks. During the summer of 1885 frost was found at a depth of five feet, and down to seven feet, when the work was stopped. This was in July or early in August. The locality was probably exposed to the action of the sun.

22. Lat. 49° to 49½° long. In the valley of the river Pembina to the extreme south of the North-West Territory.—Dr. Alfred Selwyn, Director of the Geological Survey of Canada, who has two sons settled in this region, states that those gentlemen have had several wells sunk, the deepest about 40 feet, and have never seen any permanently frozen ground. There is similar negative evidence from Brandon, a little further north.

It would be premature to draw any general conclusions from the observations thus far collected. There is want of proof of the existence of permanent ground ice beyond the district of Mackenzie's River in the North-West, but frozen soil has been shown to exist at a depth of 17 feet at Fort Simpson, at Prince Albert, and at Yorkton, and it may be questioned whether the wave of summer heat has time to descend to such a depth before it is overtaken by the refrigerating influence of the early winter. It certainly exists also in the neighbourhood of Hudson's Bay, on the eastern side, and it is evident that under favourable conditions frost, without being permanent, may in some cases last in the soil all the year round over a wide area, and in other years disappear.

At whatever level we locate the maximum of absorbed heat, it must be remembered that when the winter sets in, and freezes the surface, which it does rapidly to the depth of a foot or two, the heat will then be abstracted in both directions, and its rate of descent checked.

No expense has been incurred. The Committee recommend that they be reappointed.

Report of the Committee, consisting of General J. T. Walker, General Sir J. H. Lefroy, Professor Sir William Thomson, Mr. Francis Galton, Mr. Alex. Buchan, Mr. J. Y. Buchanan, Dr. John Murray, Mr. H. W. Bates, *and* Mr. E. G. Ravenstein (*Secretary*), *appointed for the purpose of taking into consideration the Combination of the Ordnance and Admiralty Surveys, and the Production of a Bathy-hypsographical Map of the British Isles.*

1. The Committee consider that the production of a plain outline map of the British Isles and surrounding seas, on a scale of 1:200000 (about three miles to the inch) would be desirable.

Rivers, and such other physical features as can be shown in outline, to be marked distinctly. No hill-shading to be introduced. Roads, railways, towns, &c., to be indicated faintly, and merely for the purpose of identifying localities. Principal heights and depths above and below the datum level of the Ordnance Survey of Great Britain to be inserted.

Contours to be drawn at intervals of 200 feet, with subsidiary contours where they are necessary, to give expression to the features of the ground.

Incidental features, such as cliffs, &c., to be marked.

The map to be tinted according to height.

2. A grant of 25*l.* to be applied for in order that a specimen sheet of the map may be prepared.

3. The Clyde Trustees to be approached, with a view to their undertaking the preparation of a similar map of the Clyde estuary on a suitably larger scale.

Other harbour boards to be similarly approached.

4. The Committee anticipate that, being provided with maps of this character as specimens of what is required to supply a national want, the Association may be in a better position than at present to move the Government to undertake the preparation of a similar map of the whole of the United Kingdom, based mainly upon the extensive data already available in the archives of the Ordnance Survey and the Admiralty.

Report of the Committee, consisting of Sir Joseph D. Hooker, Sir George Nares, Mr. John Murray, General J. T. Walker, Admiral Sir Leopold McClintock, Mr. Clements Markham, *and* Admiral Sir Erasmus Ommanney (*Secretary*), *appointed for the purpose of drawing attention to the desirability of further research in the Antarctic Regions.*

Your Committee, after having given full consideration to the great importance of effecting a further exploration of the Antarctic Polar Sea, desire, in the first place, to express their opinion that it would be most essential, before approaching H.M. Government with the view of urging the expediency of equipping such a naval expedition as would be required for the carrying out an exploration of such magnitude, interest, and importance, that the requirements for its success and a plan of operations should be most carefully considered, and the results embodied in a written form for the approval of the Council of the Association and for the information of the Government.

Furthermore, in order to obtain the co-operation which the matter requires from eminent men in science, your Committee feel it necessary for their body to be enlarged by the addition of influential members of the Association, and of other bodies representing the various branches of science interested in the investigation of this comparatively unknown region, and especially of the Royal Geographical Society.

Your Committee have to point out that our knowledge of the South Polar region is chiefly confined to the grand discoveries effected by that celebrated expedition under the command of Captain Sir James C. Ross, conducted between the years 1839 and 1843 with sailing ships. Since that period the facilities for effecting a more complete research have been greatly augmented by the application of steam propulsion to vessels better adapted for ice navigation. This has been proved by continuous experience in the Arctic seas during the late half-century.

For the above reasons your Committee deem it desirable to defer making their report, with a view to giving more definition to the objects sought to be obtained and to the best means of obtaining them, as also to expand this Committee, in order to elicit to the fullest extent the opinions and to secure support from those conversant with the various branches of science which are to be investigated during an exploration which, from its very important and serious nature, eminently merits the favourable consideration of this great and enterprising maritime nation.

Report of the Committee, consisting of Dr. J. H. GLADSTONE, (*Secretary*), Professor ARMSTRONG, Mr. WILLIAM SHAEN, Mr. STEPHEN BOURNE, Miss LYDIA BECKER, Sir JOHN LUBBOCK, *Bart.*, Dr. H. W. CROSSKEY, Sir RICHARD TEMPLE, *Bart.*, Sir HENRY E. ROSCOE, Mr. JAMES HEYWOOD, *and* Professor N. STORY MASKELYNE, *appointed for the purpose of continuing the inquiries relating to the teaching of Science in Elementary Schools.*

No steps in advance have been taken by any Government Department towards the more adequate provision for science teaching in elementary schools during the past year. There have been four different Vice-presidents of the Committee of Council on Education during the last twelve months; and Sir Lyon Playfair only came into office after the code for the year had been settled.

The annual return of the Education Department for England and Wales issued this year, which deals with the period from September 1, 1884, to August 31, 1885, shows that the present regulations tell unfavourably on the prospects of science.

The following statistics for the last three years show that, while the Preferential class subject ‘English’ is taken in an increasing number of departments year by year, geography shows an actual falling-off, and elementary science seems even to be losing the little footing it had.

Needlework shows a steady increase, as it is an obligatory subject in girls' schools, and it is more advantageous in a financial point of view to take it up as a class subject rather than under Article 109 (*c*), in which case it necessarily displaces geography or science:—

Class Subjects		1882–3	1883–4	1884–5
English	Departments	18,363	19,080	19,431
Geography . . .	,,	12,823	12,775	12,336
Elementary Science . .	,,	48	51	45
History	,,	367	382	386
Needlework	,,	5,286	5,929	6,499
		18,524	19,137	19,266

It must be borne in mind that the figures against 'English' represent in all cases complete departments, although those against the other subjects do not necessarily do so, as it is optional to break up the second class subject into two, in which case they count double in the official return. This applies in all cases to history, as it cannot be taken in the lower division; and there are about 3,000 mixed schools in which the boys take geography while the girls take needlework; there must therefore be some 3,500 departments in which no other class subject but 'English' is taught at all.

The anticipated reduction in the teaching of geography or science on account of drawing being made a class subject does not make its appearance in the figures of the foregoing table, and it can scarcely be expected to affect sensibly the figures of next year, as the time for the change from the Science and Art Department to the Education Department was postponed, but a considerable effect will probably be manifest two years hence.

In regard to the scientific specific subjects the following are the number of children individually examined:—

Specific Subjects		1882–3	1883–4	1884–5
Algebra	Children	26,547	24,787	25,347
Euclid and Mensuration . .	,,	1,942	2,010	1,269
Mechanics A	,,	2,042	3,174	3,527
,, B	,,	—	206	239
Animal Physiology . . .	,,	22,759	22,857	20,869
Botany	,,	3,280	2,604	2,415
Principles of Agriculture . .	,,	1,357	1,859	1,481
Chemistry	,,	1,183	1,047	1,095
Sound, Light, and Heat . .	,,	630	1,253	1,231
Magnetism and Electricity .	,,	3,643	3,244	2,864
Domestic Economy . . .	,,	19,582	21,458	19,437
Extra (Physiography) . .	,,	—	16	—
		82,965	84,515	79,774
No. of Scholars in Standards V., VI., VII. .		286,355	325,205	352,860

It is evident that while the number of scholars in the higher standards has considerably increased, the number examined in specific (scientific) subjects has considerably decreased; and this decrease has occurred in every subject except mechanics. Algebra and chemistry show rather larger numbers than last year, though not in proportion to the increase of scholars.

The comparative decrease in the attention paid to these scientific subjects will be evident from the percentages of children examined:—

In 1882–3	29·0 per cent.
In 1883–4	26·0 ,,
In 1884–5	22·6 ,,

but it must be borne in mind that in many schools the children take two subjects, in which case they count accordingly.

Increased though still very inadequate attention seems to be paid in the training colleges to the preparation of the students in the science subjects; the number of individual students who have qualified for teaching one or more sciences has risen from 2,205 in 1884 to 2,407 in 1885, and it is satisfactory to note that the increase has been mainly in passes in the first class. The number of papers worked in the several subjects in the two years under review has been as follows:—

Number of Papers worked	1884	1885
Pure Mathematics	82	121
Theoretical Mechanics	21	25
Sound, Light, and Heat	488	690
Magnetism and Electricity	693	551
Inorganic Chemistry	245	269
,, ,, practical	166	160
Animal Physiology	416	257
Botany	485	483
Physiography	1,030	1,095
Principles of Agriculture	289	386

The increase has been mainly in sound, light, and heat, and the principles of agriculture; the falling-off has been chiefly in animal physiology, and magnetism and electricity.

The Scotch Code differs from the English in regard to the teaching of science in several points, but the annual return does not exhibit a much more hopeful state of affairs.

The importance of technical instruction is making rapid progress in popular estimation, but this subject has not got a real footing as yet in elementary schools, owing to the inaction of the Government pending a definite expression of opinion by the House of Commons. In the meantime the Nottingham School Board has started classes for instruction in the use of tools in the workshops of University College, and 106 boys received such lessons during the last quarter; but on applying to the Education Department the Board learnt that, as the code did not recognise such experimental instruction, the two hours per week devoted to it could not be recognised as an attendance. They therefore drew up a memorial to the following effect:—

'That your memorialists are of opinion it is very desirable that promising boys should receive some elementary manual instruction before the close of their school career.

'That your memorialists have established a technical class for boys who have passed through a course of lessons under the Board's science demonstrator, and are thus specially prepared for this kind of instruction.

'That the department has informed the Board the code does not recognise such experimental instruction in workshops, and that the two hours per week devoted to such instruction cannot be reckoned as an attendance for the purpose of Article 12.

'That twenty boys attending the People's College Higher Grade Board School have been under instruction one half-day per week since October last at the Nottingham University College Technical Workshops, and that the experimental scheme of the Board has worked satisfactorily.

'That, in the opinion of the Board, the scheme might usefully be extended to the ordinary Board schools, which are also visited by the Board's science demonstrator. In answer to recent inquiries, ninety-six boys are reported as willing to pay a quarterly fee of 2*s.* 6*d.* for instruction at the technical workshops during one half-day per week, whilst sixty-six boys are desirous of attending but are unable to pay the fee.

'That, inasmuch as technical education, including the use of wood and iron tools, is of as much importance to senior boys as needlewook and practical cookery are to girls, your memorialists respectfully urge the department to sanction elementary technical instruction as part of the recognised school course, and to allow payments for boys thus taught, either by inclusion of the subject as another specific—Schedule IV. and Article 109 (*g*)—or by making a grant similar to that now given for instruction in cookery—Article 109 (*h*).

'Your memorialists would beg your careful consideration of the confirmatory evidence of the recent Royal Commissioners on Technical Education, who state in their second report (vol. i.) that they are satisfied that such manual work "is very beneficial as a part of the preliminary education of boys in this country who are to be subsequently engaged in industrial pursuits" (p. 524). "Your commissioners see no reason why, since grants are made on needlework in girls' schools, they should not be made on manual work in boys' schools" (p. 524), and recommend "that proficiency in the use of tools for working in wood and iron be paid for as a specific subject" (p. 537).'

This memorial has been supported by the School Boards for London, Birmingham, Gateshead, Huddersfield, Bristol, Swansea, Salford, Derby, Norwich, and Ipswich.

The same difficulty has been met with by the London Board in regard to its experiment in the use of tools, referred to in our last report, though it appears to have given much satisfaction to the boys, their parents, and the Board: it formed the subject of a question by Sir Bernhard Samuelson in the House of Commons, and he has stated his intention of bringing the matter forward again in some more definite form.

The earlier age at which children pass their standards in elementary subjects is bringing to the front the question of those who, having passed Standard VII., are willing to remain at school and take up higher subjects. Under present arrangements no grant can be earned from the Education Department for such children, and, although larger grants can be earned from the Science and Art Department, it is a matter of doubt whether School Boards can legally expend in teaching such children any sum beyond that of the fees and grants received. In the case of large classes the income from these sources might be sufficient, but in the majority of cases this cannot be secured; and it becomes a matter for consideration whether distinct sanction should not be given by the legislature to incurring the necessary expenses for this purpose.

Report of the Committee, consisting of Professor SIDGWICK, Professor FOXWELL, *the* Rev. W. CUNNINGHAM, *and* Professor MUNRO (*Secretary*), *on the Regulation of Wages by means of Sliding Scales.*

WITH the object of obtaining definite information on the working of sliding scales, your Committee issued a circular to associations of mine-owners and miners in different parts of the country asking for detailed answers on certain aspects of sliding scales. Owing to various causes, as yet only a few replies have been received. These replies are, however, very valuable, as they clearly show that each scale has special characteristics of its own, and that no comparison can be instituted between the various scales without taking into account the exact circumstances under which each scale was framed. For instance, in some districts special allowances in the way of a free house and coal are made to miners, whilst in other districts no such allowances are made. The replies received by your Committee tend to show that in the last-mentioned districts the non-allowance of a free house and coal was taken into account when the standard rates of wages were fixed, and thus an apparent inequality in two scales is definitely explained.

1. The original standards seem all to have been fixed on a common principle, viz., to take the price of coal then realised, and the wages then paid, as representing a fair and equitable division of the produce between the mine-owner and the miner, and as giving as high a wage as the industry could then afford. Some districts adopted the price of all coal sold, other districts the price of all coal raised, as the standard price. All the coal that is raised from a mine is not necessarily sold, as out of every 100 tons raised, about twenty tons are not available for the market, part being refuse, part being consumed by the engines that work the mine, and in some cases part going to the miners. No attempt was made to reduce wages to a level, the wages payable at every mine being taken as the standard wage. The real economic difficulty in framing the scale began when it had to be determined what proportion of a rise or fall in price should go to the men and what to the mine-owners. Both parties contemplated a rise rather than a fall in prices, and the changed conditions of the coal and iron industry have exposed the scales to some opposition, but their wise revision from time to time has maintained their influence with both masters and men.

2. (*a*) Free house and firing are usually given in addition to the wages mentioned in the scales, and in Cumberland, where there are no such allowances, compensation is given by the scale itself in the form of higher rates.

Apart from this, local considerations may add to or diminish the standard wages. For instance, if the working of the mine becomes more difficult an addition to the ordinary wages is usually conceded. The concession of such addition may be given by the mine-owner himself, but frequently it comes before the Committee or Board of Arbitration charged with the carrying out of the scale, and to whom all disputes are referred.

(*b*) The miner bears the expenses of lamps, powder, and tools, such as picks, shafts, sharping gear, &c. In South Wales this represents a cost of from 3*d.* to 1*s.* per week. In Cumberland it is estimated by the miners as averaging 2½*d.* per day, or taking 58½ working days for the quarter, 12*s.* 2½*d.* per quarter. The actual deduction from wages per ton in respect of the above expenses at one colliery in Cumberland was, in 1875, as follows:—

	d.	
March quarter	0·69	per ton.
June quarter	0·90	,,
September quarter	0·48	,,
December quarter	0·48	,,

In Cumberland the hewers voluntarily contribute one penny per week towards the expenses of carrying on the sliding scale, such as the cost of taking out the quarterly returns. The cost per ton to the hewers in this respect for the year 1885 was as follows:—

	d.	
March quarter	0·11	per ton.
June quarter	0·11	,,
September quarter	0·10	,,
December quarter	0·09	,,

3. The difficulties in the way of basing a scale not merely on the selling price, but on variable elements in the cost of production are universally admitted; but there is little doubt that when one trade depends on another, variations in the cost of the raw material would require to be taken into account in fixing wages. The coal trade has escaped the difficulty owing to the royalties being fixed for a considerable period of time. But were a sliding scale adopted in other trades it might not be successful, unless the price of raw material were one of the elements on which the division of the produce was made to depend. Further information on this important point is very desirable.

4. *Royalties.*—The principle of the sliding scale does not seem to have been applied to royalties to any great extent, though in some mines the landlord receives a certain proportion of the price as his royalty.

The royalty paid varies from 4*d.* to 1*s.* per ton, averaging about 8*d.* per ton. Hewers' wages vary from 7*d.* to 3*s.* per ton, though it must be remembered that there are many classes of men other than hewers employed about a mine.

Inasmuch as several gentlemen have promised further valuable information on the working of sliding scales, it is desirable that the Committee be reappointed, and it is suggested that in view of the meeting in Manchester next year their inquiries might be extended to the wages lists in the cotton industry.

Report of the Committee, consisting of Mr. H. W. BARLOW, Sir F. J. BRAMWELL, Professor J. THOMSON, Captain D. GALTON, Mr. B. BAKER, Professor W. C. UNWIN, Professor A. B. W. KENNEDY, Mr. C. BARLOW, Mr. A. T. ATCHISON (*Secretary*), *and* Professor H. S. HELE SHAW, *for obtaining information with reference to the Endurance of Metals under repeated and varying stresses, and the proper working stresses on Railway Bridges and other structures subject to varying loads.*

THE Committee have to report that certain special experiments have been undertaken by Sir J. Fowler and Mr. Benjamin Baker.

As, however, these are not yet complete, and the most recent investigations into the question of the endurance of metals now being carried on under the authority of the German Government have not yet reached such a stage that results can be communicated, the Committee request that they may be reappointed.

Report of the Committee, consisting of Dr. GARSON, Mr. PENGELLY, Mr. F. W. RUDLER, *and* Mr. G. W. BLOXAM (*Secretary*), *for investigating the Prehistoric Race in the Greek Islands.*

THE Committee beg to report that during the winter they have obtained the services of Mr. Theodore Bent, a gentleman who has devoted much time and attention to the study and investigation of Greek antiquities. Mr. Bent and his wife spent several months in the Grecian Archipelago last winter and spring, and during the time conducted researches for the Committee at places which they visited. The Committee have much satisfaction in expressing their indebtedness to Mr. and Mrs. Bent for the valuable assistance they have rendered under somewhat difficult circumstances. The work they have been able to do has been carried on with the aid of the grant placed at the disposal of the Committee at the Aberdeen Meeting of the Association, but this has been supplemented by Mr. Bent himself, so that more work has been undertaken than would have been possible with the grant alone. The result of excavations in graves on Amorgos, Antiparos, Anaphi, and Astypalæa were similar to those about which Mr. Bent read a paper at the last meeting of the Association, consisting of numerous small marble figures, marble vases, earthenware vases, and obsidian knives of the prehistoric period; in addition to these, a considerable number of skulls and bones were laid aside to be sent with them, the value of the finds far exceeding the outlay, judging by the price given by the British Museum for the things brought home before by Mr. Bent. In addition to this some slight excavations were made at the Temple of Apollo at Anaphi, and some few trifling objects of the Hellenic period were found.

The Committee ask for reappointment with a renewal of the grant.

Second Report of the Committee, consisting of Dr. E. B. Tylor, Dr. G. M. Dawson, General Sir J. H. Lefroy, Dr. Daniel Wilson, Mr. R. G. Haliburton, *and* Mr. George W. Bloxam (*Secretary*), *appointed for the purpose of investigating and publishing reports on the physical characters, languages, and industrial and social condition of the North-western Tribes of the Dominion of Canada.*

The Committee beg to report that during the past year an extensive correspondence has been carried on with representatives of the Hudson Bay Company, missionaries, and others who are in constant contact with the Indians, and that a large amount of material is gradually being collected. A series of questions is in course of being drawn up, and it is hoped that these will bring in much valuable information during the winter. Mr. Horatio Hale has, unfortunately, been prevented from making his promised visit to the Indian tribes during the past year, but the Committee hope that next spring Mr. Hale will be able to carry out his intention of visiting the North-West, and they have to acknowledge their indebtedness to Mr. Hale for much of the information already collected.

Mr. R. G. Haliburton has promised to place at the disposal of the Committee the replies of Canadian Indian agents, through the Indian Department, to circulars sent to them by him in 1870 and 1871, and also a statement of the Chief Factor of the Hudson Bay Company at Queen Charlotte Island respecting the customs, beliefs, &c., of the Indians there.

The Committee ask for reappointment.

Report to the Council of the Corresponding Societies Committee, consisting of Mr. Francis Galton (*Chairman*), Professor A. W. Williamson, Captain Douglas Galton, Professor Boyd Dawkins, Sir Rawson Rawson, Dr. J. G. Garson, Dr. J. Evans, Mr. J. Hopkinson, Professor R. Meldola (*Secretary*), Mr. W. Whitaker, Mr. G. J. Symons, *and* General Pitt-Rivers.

The Corresponding Societies Committee of the British Association beg to submit to the Council a statement of the work done at Aberdeen by the Conference of Delegates, with comments thereon.

Two Conferences were held—one on Thursday, September 10, and the other on Tuesday, September 15—both meetings having been called at 3.15 p.m., and lasting in each case about one hour.

The following is the list of the Delegates nominated, and of the Societies represented by them:—

Prof. J. W. H. Trail, M.A.	Aberdeen Natural History Society.
Mr. Thomas Lister	Barnsley Naturalists' Society.
Rev. George Robinson	Belfast Naturalists' Field Club.
Rev. H. Boydon	Birmingham Natural History and Microscopical Society.

Rev. H. W. Crosskey, LL.D., F.G.S.	Birmingham Philosophical Society.
Mr. R. T. Glazebrook, F.R.S.	Cambridge Philosophical Society.
Dr. C. Vachell	Cardiff Naturalists' Society.
Dr. J. Gilchrist	Dumfriesshire and Galloway Natural History Society.
Dr. J. Howden	East of Scotland Union of Naturalists Societies.
Prof. W. Ivison Macadam, F.C.S.	Edinburgh Geological Society.
Prof. R. Meldola, F.C.S.	Essex Field Club.
Mr. J. Barclay Murdoch	Geological Society of Glasgow.
Dr. John Evans, F.R.S.	Hertfordshire Natural History Society.
Mr. Alexander Ross	Inverness Scientific Society and Field Club
Mr. R. L. Tapscott	Liverpool Engineering Society.
Mr. G. H. Morton, F.G.S.	Liverpool Geological Society.
Mr. Mark Stirrup, F.G.S.	Manchester Geological Society.
Mr. D. Corse Glen, F.G.S.	Natural History Society of Glasgow.
Mr. W. D. Spanton, F.R.C.S.	North Staffordshire Naturalists' Field Club.
Mr. Robert Pullar, F.R.S.E.	Perthshire Society of Natural Science.
Mr. R. G. Hobbes	Rochester Naturalists' Club.
Prof. W. H. Flower, F.R.S.	Royal Geological Society of Cornwall.
Mr. Coutts Trotter	Scottish Geographical Society.
Mr. Charles P. Hobkirk, F.L.S.	Yorkshire Naturalists' Union.

At the first meeting, Mr. Francis Galton, F.R.S., in the chair, the Secretary, Prof. R. Meldola, read the first report of the Corresponding Societies Committee, which had been presented to the Council, and adopted by the General Committee of the British Association.

Methods of procedure were then discussed, and explanations as to the functions of the Conference were given by the Chairman and Secretary in reply to questions or otherwise. In accordance with Rule 7, relating to Corresponding Societies, a short discussion took place, at the invitation of the Chairman, respecting the nature of the work which admitted of being taken up by Local Societies.

At the second meeting, Mr. Francis Galton, F.R.S., in the chair, the recommendations forwarded by the Secretaries of the Sections, in accordance with Rule 7, were read to the Delegates:—

FROM SECTION C.

Erratic Block Committee.—'That Professors J. Prestwich, W. Boyd Dawkins, T. McK. Hughes, and T. G. Bonney, Dr. H. W. Crosskey, and Messrs. C. E. De Rance, H. G. Fordham, J. E. Lee, D. Mackintosh, W. Pengelly, J. Plant, and R. H. Tiddeman be reappointed a Committee for the purpose of recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England, Wales, and Ireland, reporting other matters of interest connected with the same, and taking measures for their preservation; and that Dr. H. W. Crosskey be the Secretary.'

Underground Water Committee.—'That Professor E. Hull, Dr. H. W. Crosskey, Captain Douglas Galton, Professor J. Prestwich, and Messrs. James Glaisher, E. B. Marten, G. H. Morton, James Parker, W. Pengelly, James Plant, I. Roberts, Fox Strangways, T. S. Stooke, G. J. Symons, W. Topley, Tylden-Wright, E. Wethered, W. Whitaker, and C. E. De Rance be reappointed a Committee for the purpose of investigating the Circulation of the Underground Waters in the Permeable Formations of England, and the Quality and Quantity of the Water supplied to various towns and districts from these formations; and that Mr. De Rance be the Secretary.'

Sea-Coast Erosion Committee.—'That Messrs. R. B. Grantham, C. E. De Rance, J. B. Redman, W. Topley, W. Whitaker, J. W. Woodall, Major-General Sir A. Clarke, Admiral Sir E. Ommanney, Sir J. N. Douglass, Captain Sir F. J. O. Evans, Captain J. Parsons, Captain W. J. L. Wharton, Professor J. Prestwich, and Messrs. E. Easton, J. S. Valentine, and L. F. Vernon Harcourt be reappointed a Committee for the purpose of inquiring into the Rate of Erosion of the Sea-coasts of England and Wales, and the Influence of the Artificial Abstraction of Shingle or other Material in that action; and that Messrs. C. E. De Rance and W. Topley be the Secretaries.'

Mr. C. E. De Rance, who attended the Conference on behalf of Section C, made brief statements explanatory of the work of each of the foregoing Committees, and pointed out the manner in which assistance could be rendered by the Local Societies. He stated that Corresponding Societies or individual members of these willing to assist in the inquiries of any of these three Committees could obtain full particulars on application to himself at 28 Jermyn Street, London, S.W.

FROM SECTION D.

A letter was read from the Secretary of this Section transmitting a recommendation that the subject of the preservation of the native plants of this country should be brought under the notice of the Local Societies, and deputing Professor W. Hillhouse to bring this subject before the Delegates present at the Conference.

In accordance with the foregoing recommendation, Professor Hillhouse gave numerous instances of the extermination of rare plants from certain localities by dealers, to whom their habitat had become known. He stated that, having been empowered by the Sectional Committee to represent their views on this subject, he submitted the following protest:—

'We view with regret and indignation the more or less complete extirpation of many of our rarest or most interesting native plants. Recognising that this is a subject in which Local Societies of naturalists will take great interest, and can exercise especial influence, we urge upon the Delegates of Corresponding Societies the importance of extending to plants a little of that protection which is already accorded by Legislature to animals and prehistoric monuments, and of steadily discouraging and, where possible, of preventing any undue removal of such plants from their natural habitats; and we trust that they will bring these views under the notice of their respective Societies.'

FROM SECTION H.

The following recommendation from the Committee of this Section was read by the Secretary of the Conference:—

Racial Characters Committee.—'That Mr. Francis Galton, Dr. Beddoe, Mr. Brabrook, Professor Cunningham, Professor Flower, Mr. J. Park Harrison, Professor A. MacAlister, Dr. Muirhead, Mr. F. W. Rudler, Professor Thane, and Dr. Garson (Secretary) be reappointed a Committee for the purpose of defining the Racial Characters of the Inhabitants of the British Isles.'

Dr. Garson, who attended the Conference on behalf of the Section, explained the objects of this Committee, and invited the co-operation of the Local Societies. He stated that particulars respecting the work of this Committee would be obtained on application to himself at the Royal College of Surgeons, Lincoln's Inn Fields, London, W.C.

It was then arranged: (1) That those gentlemen (or, if more convenient, the Chairman or the Secretary of the Committees they severally represent) should communicate with each of the Delegates as soon as the details of their proposed investigations had been matured. (2) That each Delegate should thereupon do his best to interest the members of his Society, and, if thought desirable, the Society itself, in the subject of investigation, and should send to his correspondent the names and addresses of such persons in his neighbourhood as might be likely to render willing and effectual help, so as to put him at once in direct communication with them.

The Committee now beg to report that at their last meeting, held on June 9, 49 applications from Local Societies for enrolment as Corresponding Societies were considered, and of these 36 are recommended for election. Twelve of last year's Corresponding Societies have not yet applied for re-election, but, as this omission may have arisen from an imperfect understanding of the rules, the Committee have communicated with the Secretaries of these Societies in order to receive their explanation. The list of selected Societies and the catalogue of their papers on local subjects published since the last Report is appended.

Selected List of Societies Recommended by the Corresponding Societies Committee for Election as Corresponding Societies of the British Association.

Full Title and Date of Foundation	Abbreviated Title	Head-quarters or Name and Address of Secretary	No. of Members	Entrance Fee	Annual Subscription	Title and Frequency of Issue of Publications
Bath Natural History and Antiquarian Field Club, 1855	Bath N. H. A. F. C.	Rev. H. H. Winwood, Royal Literary and Scientific Institution, Bath	94	5s.	10s.	Proceedings. Annually.
Bedfordshire Natural History Society and Field Club, 1875	Beds. N. H. S. F. C.	T. Gwyn Elger, F.R.A.S., Hempston, Beds.	75	None	5s.	Transactions. Every two years.
Belfast Naturalists' Field Club, 1863	Belfast Nat. F. C.	William Swanston, F.G.S., 50 King Street, Belfast	310	None	5s.	Report and Proceedings. Annually.
Birmingham Natural History and Microscopical Society, 1858	Birm. N. H. M. Soc.	John Morley and W. H. Wilkinson, Mason College, Birmingham	240	None	1l. 1s.	'Midland Naturalist.' Monthly.
Birmingham Philosophical Society	Birm. Phil. Soc.	R. Levett and J. H. Poynting, Medical Institute, Birmingham	124	None	1l. 1s.	Proceedings. Annually.
Bristol Naturalists' Society, 1862	Bristol Nat. Soc.	University College, Bristol. Professor Adolph Leipner, 47 Hampton Park, Clifton, Bristol	183	5s.	10s.	Proceedings. Annually.
Burton-on-Trent Natural History and Archæological Society	Burt. N. H. Arch. Soc.	Burton Institute. Frank E. Lott, Bridge Chambers, Burton	145	None	5s.	Annual Report. Transactions occasionally.
Cardiff Naturalists' Society	Cardiff Nat. Soc.	J. Gavey, Clieve House, Cardiff	450	None	10s.	Report and Transactions. Annually.
Chester Society of Natural Science, 1871	Chester Soc. Nat. Sci.	Museum. G. R. Griffith, Grosvenor Street, Chester	545	None	5s.	Annual Report; Proceedings every three or four years.
Chesterfield and Midland Counties Institution of Engineers, 1871	Chesterf. Mid. Count. Inst.	Stephenson Memorial Hall. W. F. Howard, 13 Cavendish Street, Chesterfield	263	1l. 1s.	1l. 11s. 6d.	Transactions. Quarterly.
Cornwall, Mining Association and Institute of, 1884	Cornw. Min. Assoc. Inst.	William Thomas, Tuckingworth, Camborne	215	10s. 6d.	10. 6d. minimum	Transactions. Annually.
Cornwall, Royal Geological Society of	Cornw. R. Geol. Soc.	G. B. Millett, Penzance	115, and 17 Associates	None	1l. 1s.	Report and Transactions. Annually
Cumberland and Westmoreland Association for the Advancement of Literature and Science, 1876	Cumb. West. Assoc.	W. J. R. Crowder, jun., M.A., Stanwix, Carlisle	1,259 (belonging to affiliated Societies)	None	5s.	Transactions. Annually.
Dorset Natural History and Antiquarian Field Club	Dorset N. H. A. F. C.	M. G. Stuart, East Harptree, near Bristol	170	None	10s.	Proceedings. Annually. Additional volumes occasionally.

SELECTED LIST OF SOCIETIES, &c. (*continued*).

Full Title and Date of Foundation	Abbreviated Title	Head-quarters or Name and Address of Secretary	No. of Members	Entrance Fee	Annual Subscription	Title and Frequency of Issue of Publications
Dumfriesshire and Galloway Scientific, Natural History, and Antiquarian Society, 1876	Dum. Gal. Sci. N. H. Soc.	Dumfries. J. Wilson, 3 Norfolk Terrace, Dumfries	204	2*s.* 6*d.*	2*s.* 6*d.*	Transactions and Proceedings. Every two years.
East Kent Natural History Society	E. Kent. N. H. Soc.	William P. Mann, 6 High Street, Canterbury	87	None	10*s.*	Transactions. Occasionally.
East of Scotland Union of Naturalists' Societies, 1884	E. Scot. Union	William D. Sang, 12 Townsend Crescent, Kirkcaldy, N.B.	10 Societies	None	Variable assessment	Proceedings. Annually.
Edinburgh Geological Society, 1834	Edinb. Geol. Soc.	Thomas Stock, 16 Colville Place, Edinburgh	241	10*s.* 6*d.*	12*s.* 6*d.*	Transactions. Annually.
Essex Field Club, 1880	Essex F. C.	William Cole, 7 Knighton Villas, Buckhurst Hill, Essex	450	10*s.* 6*d.*	10*s.* 6*d.*	Transactions, Proceedings, and Special Memoirs. Irregularly.
Glasgow, Geological Society of, 1858	Glasgow Geol. Soc.	J. B. Murdoch, 207 Bath Street, Barclay Langside, Glasgow	250	None	10*s.*	Transactions. Annually.
Glasgow, Natural History Society of, 1851	Glasgow N. H. Soc.	D. A. Boyd and W. Goodwin, 207 Bath Street, Glasgow	277	7*s.* 6*d.*	7*s.* 6*d.*	Proceedings and Transactions. Annually.
Glasgow, Philosophical Society of, 1802	Glasgow Phil. Soc.	Prof. J. G. McKendrick, 207 Bath Street, Glasgow	729	1*l.* 1*s.*	1*l.* 1*s.*	Proceedings. Annually.
Hertfordshire Natural History Society and Field Club, 1875	Herts N. H. Soc.	F. G. Lloyd, Westleigh, Watford, Herts	300	10*s.*	10*s.*	Transactions. About five parts annually.
Holmesdale Natural History Club	Holmesdale N. H. C.	T. P. Newman, Springfield, Reigate, Surrey (*pro tem.*)	84	10*s.*	10*s.*	Proceedings every two or three years.
Inverness Scientific Society and Field Club, 1875	Inverness Sci. Soc.	Thomas Wallace, High School, Inverness	160	None	5*s.*	Transactions. Occasionally.
Ireland, Royal Geological Society of, 1831	R. Geol. Soc. Ireland	Prof. W. J. Sollas, F.G.S., Trinity College, Dublin	140	None	1*l.* 1*s.*	Journal. Generally annually.
Ireland, Statistical and Social Inquiry Society of, 1847	Stat. Soc. Ireland	W. F. Bailey, 35 Molesworth Street, Dublin	190	None	1*l.*	Journal. Annually.
Leicester Literary and Philosophical Society	Leicester Lit. Phil. Soc.	C. J. Billson, M.A., St. John's Lodge, Clarendon Park Road, Leicester	300	None	1*l.* 1*s.*	Report and Transactions. Annually.
Liverpool Engineering Society	Liv'pool E. Soc.	Royal Institution. Thomas L. Miller, 19 Percy Street, Liverpool	128	None	1*l.* 1*s.* and 10*s.* 6*d.* (students)	Transactions. Annually.
Liverpool Geological Society	Liv'pool Geol. Soc.	Royal Institution. W. Hewitt, B.Sc., 21 Verulam Street, Liverpool	54	None	1*l.* 1*s.* for Res. Members	Proceedings. Annually.
Liverpool, Literary and Philosophical Society of	Liv'pool Lit. Phil. Soc.	Royal Institution. James Birchall, Kirkdale, Liverpool	320	10*s.* 6*d.*	1*l.* 1*s.*	Proceedings. Annually.
Liverpool Microscopical Society	Liv'pool Mic. Soc.	Royal Institution, Liverpool. Isaac C. Thompson, Woodstock, Waverley Road, Liverpool	162	10*s.* 6*d.*	10*s.* 6*d.*	Transactions. Annually.

Man, Isle of, Natural History and Antiquarian Society, 1879	I. of Man N. H. A. Soc.	W. J. Cain, Woodbourne Square, Douglas, Isle of Man	90	2*s.* 6*d.*	5*s.*	—
Manchester Geological Society, 1838	Manch. Geol. Soc.	36 George Street, Manchester	?	None	1*l.*	Transactions. Nine or ten parts annually.
Manchester Statistical Society, 1833	Manch. Stat. Soc.	Francis E. M. Beardsall and G. H. Pownall, 25 Booth Street, Manchester	193	10*s.* 6*d.*	10*s.* 6*d.*	Transactions. Annually.
Marlborough College Natural History Society, 1864	Marlb. Coll. N. H. Soc.	The College, Marlborough. Rev. T. N. Hart Smith (Pres.)	124	1*s.* 6*d.*	1*s.*	Annual Report.
Midland Union of Natural History Societies, 1877	Mid. Union	Thomas H. Waller, 71 Gough Road, Birmingham	2,000	—	—	'Midland Naturalist.' Monthly.
North of England Institute of Mining and Mechanical Engineers, 1852	N. Eng. Inst.	Newcastle-on-Tyne. Theo. Wood Bunning	774	—	21*s.*, 42*s.*, 63*s.*	Transactions. Annually.
North Staffordshire Naturalists' Field Club and Archæological Society, 1865	N. Staff. N. F. C. A. Soc	Rev. T. W. Daltry, M.A., Madeley Vicarage, Newcastle, Staffs.	469	5*s.*	5*s.*	Report. Annually.
Northamptonshire Natural History Society and Field Club, 1876	N'ton. N. H. Soc.	The Museum, Guildhall Road. H. J. Eunson, 20 St. Giles Street, Northampton	212	None	10*s.*	Journal. Quarterly.
Paisley Philosophical Institution, 1808	Paisley Phil. Inst.	J. Gardner, 3 County Place, Paisley	340	5*s.*	7*s.* 6*d.*	Report. Annually.
Penzance Natural History and Antiquarian Society, 1839	Penz. N. H. A. Soc.	G. B. Millett and E. D. Marquand, Penzance	95	None	10*s.* 6*d.*	Report and Transactions. Annually.
Perthshire Society of Natural Science, 1867	Perths. Soc. N. Sci.	Tay Street, Perth. S. T. Ellison	330	2*s.* 6*d.*	5*s.* 6*d.*	Proceedings. Annually.
Rochester Naturalists' Club, 1878	Rochester N. C.	Sir Joseph Williamson's Mathematical School, Rochester. John Hepworth	118	2*s.* 6*d.*	3*s.* 6*d.*	'Rochester Naturalist.' Quarterly.
Scottish Geographical Society, 1884	Scot. Geog. Soc.	80A Princes Street, Edinburgh. N. Silva White	1,065	None	1*l.* 1*s.*	Monthly Magazine.
South African Philosophical Society, 1877	S. African Phil. Soc.	W. H. Finlay, M.A., Royal Observatory, Cape of Good Hope	—	—	2*l.*	Transactions. Annually.
Warwickshire Naturalists' and Archæologists' Field Club, 1854	Warw. N. A. F. C.	Rev. P. B. Brodie, M.A., Rowington Vicarage, Warwick	Limited to 100	2*s.* 6*d.*	5*s.*	Proceedings. Annually.
Yorkshire Geological and Polytechnic Society, 1837	Yorks. Geol. Poly. Soc.	James W. Davis, Chevinedge, Halifax	250	None	13*s.*	Proceedings. Annually.
Yorkshire Naturalists' Union	Yorks. Nat. Union	W. Eagle Clarke, Headingley, Leeds, and W. Denison Roebuck, Sunny Bank, Leeds	350 and 2000 Associates.	None	5*s.*	Transactions. Annually.

Index of Papers referring to Local Scientific Investigations published during the Past Year by the above-named Societies.

⁂ This catalogue contains only the titles of papers published in the volumes or parts of the publications of the Corresponding Societies sent to the Secretary of the Committee in accordance with Rule 2.

Section A.—MATHEMATICAL AND PHYSICAL SCIENCE.

Name of Author	Title of Paper	Abbreviated Title of Society	Title of Publication	Volume or Part	Page
Bucnan, A.	The Rainfall of the British Islands	Glasgow Phil. Soc.	*Proc.*	XVII.	54
Campbell, Rev. A.	The Climate of the British Islands, with special reference to Perthshire	Perths. Soc. N. Sci.	"	I.	206
Cory, F. W.	The use of the Hygro-Spectroscope in Meteorology	Essex F. C.	*Trans.*	IV.	123
Evans, F. G.	Annual Meteorological Report	Cardiff Nat. Soc.	*Report and Trans.*	XVII.	120
Fielding, Rev. C. H.	The Summers of 1868 and 1884	Rochester N. C.	*Roch. Naturalist*	7	124
Gamble, J. G.	Catalogue of Printed Books and Papers relating to South Africa. Part II., Climate and Meteorology	S. African Phil. Soc.	*Trans.*	III.	151
Harvey, Rev. C. W.	Meteorological Observations taken at Throcking in 1884	Herts. N. H. Soc.	"	"	239
" "	Report on the Rainfall in Hertfordshire in 1884	" "	"	"	247
Henderson, Rev. A.	Meteorological Observations	Paisley Phil. Inst.	—	—	—
Hopkinson, J.	Meteorological Observations taken at Watford in 1884	" "	*Trans.*	III.	219
" "	Report on Phenological Phenomena observed in Herts in 1884	" "	"	"	227
McLandsborough, J., & A. E. Preston	Meteorology of Bradford for 1884	Yorks. Nat. Union	"	8	Not paged
McLellan, D.	Meteorological Notes for 1884, and Remarks on the State of Vegetation in the Public Parks of Glasgow	Glasgow N. H. Soc.	*Proc. and Trans.*	I.	123

Meldola, Prof. R.	The Great Essex Earthquake of April 22, 1884	Herts. N. H. Soc.	*Trans.*	IV.	23
Meldola, Prof. R., and W. White	Report on the East Anglian Earthquake of April 22, 1884	Essex F. C.	*Special Memoirs*	I.	—
Newman, T. P.	Wind and Storm	Holmsdale N. H. C.	*Proc.*	For 1884–85	35
Smith, A.	On Disturbances to Thermometer Readings from Local Causes	S. African Phil. Soc.	*Trans.*	III.	64
Terry, H., and F. Law	Meteorological Observations	N'ton. N. H. Soc.	*Journal*	3	208, 238, 310, 328
Turtle, Lancelot	Meteorological Summary for 1885	Belfast Nat. F. C.	*Annual Report and Proc.*	II.	381
Tyndall, W. H.	Meteorological Notes for 1883	Holmesdale N. H. C.	*Proc.*	For 1884–85	4
" "	Meteorological Notes for 1884	" "	"	"	48
Various	The Weather, 1885	Marlb. Coll. N. H. Soc.	*Report*	34	125
Wells, J. G.	Meteorological Summary for 1885	Burton N. H. Arch. Soc.	"	Tenth	20

Section B.—CHEMICAL SCIENCE.

Atkinson, R. W.	Japanese Lacquer	Cardiff Nat. Soc.	*Report and Trans.*	XVII.	49
Bedson, Prof. P. P.	The Testing of Safety Lamps: an Account of Experiments made by Professors Kreischer and Winkler	N. Eng. Inst.	*Trans.*	35	3
Beringer, J. J.	On the Determination of Lead in Galena	Cornw. Min. Assoc. & Inst.	"	I.	117
Maurice, A. H.	Maurice's Firedamp Indicator	Chesterf. Mid. Count. Inst.	"	XIV.	133
Player, J. H.	Analyses of Basalts	Birm. Phil. Soc.	*Proc.*	V.	122
Stocks, H. B.	Analysis of a Hydraulic Limestone Concretion from the Yorkshire Coast, with remarks on Concretions generally	Yorks. Geol. Poly. Soc.	"	IX.	55

Section C.—GEOLOGY.

Name of Author	Title of Paper	Abbreviated Title of Society	Title of Publication	Volume or Part	Page
Anderson, W	Note on the Occurrence of a New Species of Carboniferous Crustacean from Ardross, Fife	Edinb. Geol. Soc.	*Trans.*	V.	280
„ „	Fish Remains from the Bone Bed at Kinghorn	„ „	„	„	310
Baily, W. H	On Trilobites and other Fossils from Lower or Cambro-Silurian Strata in the County of Clare	R. Geol. Soc. Ireland	*Journal*	VII.	29
„ „	Pentremites new to Ireland from the Carboniferous Limestone	„ „	„	„	71
Beasley, H. C	A Quarry at Poulton, and the relation of the Glacial Markings there to others in the neighbourhood	Liv'pool Geol. Soc.	*Proc.*	V.	84
Bell, D.	On the Geology of Ardrossan and West Kilbride	Glasgow Geol. Soc.	*Trans.*	VII.	342
Brodie, Rev. P. B.	On the Discovery of Blatta and a Scorpion in British and Foreign Silurian Rocks	Warw. N. A. F. C.	*Proc.*	For 1885	18
„ „	On the last Boring near London, and its results	„ „	„		
Brongniart, C.	The Fossil Insects of the primary group of Rocks; a rapid survey of the Entomological Fauna of the Palæozoic Systems	Manch. Geol. Soc.	*Trans.*	XVIII.	269
Cameron, D.	Geology of Fearn and Tarbat	Edinb. Geol. Soc.	„	V.	330
Cole, Rev. E. M.	On some Sections at Cave and Drewton	Yorks. Geol. Poly. Soc.	*Proc.*	IX.	49
„ „	On the Physical Geography and Geology of the East Riding of Yorkshire	„ „	„	„	113
„ „	Note on the Parallel Roads of Glen Gloy	„ „	„	„	123
Collingwood, W. G.	The Lake Basins of the Neighbourhood of Windermere	Cumb. West. Assoc.	*Trans.*	X.	1
Craig, Robert	Volcanic Disturbance of the Ironstone Measures in the vicinity of Dalry during the Carboniferous Period	Glasgow Geol. Soc.	„	VII.	233
Crosskey, Rev. H. W.	Note on the Glacial Geology of the District around Loch Sween, Argyllshire	Birm. Phil. Soc.	*Proc.*	V.	219

Davis, J. W.	On the Contortions in the Chalk at Flamborough Head	Yorks. Geol. Poly. Soc.	„	IX.	43
Davison, Chas.	On the existence of undisturbed spots in earthquake-shaken areas	Birm. Phil. Soc.	„	V.	57
Forsyth, D.	A Bed of Post-Glacial Clay, exposed by dredging in the Harbour of Girvan, Ayrshire	Glasgow Geol. Soc.	„	VII.	251
„ „	The Silurian Rocks of the Girvan District	„ „	„	„	358
Galloway, W.	On the Mode of Occurrence of Coal	Cardiff Nat. Soc.	*Report and Trans.*	XVII.	20
Geikie, Prof. Jas.	Presidential Address on the Geology of the East of Scotland	E. Scot. Union	*Proc.*	2	3
George, T. J., and B. Thompson	A Catalogue of the Geological Collection in the Northampton Museum:—Part III. The Carboniferous System	N'ton. N. H. Soc.	*Journal*	3	240
Harvey, S.	The Earthquake of April 1884	East Kent N. H. Soc.	*Trans.*	1	40
Herdman, Prof. W. A.	The Presence of Calcareous Spicula in the Tunicata	Liv'pool Geol. Soc.	*Proc.*	V.	42
„ „	The Conservative Action of Animals in relation to Dynamical Geology	„ „	„	„	46
Holmes, T. V.	Notes on the Geological Position of the Human Skeleton lately found at the Tilbury Docks, Essex	Essex F. C.	*Trans.*	IV.	135
Hopkinson, J.	Works on Geology of Hertfordshire	Herts. N. H. S. F. C.	„	III.	165
Horne, J.	The Geology of the Isle of Man	Glasgow Geol. Soc.	„	VII.	254
Hull, Prof. E.	On the Occurrence of a Tract of Old Red Sandstone and Conglomerate amongst the Knock Alea Hills, Co. Donegal	R. Geol. Soc. Ireland	*Journal*	„	74
Hunter, Dr. J. R. S.	Biographical Sketch of the late Robert Slimon	Glasgow Geol. Soc.	*Trans.*	VII.	238
„ „	Three Months' Tent Life amongst the Silurian Hills of Logan Water, Lesmahagow	„ „	„	„	272
Johnstone, A.	On the Action of Carbonic Acid Water on Minerals and Rocks	Edinb. Geol. Soc.	„	V.	282
Kendall, J. D.	On the best locality for Coal beneath the Permian Rocks of North-West Cumberland	Cumb. West. Assoc.	„	X.	109
Kinahan, G. H.	Notes on the Coalfields of Leinster and Tipperary	R. Geol. Soc. Ireland	*Journal*	VII.	20
„ „	A Table of the Irish Lower Palæozoic Rocks	„ „	„		
Lett, Rev. H. W.	Remains of Red Deer at Maralin	Belfast Nat. F. C.	*Annual Report and Proc.*	II.	378

Section C.—GEOLOGY (*continued*).

Name of Author	Title of Paper	Abbreviated Title of Society	Title of Publication	Volume or Part	Page
Macadam, W. I.	Exhibition of and Notes on Specimens of Red Deer Horns from the Sand Deposits at the Mouth of the Nith	Edinb. Geol. Soc.	*Trans.*	V.	305
" "	Notice of a new Fossiliferous Bed in Arran	" "	"	"	316
McDakin, Capt.	The Cypris Clay of the Weald	East Kent N. H. Soc.	"	1	13
McMurtrie, J.	Notes on the Occurrence of Salt Springs in the Coal Measures at Radstock	Bath N. H. A. F. C.	*Proc.*	VI.	84
Mayer, J.	New Discovery of rich Cannel Coal near Bathgate	Glasgow Phil. Soc.	"	XVII.	50
Melvin, J.	The Parallel Roads of Lochabor	Edinb. Geol. Soc.	*Trans.*	V.	268
Millett, F. W.	Additional Notes on the Foraminifera of the St. Erth Clay	Cornwall R. Geol. Soc.	*Report and Trans.*	X.	222
" "	On the Abrading Action of a Stone kept in Motion by a Current of Water	" "	" "	"	227
Moore, Dr. C. A.	Notes on the Geology of the Neighbourhood of Rugby	Leicester Lit. Phil. Soc.	" "	For 1885	117
Morgan, Prof. C. Lloyd	On the Mapping of the Millstone Grit at Long Ashton, near Bristol	Bristol Nat. Soc.	*Proc.*	IV.	163
" "	Sub-Aërial Denudation and the Avon Gorge	" "	"	"	171
Morrison, W.	The Glacial Terraces of Achnasheen, Ross-shire	Edinb. Geol. Soc.	*Trans.*	V.	275
Mortimer, J. R.	On the Origin of the Chalk Dales of Yorkshire	Yorks. Geol. Poly. Soc.	*Proc.*	IX.	29
Morton, G. H.	The Microscopic Character of the Triassic Sandstones of the Country round Liverpool	Liv'pool Geol. Soc.	"	V.	52
Mott, F. T.	The Geological History of Charnwood Forest	Chesterf. Mid. Count. Inst.	*Trans.*	XIV.	213
O'Reilly, Prof. J. P.	On the Occurrence of Beryl with Schorl in Glencullen Valley	R. Geol. Soc. Ireland	*Journal*	VII.	69
Patton, A., and J. Coutts	Geological Observations in the Parish of East Kilbride, Lanarkshire; with a list of Fossils	Glasgow Geol. Soc.	*Trans.*	VII.	309
Paul, J. D.	The Drift at the Countesthorpe Brickyard	Leicester Lit. Phil. Soc.	*Report and Trans.*	—	115

Pleydell, J. C. M.	Geological Notes on the Isle of Portland	Dorset N. H. A. F. C.	*Proc.*	VI.	58
" "	A Fossil Chelonian Reptile from the Middle Purbecks	" "	"	"	66
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Report of the Committee, consisting of Professors ARMSTRONG *and* LODGE (*Secretaries*), Sir WILLIAM THOMSON, Lord RAYLEIGH, Professors SCHUSTER, POYNTING, J. J. THOMSON, FITZGERALD, CRUM BROWN, RAMSAY, FRANKLAND, TILDEN, HARTLEY, MCLEOD, CAREY FOSTER, ROBERTS-AUSTEN, RÜCKER, REINOLD, *and* S. P. THOMPSON, Captain ABNEY, Drs. GLADSTONE, HOPKINSON, *and* FLEMING, *and* Messrs. W. N. SHAW, H. B. DIXON, J. T. BOTTOMLEY, W. CROOKES, SHELFORD BIDWELL, *and* J. LARMOR, *appointed for the purpose of considering the subject of Electrolysis in its Physical and Chemical bearings.—Edited by* OLIVER LODGE.

THE members of the Committee have communicated with each other by correspondence, and have individually undertaken the investigation of various points more or less closely bearing on the subject, some of which were specified by the present editor at the conclusion of a paper on Electrolysis, printed in the annual volume for last year. (See page 765.)

The sum of 20*l.* granted to the Committee has been expended, partly in providing chemicals and simple appliances for experiments, and partly in printing and circulating various interim communications, to wit, letters among the members and letters received from foreign philosophers.

The work of the Committee is greatly facilitated by being thus able freely to communicate on matters of interest; and, inasmuch as it is thought desirable to continue this practice, and also to experiment on material of special purity, a somewhat larger grant is asked for this year. Some of the work undertaken by the members is only recently begun, and not yet reported on, but that concerning which an account has been communicated to the Committee is here appended, together with a few abstracts and translations of foreign memoirs, which it seemed desirable to bring together in an accessible form. (For Table of Contents, see p. 412.)

Sir William Thomson communicates to the Committee Mr. Thomas Gray's paper 'On the Electrolysis of Silver and of Copper, and the application of Electrolysis to the Standardising of Electric Current and Potential Meters,' as published in the 'Philosophical Magazine' for November 1886; and remarks that it treats of questions referred to in the rest of the Report, especially to those raised by Mr. Shaw in Table IV. on p. 325.

Professor Armstrong's paper 'On Electrolytic Conduction in relation to Molecular Composition, Valency, and the Nature of Chemical Change: being an attempt to apply a theory of "Residual Affinity,"' is published in the 'Proceedings of the Royal Society,' No. 243, 1886.

Professor McLeod's paper 'On the Electrolysis of Aqueous Solutions of Sulphuric Acid, with special reference to the forms of oxygen obtained,' is to be found in the 'Journal of the Chemical Society' for August 1886, vol. xlix.

Professor J. J. Thomson and Mr. Newall have been working at Cambridge on conduction through very bad conductors, such as olive oil, bisulphide of carbon, paraffin oil, &c. They find that for electromotive forces up to 100 volts these conductors obey Ohm's law. This result, they say, is interesting, since Quincke has lately proved that for very much greater forces these substances do not obey Ohm's law: the departure from it being very marked. They also find that the conductivity is improved by raising the temperature. A full account of these experiments is to be communicated to the Royal Society shortly.

On Continuity of Electric Conduction. *By* Dr. JOHN HOPKINSON, *F.R.S.*

In my experiments on residual charge I touched upon the second question in Dr. Lodge's programme ('Is Ohm's law obeyed by very bad conductors?'),[1] and pointed out that Ohm's law could be regarded as a limiting case of a more general law of superposition. In the case of mechanical after-effects the law of superposition does not hold even approximately. The fourth question ('Is there any relation between optical opacity and electrolytic conductivity?') appears to me to be very intimately associated with the fact that bodies which, if they conducted, would be electrolysed do not follow Maxwell's law, whereas some other insulators do. My own present impression is that an electrical displacement in glass may, although continuous, be roughly divided into four successive stages. 1st. A yielding of the dielectric during a time corresponding to the time of wave-frequency of light, for which $K=2\frac{1}{2}$ about. 2nd. A further yielding during a time corresponding to great absorption below the red, bringing K up to from 6 to 10. 3rd. A further slow yielding, partly recoverable, hardly sensible in time less than a second or such like, and going on with diminishing amount for days. 4th. A yielding corresponding to an actual decomposition of the material. Superposition probably applies to all these continuously connected successive events. Probably if we could experiment fast enough on any ordinary electrolyte, like solution of $CuSO_4$, we should find a similar succession of phenomena.

[Dr. Hopkinson's note is of extreme interest, and the references to his papers are as follows: Residual Charge in Leyden Jar, 'Phil. Trans.' January 1877; Strain in Glass Fibre, 'Proc. Roy. Soc.' October 4, 1878; Refractive Index and Specific Inductive Capacity, 'Phil. Mag.' April 1882. This last paper I may abstract thus:—

Maxwell's laws are that $\mu^2=K$, and that transparent bodies must insulate. They are true for mineral oils and solid paraffin; not true for glass, Iceland spar, and organic oils. Consider, for instance, light flint glass: K is 6·7 for disturbances whose period is longer than 10^{-5} second, and for these disturbances it behaves as an insulator. It ought, therefore, for such waves to be transparent, and to have an index 2·6. But, for disturbances of period about 10^{-15} second, its index, reckoned for very long waves by extrapolation formula, comes out about 1·5. Is there any way of accounting for this discrepancy? Yes; perhaps by the known fact that on waves *between* these two periods glass exercises a strong selective absorption, and that this is usually accompanied by anomalous dispersion; which at once renders all empirical reasoning towards the state of things for very long waves, from the observed condition for very short waves, utterly futile and misleading. Perhaps, therefore, Maxwell's law is after all obeyed by these substances for long waves; and one way to test the question is by using rays from a thermopile to a freezing mixture. O. L.]

On Diathermancy and Electrolytic Conductivity.
By SHELFORD BIDWELL, *F.R.S.*

The following is one of the questions suggested by Dr. Lodge for the consideration of the Committee on electrolysis:—Is there any relation between optical opacity and electrolytic conductivity? [2]

Assuming that 'optical opacity' is included in the more comprehensive term 'opacity to radiation,' I have endeavoured to ascertain experimentally whether

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[1] See *Brit. Assoc. Report* for 1885, p. 765.

[2] *Ibid.* p. 768.

those electrolytes which transmit radiation with the greatest facility, as evidenced by the effect produced upon a thermopile, are also the worst conductors of electricity. I may say at once that this was undoubtedly not the fact, and the relation which was supposed to be possible does not exist.

Considerable time and care were bestowed upon the experiments, and every precaution was taken with the view of ensuring accuracy. The thermopile used was a delicate one, containing 54 bismuth-antimony pairs; it was enclosed in a flannel-covered box, fitted with a pane of glass 1·5 mm. thick opposite the face of the pile. The galvanometer was an astatic reflecting instrument of ·545 ohm resistance made by Elliott. The source of radiation was a small paraffin lamp, having a glass chimney about 2 mm. thick.

The parallel glass sides of the cells, used to contain the liquids, were 13 mm. apart, and 1·9 mm. in thickness. A screen, with a small aperture, which could be instantly opened or closed by a sliding shutter, was interposed between the cell in use and the lamp. The various solutions were in every case exposed to radiation for a period of 30 seconds, and each observation was checked and standardised by the aid of a certain cell containing water. It is hardly necessary to describe the arrangements and method of observation in greater detail.

A few of the results, which, for the most part, need no comment, are given in the following table:—

Solutions, &c.	Diathermancy.
Empty cell	1000
Water distilled	197
,, from tap	200
Alum, saturated solution	204
Ammonium chloride solution	215
Zinc sulphate sol. sp. gr. 1·157	207
Sulph. acid 1·032 (5 per cent.)	208
,, ,, 1·225 (30 ,,)	216
,, ,, 1·638 (72 ,,)	292

The observations with sulphuric acid are the most instructive. It is well known that the electrical conductivity of sulphuric acid at first increases with the concentration, reaching a maximum when the strength of the solution is about 30 per cent., and afterwards rapidly diminishing. That there is no corresponding minimum diathermancy appears clearly enough from the above table, which seems to furnish a conclusive answer in the negative to the question proposed.

The diathermancy of a solution of zinc sulphate was almost independent of its strength, being nearly the same for a 5 per cent. as for a saturated solution. It was quite unaffected by the passage through the solution of a strong battery current.

Translation of Letters received from Dr. ARRHENIUS. *By* Oliver Lodge.

POLYTECHNICUM, RIGA, *May* 17, 1886.

DEAR SIR,—I have been much interested in your electrolysis memoir, and since it seems intended to open a discussion, I beg to be allowed to express my views on a few important questions there touched on, especially concerning wandering of ions.

As I have shown, and a little later also Bouty, one must regard all positive ions, in extremely dilute solutions, as possessing nearly equal velocities; and in the same way also all negative elements as having an equally great velocity among themselves. It is very probable that these two velocities are also equal to each other for those salts which, by reason of excessive dilution, already approximate closely to the ideal condition; that is to say, the best conducting salts like KCl, NH_4Cl, &c., whose ions have nearly equal velocities.

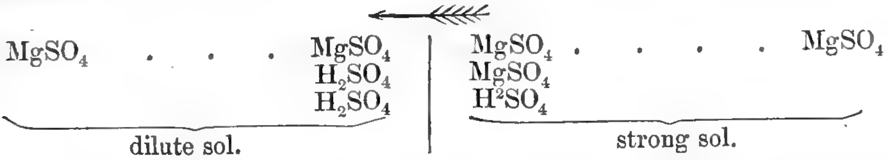
One could best represent the ions to oneself as spheres of about equal size (though of unequal weight) which are urged through a resisting medium with the same force, and which very soon attain their terminal velocity. But if the motion of the ions is disturbed by collision with other ions (or molecules), a certain departure from equal velocities will arise. This departure is, nevertheless, so small that it cannot be regarded as accurately established.

But if one considers greater concentration, the molecules are jammed together, to a degree which may be represented by $\frac{1020}{\mu} \times 10^{-8}$, where μ is the molecular conductivity of the given concentration. Thus arise double molecules, treble molecules, and so forth. The electrolysis of a double molecule I_2J_2 occurs either according to the scheme $I + IJ_2$, or according to the scheme $I_2J + J$; though indeed the former occurs much the more often.

To take an example: if all the molecules in a solution are double molecules, then, according to the first alternative (if one assumes all ions to travel at the same pace, which is nearly correct), analysis will show that I remains quite still (i.e. it wanders equally in opposite directions), and the whole motion is performed by J_2. According to the second alternative, one is led direct to the opposite result. If part is decomposed under scheme 1 and the rest under scheme 2, all intermediate conditions can be represented. This is, I believe, the true cause of the so-called unequal wandering of the ions.

That water has an extremely small conductivity, its chemical behaviour makes clear. Indeed it will probably never be detected by electrolysis. The phenomena accompanying the electrolysis of $CuSO_4$ are explicable in the simplest way by supposing that $CuSO_4$ is decomposed by water, even though but very little (one knows that $CuSO_4$ has an acid reaction), and naturally the so-formed sulphuric acid takes part in the electrolysis, whence arises the free acid at anode. This will after all be scarcely noticeable. With stronger currents H_2SO_4 appears at the kathode, and the hydrogen of this will be gradually transported to the anode by electrolysis.

The experiment with $MgSO_4$ can be explained in a similar way, without supposing a noticeable electrolysis of water. The dilute solution contains much more free H_2SO_4 than the concentrated. So if a current flows according to annexed scheme—



the left-hand side of the partition will lose two H_2SO_4 and gain one, so the solution will become alkaline; whereupon $Mg(OH)_2$, which is only soluble in excess of acid, will precipitate. This $Mg(OH)_2$ we can neglect in electrolysis, for it probably conducts no better than NH_3. Besides, CO_2 in the solution could cause a small precipitate of $MgCO_3$.

I should be very glad to hear your view of the expositions in my essay,[1] if you will kindly pass an opinion on it. You will probably think my enunciations too bold, and that I have insufficiently established my conclusions; meanwhile, I may refer to the work of Ostwald, who has found my statements, in § 15 of the second part, to fully correspond with experiment; also, I can refer to the simultaneous work of Bouty (February 1884; my work was undertaken June 6, 1883), and the later investigations of Kohlrausch, which completely prove that with extreme dilution all salts examined conduct about equally well (Part I. page 41, law 3).

It follows moreover from Ostwald's experiments that the law 41 (Part II. p. 46), which I have deduced from purely theoretic considerations, corresponds exactly with experience.

I hope that these circumstances will mitigate your criticism of the many incompletenesses, since they show that I have gone at least partly on right lines,

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[1] First part, 'On the Conductivity of very Dilute Solutions'; second part, 'On the Chemical Theory of Electrolytes.'—*Acad. des Sciences de Suède*, June 1883. See below, page 357.

although I have not had the power of setting forth with sufficient clearness what is abundantly evident to myself.

With assurances that I shall be grateful to learn your views, &c., &c.

SVANTE ARRHENIUS.

RIGA, *June* 8, 1886.

DEAR SIR,—Thanks for note and British Association circulars. Since you speak of communicating something of my views to the Committee, I will, to avoid misunderstanding, just try in a few lines to explain my position. In my small notice on the conductivity of gelatinous solutions, I am led to the view that internal friction (viscosity) exerts no influence on conductivity. By experiments on the conductivity of mixtures, with which I am now working, it appears, however, that gelatinous solutions (and probably other pseudo-solutions) form an exception; since for other (actual) solutions a very close relation exists between conductivity and limpidity. It seems as if, when one adds to water a liquid, or in general any foreign body (with the exception of all the best conducting salts), the limpidity of the solution becomes less than that of pure water, no matter whether the limpidity of the added body be less or greater than the water. It appears as though the friction experienced by a molecule travelling through a liquid greatly depends on the heterogeneity of the liquid. One could propel a water molecule more easily through pure water than through water with which some other substance had been mixed. But a water molecule consists of the ions H and OH, and what is valid for the whole molecule must be valid also for a part of it. If this is correct, the advance of an ion through a liquid whose molecules have this ion as a constituent must be opposed by a smaller resistance (friction) than if the molecules of the liquid had not, or only partly had, this ion as a constituent. This serves as a sort of explanation of the greater velocity of the ions H and OH in aqueous solutions in comparison with the velocity of other ions. I regard it as certain that the ions H and OH travel quicker than other ions, which go at a pace pretty nearly equal (not quite equal) among themselves. But the influence of heterogeneity on the internal friction and also on conductivity appears to diminish with increasing temperature. So it is very possible, and indeed probable, that at some temperature, higher than any hitherto employed in such observations, the ideal case might be reached when all ions should go at the same rate—which would mean that at that temperature all electrolytes, in extremely dilute solutions, should conduct equally well; just as a gas's obedience to Boyle's law approaches exactitude at low pressures and high temperatures.

This will probably be the tendency of the results of my not yet concluded investigation on this interesting subject. It is impossible for me to give you the experimental proof for the view above expressed, though I should have had much pleasure in doing so. I should be obliged by your sending me the results and report of the Committee, and on my side I will willingly, if you regard this as not wholly without value, communicate to the Committee the results of my experiments now being carried on.

Professor Ostwald is sending you some of his papers.

Yours &c.,

DR. SVANTE ARRHENIUS.

On the Accuracy of Ohm's Law in Electrolytes.

By Professor G. F. FITZGERALD, *F.R.S., and* Mr. TROUTON.

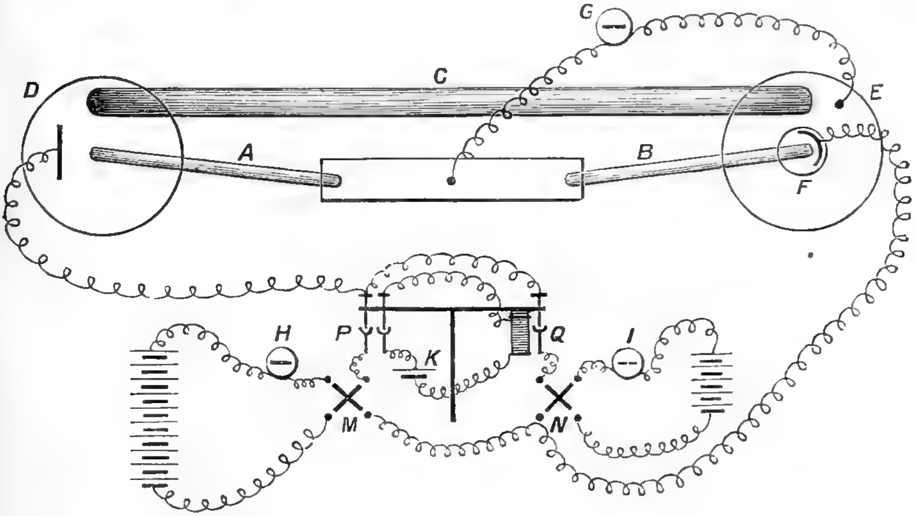
Some preliminary experiments were begun in the spring of this year, and have been carried on from time to time since, with a view to determining how far Ohm's law may be relied on in the case of electrolytes.

Though as yet no very high limits of accuracy in the experiments have been attained, owing to causes which will be later on explained, still it is hoped that from the experience already gained most of the difficulties have been got over, and that soon results of a much greater degree of accuracy will be arrived at.

The method adopted is that described in the British Association Report for Glasgow, 1876, which Professor Chrystal, in connection with Clerk Maxwell, employed in the case of metal conductors, namely, that of a Wheatstone's bridge, two of the arms of which are of about equal section and resistance, while the remaining two, though of equal resistance, are of very different sections. If Ohm's law be not true, the point of balance of the bridge varies with the amount of current passing through it. Balance having been obtained, the battery-power is altered, and if balance still subsists, the deviation from Ohm's law, if there be any, is such as cannot be detected with apparatus of the sensitiveness employed.

The great difficulty in experimenting in this way is that the change in the current alters the temperature of the two arms of unequal section very differently, and proportionately also their resistances. While the thick conductor alters little in temperature, the thin one alters considerably. Thus the point of balance is changed, even though Ohm's law be true. To avoid this effect it is necessary, having balanced with the large current, to immediately pass the smaller current before the temperature can sensibly alter. As this requirement is practically impossible to satisfactorily fulfil, the method employed is a rapid alternation of a large and small current. If Ohm's law be not true, a balance in this case can only be apparent, and on reversing the direction of one of them, the two currents which before neutralised each other's action now conspire to deflect the galvanometer. The mode of experimenting is to find balance with a large and a small battery alternately in circuit, and rapidly enough for the temperature during the smaller current to be sensibly the same as while the larger one is acting, then to change the direction of one of the currents and to again balance. The distance is observed between the two points of balancing, but if the bridge still balances it is assumed for the purposes of calculation that the distance is what the galvanometer employed only just detects. From this, from the two currents the section and resistance of the thin conductor, h is calculated, where $e = rc(1 - hc^2)$, as is explained in the above-mentioned Report.

The liquid, chosen for experimenting with, was a solution of copper sulphate in water. The equal arms consisted of two glass tubes bent at right angles at each end, A and B, arranged syphon-like, and contained the solution. They dipped into a long narrow trough, as shown in the diagram. The arm of large section C, a tube 119 cm. long and 2·38 cm. in internal diameter, reached from the bowl D into which the tube A also dipped, to the bowl E. The small arm was a hole ·055 cm. in diameter, drilled in the side of the beaker F, ·063 cm. in thickness, into which the tube B dipped.



The battery poles consisted of copper plates, one in the beaker, the other in the bowl D. The contact breaker was a T piece worked by an electromagnet and cell

K, as shown in the diagram. One of the batteries contained ten Grove cells, the other five, and both could be thrown in circuit in either direction by means of the reversing keys M and N. By proper adjustment of the mercury cups P and Q one of the batteries went in circuit, just as the dipper on the other side, coming out of the mercury, threw the second battery out of circuit. By means of the galvanometers H and I it could be seen, during the course of an experiment, whether the contacts were working properly or not.

One of the copper wires leading to the galvanometer dipped into the bowl E, the other into the trough, and could be moved up and down it in order to obtain balance, the distance moved being read off a scale along the trough. There was always more or less of a permanent current through the galvanometer, even though the poles were both of copper; this especially, as it was liable to sudden changes in amount, caused by moving the trough pole or by accidental shaking, necessitated the employment of the galvanometer in a comparatively insensitive condition. Various devices were tried with a view of avoiding this current, such as electroplating the poles, using chemically pure copper sulphate, or employing for poles either end of a broken wire, so as to have, if possible, metallically like poles; these were found to give an indication of current even in distilled water.

The resistance of the smaller arm was about 800 ohms, but owing to its smallness varied greatly with the current through the change of temperature. A good deal of trouble was experienced through the resistance of the smaller arm at times, being less when the current passed in one direction than when it passed in the other. This occurred so often that until its cause was understood, and steps thus could be taken to prevent it, there was little hope of completing the experiments. After various attempts it was discovered to be due to the density of the solution on the outside of the beaker in the bowl being slightly different from that inside, so that the density in the hole, and consequently its resistance, depended on the direction of the current, the electric transfusion of the liquid always changing direction with the current.

A number of experiments were made of a more or less satisfactory nature; in all no difference in the position of balance was found on reversing one of the batteries. Taking the difference then to be what the galvanometer would just detect, h is calculated to be less than 10^{-4}. This is, of course, very large. The limit Professor Chrystal reached in his experiments with metal conductors was less than 10^{-12}.

With a view to reaching a higher limit a smaller hole was next tried. It was ·017 cm. in diameter, drilled in a plate of glass ·022 cm. thick. Its resistance was about 2700 ohms, so that a longer tube had to be used for the large arm. The balance was always found to be very different when one of the batteries was changed in direction. However, this was probably entirely due to the difference in temperature during the small and large currents, for h calculated from this was not even as small as in the first experiments; also the difference between the balance points varied with the speed of the contact breaker. Unfortunately the contact breaker, which was adjustable in its rate of vibration, had reached its limit of speed, so that a completely new arrangement has now to be employed.

On the Electric Resistance of Magnetite.

By Professor SILVANUS P. THOMPSON, *D.Sc.*

This is a preliminary note on a research begun with the view of elucidating the question whether the conduction exhibited by various mineral ores and metallic oxides and sulphides possessing quasi-metallic conductivity is or is not accompanied by electrolysis. The substance selected, magnetite or magnetic iron ore, is a thoroughly good conductor, as is evidenced by the simple fact that if a piece of it be interposed in the circuit of an ordinary electric bell the bell can be rung through it.

The sample selected was a fine homogeneous piece of ore from Arkansas, and was reduced by the lapidary's wheel to parallelopipedal bar. Its total length was 5·53 centimetres, its breadth 1·52 centimetre, and its thickness 1·27 centimetre.

The bar was placed between electrodes of platinum foil, which were clamped against its end-faces by means of screws; it was then placed in a bath of paraffin oil, enabling it to be heated to any desired temperature up to 135° C.

To test for electrolytic polarisation a current of about 1 ampère was passed through it from three nitric acid cells for some minutes. On stopping the current there appeared a slight polarisation, not, however, exceeding 0·0005 volt, and therefore of an order indicating a thermo-electric rather than an electro-chemical origin.

The specific resistance was then measured by observing the fall of potential between two marked points, 3·22 centimetres apart, upon the bar, and comparing this with the fall of potential between the two ends of a standard resistance coil, intercalated in the same circuit. The resistance was found to diminish very remarkably as the temperature was raised. Observations were made at intervals of from twenty to forty minutes apart, with the following result:—

Temperature (C.)	Resistance of centimetre cube in B.A. units
23°	0·719
54°	·709
79·5°	·505
107°	·416
133°	·287

It appears that the resistance of magnetite agrees with that of carbon and electrolytes in possessing a negative temperature coefficient.

A somewhat longer and thinner bar of hæmatite prepared for future experiments showed a resistance of about 108 megohms, which in a preliminary heating fell to 81 megohms.

The determinations were made by the author's chief assistant, Dr. R. M. Walmsley.

On the Conductivity of Mixtures of Aqueous Acid Solutions.
By Dr. Svante Arrhenius *of Stockholm.*

An abstract of a paper to appear in Wiedemann's 'Annalen,' specially made by the author, and communicated through Oliver Lodge. *The translation of the abstract made by* W. N. Shaw.

1. *Methods employed. Previous authors.*—Hitherto only comparatively few experiments on the conductivity of mixtures of electrolytes have been made, by Bouchotte,[1] Paalzow,[2] Bender,[3] and Klein.[4] These experiments have moreover led to no definite general results, mainly on account of the paucity of experimental data.

My experiments have been made at 25° C. in the chemical laboratory of the Polytechnic at Riga on Kohlrausch's well-known method, with the use of the telephone.

2. *Distribution of the water among solutions.*—When two electrolytes are dissolved in the same water two different views of the nature of the solution may be held: either *all* the water affects the one electrolyte as well as the other, or the water divides itself so that only one part of it affects the one electrolyte and only the remainder the other electrolyte. Experiments (by Ostwald) have been made with acetic acid and butyric acid. Normal solutions of these acids have conductivities respectively of 1·478 and 1·020. According to the second view the conductivity of the mixture would be $\frac{1}{2}(1·478 + 1·020)$. It was found to be 1·250 (instead of 1·249). According to the first view the mixture would have a conductivity equal to the sum of the conductivities, of acetic acid at half normal strength (1·119), and of butyric acid at half normal strength (0·853); this would give

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[1] *C.R.* tome lxii. p. 955, 1864.

[2] Poggendorff's *Annalen*, Bd. cxxxvi. p. 489, 1869.

[3] Wiedemann's *Annalen der Physik und Chemie*, Bd. xxii. p. 197, 1884.

[4] *Inaug. Diss.* Würzburg, 1885.

the conductivity of the mixture 1·972. Many such experiments were arranged, and all showed the superiority of the second view. All the experiments discussed in this paper also prove the soundness of this view. We shall consequently adopt this second view in what follows.

3. *Fundamental formula.*—If two electrolytes (in dilute aqueous solution) are mixed in the proportion of $m : n$, and if the conductivity of the one solution be a, and that of the other b, then the conductivity of the mixture will be $\frac{ma + nb}{m + n}$ if the solutions suffer no change in the mixing. This formula is the mathematical expression of the idea that the conductivity depends solely upon the number of electrolytic (active) molecules per unit volume, and on the friction of the ions in the solvent. This friction undergoes no appreciable change in very dilute solutions.

4. *Consequences of the interchange of water in the mixture of solutions.*—When *hydrochloric* acid solution is diluted, the number of electrolytic molecules increases but very little:[1] for the sake of simplicity we may assume that the number does not increase at all. When, however, a solution of *acetic* acid is diluted, the number of electrolytic molecules is considerably increased (*e.g.*, by dilution to twice the volume, from a standard solution, the increase is in the ratio of 1·51 : 1). When therefore solutions of hydrochloric acid and acetic acid are mixed, the conductivity will be greater than the above formula shows, if water is transferred from the hydrochloric acid to the acetic acid solution, and *vice versâ.* In general when solutions of a stronger and a weaker acid are mixed, and the weaker acid takes water from the stronger, the conductivity will be greater than that given by the formula; and conversely if the stronger acid takes the water of solution from the weaker. A formula for this phenomenon is easily deduced; it shows that if the above consideration is valid the conductivities of the original solutions must not be very widely different; it likewise shows that the greatest deviations from the formula occur when the solutions are mixed in equal quantities.

5. *Isohydric solutions.*—If a given solution of an acid be mixed in equal volumes with solutions of another (stronger) acid of different degrees of concentration it is found that the above formula is applicable for a certain degree of concentration. For greater concentration negative deviations will be found, and on the other hand for less concentration positive deviations; according to the explanation given above, that solution of the second stronger acid, which possesses the particular degree of concentration, is of such a nature that it neither takes away water from the first solution nor gives any up to it when the two are mixed. On this ground I call two such solutions of different acids relatively *isohydric.* I have defined the concentrations of the solutions by their conductivities.

The experimental method for the determination of the conductivity of isohydric solutions will be most easily explained by means of an example.

To find the hydrochloric acid solution which is isohydric with tartaric acid (75·51).[2] Under 'observed' is placed the conductivity found, under 'calculated,' the conductivity calculated by the formula given.

	Obs.	Cal.	Diff.
5 cc. tartaric acid solution (75·51) + 5 cc. hydrochloric acid solution (94·62) .	84·49	85·07	−0·58
5 cc. tartaric acid solution + 5 cc. hydrochloric acid solution (85·68) . .	81·34	80·60	+·78

By interpolation (and allowing for error of observation = 0·5 p.c.), we get as isohydric with the tartaric acid solution (75·51) the hydrochloric acid solution (89·2 ± 2·9). In a similar manner the numerical values contained in what follows have been obtained.

6. *Examination of the view adopted in* § 2.—This examination was conducted

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[1] *I.e.*, the molecular conductivity increases very little—I refer always here to dilute solutions.

[2] By this is understood tartaric acid of conductivity 75·51. The units here employed may be reduced to Kohlrausch's by multiplication by 10^{-8}.

in two different ways: (*a*) *Solutions which are found to be isohydric when mixed in equal volumes must also be isohydric when they are mixed in other proportions.*

This proved to be the case. Phosphoric acid (223·7) and hydrochloric acid (167·4) were mixed in the ratios 3 : 1, 2 : 2, and 1 : 3; oxalic acid (4·947) and acetic acid (4·837) in the ratios 10 : 3, 1 : 1, and 3 : 10; tartaric acid (1·566) and hydrochloric acid (1·757) in the ratios 10 : 3, 1 : 1, and 3 : 10; acetic acid (12·18) and hydrochloric acid (14·54) in the ratios 10 : 1, 10 : 2, 10 : 4, 10 : 7, 1 : 1, 2 : 3, 1 : 2, 1 : 5, and 1 : 10. In no case was there a difference between the observed and calculated conductivities which reached the limit of the error of observation (0·5 p.c.).

(*b*) *Solutions which are isohydric with any the same solution must also be isohydric with each other.* Otherwise, as is easily seen, we might have three solutions, among which a permanent current of water would circulate always in the same direction. I have found—

A. (α) Phosphoric acid (225·6) isohydric with oxalic acid (139·7 ± 7·5).
„ „ „ „ „ hydrochloric acid (168·8 ± 10).
(β) Oxalic acid (141·7) „ „ „ „ (166·4).
B. (α) Hydrochloric acid (88·59) „ „ tartaric acid (75·00 ± 2·5).
„ „ „ „ „ oxalic acid (85·07 ± 3·5).
(β) Tartaric acid (75·39) „ „ „ „ (82·08 ± 3·3).
C. (α) Formic acid (5·576) „ „ „ „ (4·901).
„ „ „ „ „ hydrochloric acid (5·309).
(β) Oxalic acid (4·915 ± 0·17) „ „ „ „ (5·336 ± 0·13).

It will be seen that the numbers are perfectly satisfactory.

7. *Table of isohydric solutions.*—In the following table particulars of isohydric solutions of six acids, as different as possible, are collected; their conductivities (multiplied by 10^8) are given, together with the possible errors. Above the conductivities I have put in brackets the number of gramme-molecules per litre of the corresponding solutions. These are calculated from Ostwald's numbers. Solutions more concentrated than normal ones have not been investigated.

Hydrochloric acid	Oxalic acid	Phosphoric acid	Tartaric acid	Formic acid	Acetic acid
(0·1737) 609 ± 35	(0·513) 607				
(0·0461) 168·8 ± 10·0	(0·0625) 139·7 ± 7·5	(0·337) 225·6			
(0·02 38 88·6 ± 2·9	(0·0331) 85·1 ± 3·5	(0·0764) 82·2 ± 8·2	(0·520) 75·0		
(0·00475) 17·98 ± 0·46	(0·00488) 16·27 ± 0·46	(0·00702) 16·11 ± 0·72	(0·0260) 16·41 ± 0·45	(0·1077) 16·85 ± 0·64	(1·000) 13·81
(0·001402) 5·336 ± 0·134	(0·00135) 4·915 ± 0·175	(0·00163) 4·926 ± 0·174	(0·00324) 4·903 ± 0·146	(0·01261) 5·467(± 0·15)	(0·0965) 4·855
(0·000349) 1·524 ± 0·032	(0·000396) 1·582(± 0·05)	(0·000440) 1·479 ± 0·057	(0·000498) 1·499 ± 0·20		(0·009175) ·1·476

8. Since obviously any solution of two acids in the same water can always be represented as two isohydric solutions, it follows that *when two acid solutions are mixed the two acids divide themselves with reference to the water, so that two isohydric solutions are formed.*

From the above table it follows that the specific conductivities of isohydric solutions are approximately equal.

Further considerations, which cannot here be given, show that if the conductivity of a mixture of acids is calculated on the assumption that solutions of equal conductivity are isohydric, the probable error amounts to 1 p.c.; being rather greater if the strengths of the acids are very different, and less if they are nearly equal.

9. *Supplementary remarks.*—The different bases have also been examined in a perfectly similar manner. The results obtained are strictly analogous, including the equality of the conductivities of isohydric solutions. But the carbonic acid of the air had produced a disturbing effect to such an extent that the numbers are too uncertain for publication. I have also found that acetic acid (1·166) is isohydric with ammonium acetate (0·469). The ratio of the conductivities of the two (2·485 : 1) is nearly the same as the ratio of the maximum values of the conductivities of acids and salts (2·83 : 1 according to Kohlrausch). This seems to point to the conclusion that an electrolytic or active molecule of an acid, in water, at ordinary temperature conducts 2·83 times as well as an electrolytic molecule of a salt; and not that in extreme dilution the acids are any more loosely combined ('disagregirt') than the salts. This arises probably from a smaller friction of the ion H of the acid (probably also of the OH of the bases) with respect to the water, in which it also occurs as an ion, than occurs with the other ions. This difference might disappear at higher temperatures.

From the hypothesis that the different electrolytes divide the water between them, there arise relations which promise to explain some very curious phenomena. If for example a weak acid or base and a neutral salt are dissolved in water, isohydric solutions will be formed in which the weak acid or base will get extremely little water. In consequence, its molecular conductivity, and accordingly the number of active molecules, will be very considerably diminished. I anticipated this on other grounds in my paper of 1884,[1] and endeavoured in that way to explain that the weak acids prove to be much weaker on mixing with bases than they are for the same concentration when no other bodies are in the same solution. The same hypothesis may also explain the great depreciation of strength of weak acids when neutral salts are present, as calculated from the rapidity of reactions,[2] and of the weaker bases in saponification reactions. I am still engaged upon the solution of similar questions.

On the Verification of Faraday's Law of Electrolysis with reference to Silver and Copper. By W. N. Shaw, M.A.

Since the time of Faraday his law of electrolysis has not been subjected to any very extensive experimental investigations. A summary of the results obtained is given in the article on Electrolysis in the 'Encyclopædia Britannica.' The most accurate verification appears to have been conducted by Soret, who attributes to the law an accuracy of 0·2 per cent. for copper and silver. Buff used different currents and found the law verified by experiment to about 1 per cent., but the general impression has been that the law was only true to a somewhat rough approximation.

A practical acquaintance with the behaviour of an electrolytic cell of copper sulphate shows that it is not *necessary* to attribute the defect from the theoretical value of the chemical equivalent obtained in that way to the failure of Faraday's law. In depositing copper upon a copper plate it may often be observed that small but brilliant red crystals are formed on the deposit. These crystals under the microscope are very beautiful; they may probably be regarded as a suboxide of copper formed by the action of the copper on the solution. A purple coloration is, moreover, often formed on the cathode, and this is possibly due to the presence of the same compound of copper. This secondary action produces, of course, a difference in the weight of the deposit formed, and the true amount of electricity which has passed cannot be inferred either from the weight of the copper with the compound or from the weight of copper remaining when the crystals have been removed.

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[1] 'La Conductibilité Galvanique des Électrolytes,' Partie II. p. 77 (see below, p. 357)

[2] Spohr, *Journ. f. prakt. Chem.* [2], xxxii. p. 32.

Further, it is well known that a copper plate when immersed in a solution of copper sulphate, without any current, gives rise to some chemical action which causes the copper plate to alter in weight. The alteration may be in the direction either of increase or of decrease of the weight, the effect depending upon the state of the plate and the state of the solution.

In considering the increase in weight of a copper cathode in an electrolytic cell we cannot without definite experimental reasons neglect to consider the possibility of both these actions occurring together, and, moreover, the passage of the current may produce complicated results which cannot be inferred from the action of the solution in the cell under other conditions. Dr. Gore has made very numerous experiments upon this subject, without, however, arriving at any very satisfactory result.

In view of the importance of the subject, a very large number of experiments have been made at the Cavendish Laboratory at Cambridge under my direction during the past two years. They may be divided into two groups. (A). Experiments to ascertain whether two copper cells give the same amount of deposit for the same current; and (B). Experiments to determine whether a copper cell can be arranged so that, on comparison with a silver cell, within sufficiently wide limits of current it will give a value of the chemical equivalent of copper agreeing with that obtained by chemical methods.

A. Experiments on Copper Cells only.

These experiments consisted in arranging pairs of copper cells with various electrodes, as copper plates, copper wires, copper cylinders having wire connections, platinum wires, in order to ascertain whether the disturbing actions were limited to the surface. The results were very irregular and disappointing. Errors amounting frequently to more than 1 per cent. occurred without any assignable cause.

The same is all that can be said about experiments with different solutions of sulphate, including solutions from which air had been expelled by boiling, the experiments being then conducted under the receiver of an air-pump. Endeavours to allow for the differences of the cathode weighings, by supplementary experiments on the effect of the solution upon plates not connected with the electrodes, have likewise proved fruitless. The enumeration of these experiments would serve no practical purpose, as they lead to no generalisation; I shall therefore pass over them.

B. Experiments on the Comparison of Silver and Copper Cells.

One of the most disagreeable features of the experiments referred to in the preceding section was that when two cells were compared, and a difference in the increase of weight of the cathodes was obtained, it was impossible to say whether either or both of the two cells was at fault, and it was therefore decided to employ a silver cell as a standard. Lord Rayleigh was at the time engaged on his experiments upon absolute value of the electro-chemical equivalent of silver, and had not yet arrived at a result. Experiments were therefore made to obtain a silver cell that might be fairly regarded as a standard. The only difficulty in the way was that the deposit of silver from pure nitrate is crystalline and very rough. The deposit was taken upon a platinum crucible, and it was feared that error might arise, either from mechanical loss of the silver during the operation of drying, or from the retention by the deposit of water, or salt in solution. Attempts were therefore made to use as electrolyte (1) a solution of chloride of silver in hyposulphite of silver, (2) a solution of nitrate of silver containing glycerine, (3) a solution of nitrate of silver containing acetate of silver. The deposits obtained with all these are much closer and harder, but the hyposulphite solution is very unstable, and a current beyond a certain density precipitates a black sulphide which destroys the experiment. The other solutions were also discarded after consultation with Lord Rayleigh, who had then shown that a 15 per cent. solution of pure nitrate gave a perfectly satisfactory silver cell if proper precautions were taken with the drying, whereas the solutions containing organic salts were liable to serious error, probably in consequence of the inclusion of the solution in the pores of the deposit.

It was originally intended to use only those experiments from which the loss of the anode was obtained equal to the gain of the cathode. It was found, however, that the possibility of weighing the loss of the anode was simply fortuitous, the action of the solution upon the silver always producing a sort of honeycomb formation, and ultimately leaving smaller particles which fell off in washing. This was the case even when a silver crucible was used as the anode. It was therefore decided to use the gain of the cathode only. The form of silver cell adopted is that of Poggendorff's voltameter in which a platinum crucible standing on a copper plate is the cathode and a silver rod the anode. The crucibles were about $1\frac{1}{2}$ inch in diameter and 2 inches high, and the silver rod forming the anode was about half an inch in diameter.

The method of drying the deposit was to wash in distilled water by filling up the crucible several times and allowing it to stand for some time, then after thoroughly rinsing, to wash it out with alcohol and dry in a hot air-bath at about 260° C.

As the crucibles were very different in size from those used by Lord Rayleigh some experiments were made to determine their behaviour.

The following are the results:—

Comparison of Two Crucibles of Different Sizes

Date	Time in minutes	Current in ampères	Large crucible grammes	Small crucible grammes	Difference
Feb. 6	100	·3096	2·0789	2·0802	−·0013
„ 7	120	·3638	2·9312	2·9364	−·0052

Comparison of an Old and New Crucible.

Date	Time in minutes	Current in ampères	Old crucible	New crucible	Difference
Feb. 11	120	·4677	2·5203	2·5183	·0020

Comparison of Cell with Acetate with one without.

Date	Time in minutes	Current in ampères	Crucible with no acetate	Crucible with acetate	Difference
Feb. 13	123	·3084	2·5391	2·5467	+·0076
„ 14	120	·3521	2·8251	2·8368	+·0117
„ 16	125	·4047	3·3850	3·4016	+·0166
					The crucibles were made red-hot and re-weighed
„ 18			3·3850	3·3966	+·0116
„ 18	120	·3416	3·0610	3·0777	+·0167
					Heated and re-weighed
„ 19			3·0609	3·0685	+·0076
„ 19	120	·2794	2·2429	2·2512	+·0103
„ 22	120	·4510	3·2261	3·2473	+·0212
					Heated and re-weighed
„ 23			3·2258	3·2431	+·0173
„ 23			2·9957	3·0114	+·1183

Comparison of Pure Nitrate Cell with Chlorate Cell.

Date	Time in minutes	Current in ampères	Chlorate Cell	Nitrate Cell	Difference
May 14	—	—	2·0904	2·0895	·0009 Heated to redness and re-weighed
„ 15	—	—	2·0902	2·0891	·0011
June 5	120	·3093	2·2270	2·2271	·0001
„ 7	130	·2852	2·4901	2·4900	·0001

The chlorate deposit after being heated to redness was dissolved in pure nitric acid and the solution tested for chloride, but none was found.

The silver cell being thus shown to be capable of working quite satisfactorily, the arrangement and comparison of copper cells were proceeded with. It was found in the previous experiments on copper that the deposits obtained on platinum wires gave much more concordant results than any other form of cell. This form of cell had been already used by Soret. It was accordingly decided to adopt that form. The cathodes were platinum wires about 15 cm. long and 1 mm. in diameter, and the anodes were wires of electrolytic copper whose diameter was somewhat greater. It is, however, well known that the density of the solution alters very considerably in the neighbourhood of the cathode, and if the electrodes are vertical this effect is not so much interfered with by convection currents as when the electrodes are horizontal. The wires were therefore placed horizontally in the solution; for this purpose they were bent at right angles, and the one end fastened to a binding screw attached to a thick wooden rod that lay on the edges of a porcelain dish that contained the electrolyte. A number of cells were prepared respectively for 1, 2, 3 . . . . . . up to 16 wires. The wires were arranged about 2 inches apart, and between them lay the anode wires attached to a similar piece of wood that rested on the other end of the dish; the wires in the same cell were put in multiple arc by a strip of copper laid along the wood, through which the binding screws passed. Some difficulty was met with in arranging that the anodes and cathodes did not touch, but with care it was surmounted. The solution was an approximately saturated solution of Hopkin and Williams's pure copper sulphate. No acid was added. The wires with their deposits were washed by rinsing them in several changes of distilled water and then dipped in alcohol and dried in an air-bath at a temperature of about 100° C.

In the experiments given below the copper deposits were brilliantly clean and generally showed no trace of oxidation on drying. The reason for this was never made clear; it is, however, easily recognised that under certain circumstances, defined perhaps by current density or the state of the solution, the copper deposits do not easily oxidise on drying, whereas in other experiments it seems almost impossible to dry them without considerable oxidation.

In all the experiments a rough tangent galvanometer was included in the circuit, so that any considerable variations of the current might be detected. A water or dilute copper sulphate cell, with copper electrodes whose distance apart could be adjusted, was also included to serve the purpose of a rheostat.

In a first series of experiments a silver cell was compared with each one of the copper wire cells in turn; the results are given in the following table:—

TABLE I.—*Comparison of Amounts of Silver and Copper Deposits.*.

Date	Time in min.	No. of wires	Cu. deposit	Ag. deposit	Ratio	Current in ampères
June 10	145	1	·7309	2·4848	3·400	·2553
„ 11	120	2	·9268	3·1445	3·393	·3903
„ 11	120	3	·7651	2·5967	3·394	·3222
„ 12	115	4	1·0384	3·5130	3·383	·4549
July 7	120	2	·8417	2·8571	3·394	·3546
„ 7	120	1	·9245	3·1401	3·397	·3897
„ 8	120	3	·9764	3·3186	3·399	·3954
„ 8	—	4	·9740	3·3137	3·402	—
„ 8	120	5	·4206	1·4332	3·408	·1778
„ 9	120	6	·9969	3·3872	3·398	·4203
„ 9	—	7	·9482	3·2297	3·406	—
„ 10	120	8	·9471	3·2268	3·407	·4004
„ 10	120	9	1·1369	3·8721	3·406	·4806
„ 11	123	10	1·1261	3·8383	3·408	·4648
„ 11	123	11	1·0792	3·6783	3·408	·4454
„ 14	125	12	1·0416	3·5610	3·419	·4248
„ 14	128	1	·7318	2·4876	3·399	·2895
„ 17	125	2	·7577	2·5770	3·401	·3071

Mean . . . . . . 3·4010.

It will be seen that the extreme divergence of the values from the mean amounts to rather less than ½ per cent.; the errors are irregular, but the difficulty of keeping the current constant was very great, and in some cases there was considerable difference, so that no inferences as to the effect of current density could be drawn. The arrangement was therefore altered and five copper cells containing respectively 1, 2 4, 8, and 16 wires, were all included in the same circuit with one silver cell. The electromotive force was obtained from 12 storage cells, or from Grove cells. The observations are included in the first part of Table II. There was still some difficulty in keeping the current constant, and the apparatus was in consequence transferred to Emmanuel College, where a dynamo working at 110 volts for electric lighting was available; a satisfactory series of observations was obtained, shown in the latter part of Table II.

TABLE II.—*Ratio of Weight of Silver to Weight of Copper.*

Date	Time in min.	Weight of silver in grammes	For 1 wire	For 2 wires	For 4 wires	For 8 wires	For 16 wires	Current in ampères	Remarks
				I. AT THE CAVENDISH LABORATORY.					
Oct. 10	130	·9717	3·407	3·414	3·417	3·416	3·419	·1113	Galvanometer deflexion variable. In the 4-wire cell 3 wires only received deposits.
„ 20	300	2·7019	3·401	3·408	3·409	3·420	3·447	·1341	Galvanometer deflexion variable. In the 4-wire cell 3 wires only received deposits.
„ 26	170	3·3682	3·393	3·398	3·397	3·401	3·407	·2951	Galvanometer deflexion variable. 'One wire' slightly discoloured.
„ 29	120	2·8930	3·397	3·398	3·400	—	3·414	·3591	—

TABLE II.—*Ratio of Weight of Silver to Weight of Copper*—continued.

Date	Time in min.	Weight of silver in grammes	For 1 wire	For 2 wires	For 4 wires	For 8 wires	For 16 wires	Current in ampères	Remarks
II. At Emmanuel College.									
Nov. 27	120	3·9089	3·401	3·404	3·405	—	—	·5229	—
Dec. 10	110[1]	3·0259	3·413	—	—	3·411	3·408	·4093	Copper left in hot chamber too long, and was discoloured
" 15	120	4·9954	3·397	3·399	3·400	3·402	3·408	·6202	—
" 16	130	4·0393	3·398	3·401	3·400	3·403	3·398	·4629	—
" 17	120	4·0895	deposit loose	3·398	3·398	3·403	3·406	·5076	—
" 18	120	5·1570	—	3·400	3·399	contact	3·400	·6399	A copper crucible in the same circuit gave 3·407

DISCUSSION OF THE OBSERVATIONS.

The numbers quoted in the table give the ratios of the amounts of silver to the corresponding amounts of copper deposited to the 4th significant figure. The balance used was a triangular beam Oertling, which could be relied upon for an accuracy reaching 0·1 mgm. The copper deposits generally amounted to about 1 gramme, and the accuracy of the weighings (corrected when necessary for the differences in the buoyancy of the air at the times of the initial and final determination of the weights) may be assigned as ·01 per cent. for copper deposits, and ·003 per cent. for silver. The numbers in the table are carried to one place less than the weighings permit. This is done intentionally in order to enable the reader to obtain a better general idea of the whole series of observations. It is easily seen that the differences in the table are real differences, and correspond to some real characteristic of the electrolytic action in the cells. A glance at the sets of observations belonging to the same experiment is sufficient to suggest a diminution of the amount of copper deposited as the current-density diminishes. The area of each wire was about 5 square centimetres, so that the current-density varies for the observations in Table II. between ·001 and ·15 ampère per square centimetre, and practically includes all current-densities that can come under observation with this form of cell. In some cases the density was so great in the 'one-wire cell' that the copper deposit was flocculent, and could not be weighed in consequence; and in some of the sixteen-wires the deposit was not sufficient to cover the wires, but occurred in patches with small groups of copper masses.

If we proceed, on the assumption of the accuracy of Faraday's law, to attempt to explain the observed differences, we must first look to the action of the solution upon the deposit, since it is known that such an action actually takes place when copper is immersed in a solution of sulphate, and that the weight of copper might be reduced by solution. This action is said to depend upon the solution and the temperature. These considerations make it difficult to infer the action in the cell from that upon a wire without a current flowing: for, in the first place, the solution is weakened in the immediate neighbourhood of the cathode by the electrolysis; and, in the second place, the temperature is altered by the current itself, and was sensibly different in the different cells in some of the experiments; but to measure the temperature and allow for it is not very practicable, as it is not uniform throughout the cell.

Further, there may possibly be a division of the current between the salt and the solvent, and any action of the kind would probably have an effect upon the action of the solution on the cathode.

The only plan that has suggested itself to me is to arrange the observations in the order of current-density, and to see if any correction could be applied that

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[1] Discarded.

would make the observations fairly comparable. This may fairly be applied, since the disturbing causes I have mentioned depend upon the current-density.

In order to put this to the test, I have assumed in the first place that the action upon the deposit may be represented by an expression of the same form as would be required to represent the action of the solvent upon a wire immersed in the solution without any current. This we may take to be, for the comparatively short times of the experiments, a case of solution going on at a constant rate, and proportional to the area exposed. Thus if δ be the actual loss of copper in an experiment when the area exposed is A, and the time t, we shall take

$$\delta = kAt,$$

and shall investigate whether a constant value of k can be taken to bring the observations into agreement. It is easily seen that this is equivalent to $\frac{\delta}{c} = \frac{k'}{d}$ where c is the total amount of copper deposited during the experiment, and d the current-density; and where k is also constant, but numerically different from k. In words we may express this by saying that the fractional correction is inversely proportional to the current-density.

LAW OF VARIATION OF THE DEPOSIT WITH CURRENT-DENSITY.

It is difficult to settle what value to assume for k'. If k' be a true constant, its value can of course be calculated from any pair of observed results; but the magnitude of possible experimental errors, in comparison with that of the quantity under consideration, makes it highly improbable that the results would be at all concordant. It will at any rate be well, in order to avoid a possible error in the weighing of the silver, to use observations belonging to the same experiment for determining the value of k'. I have determined the values of k' for several pairs of observations, taken somewhat at random, with the following results:—

TABLE III.

Experiment	Range of current-density	k'
Oct. 10	·0014 – ·023	·0000052
„ 20	·0017 – ·026	·000025
„ 26	·0037 – ·015	·000014
„ 29	·0045 – ·036	·000024
Dec. 15	·0077 – ·0310	·000025
„ 16	·0115 – ·092	·000017
„ 17	·0063 – ·051	·000017

The values of k' thus obtained are not very concordant. It must, however, be remembered that it is difficult to assign with confidence a numerical value to the current-density, since the effective area of the copper surface may be practically very different from that of the platinum on which the copper is deposited. In the expectation that the action of the solution upon the copper when no current is flowing might help to decide which value of k' to take, the 'one wire' and 'sixteen wires' of October 20 were replaced in the solution, after the weighing was completed, and remained there for the time of duration of the experiment, viz., five hours. The 'one wire' lost ·0008 gm., and the 'sixteen wires,' ·0110 gm. This gives a loss of ·0007 gm. per wire, and corresponds to a value of $k' = ·000025$. On November 27, a loose copper wire was left in each of the cells during the experiment; and the mean loss of each of the wires during the time was ·0003 gm., which corresponds to approximately the same value. It will therefore be well to see what effect the correction of the weighings on the hypothesis that $k' = ·000025$ would have upon the tabulated results. The correction may be introduced by adding ·00014 gm. to the weight of each wire immersed for each hour during which the experiment lasts. The following table shows the weights of copper as thus corrected:—

TABLE IV.

Date	1 wire	2 wires	4 wires	8 wires	16 wires	Mean	Mean percentage error
Oct. 10	·2855	·2853	·2853	·2869	·2889	·2864	0·4
„ 20	·7952	·7942	·7941	·7957	·7949	·7948	0·06
„ 26	·9932	·9922	·9931	·9934	·9950	·9934	0·06
„ 29	·8519	·8516	·8520	—	·8518	·8518	0·02
Nov. 27	1·1498	1·1490	1·1489	—	—	1·1492	0·04
Dec. 15	1·4708	1·4700	1·4703	1·4704	1·4698	1·4703	0·02
„ 16	1·1888	1·1882	1·1892	1·1894	1·1932	1·1898	0·11
„ 17	—	1·2039	1·2043	1·2037	1·2048	1·2042	0·03
„ 18	—	1·5172	1·5183	—	1·5215	1·5190	0·11

An examination of this table shows that, with some few exceptions, the results, as corrected, are very fairly concordant. That no value of k' could be found which would apply equally to all the observations is obvious from the discordance in the values of a k' tabulated above. A striking feature of the table is that the numbers under the heading of '2 wires' seem now to be the minimum values of the table; the '1 wire' values are all greater; and the numbers in the other columns are very rarely less, and then only by very small quantities. This shows that the correction applied is probably too large, though it is sometimes very successful. It is probable that the correction ought not to be applied when the current-density is very great, as the difference between the '1 wire' and '2 wires' is increased by the correction, though not entirely due to it. This, as already pointed out, is probable *à priori*, since the more rapid deposition of copper would weaken the solution in the immediate neighbourhood of the cathode. The correction may, however, be fairly adopted for the smaller current-densities. It appears on examination of the current-densities that the exceptional cases do not arise when the current-density is below ·02 ampère per square centimetre, so that the weights of copper deposited with currents of current-density less than ·02 ampère per square centimetre may be corrected by multiplication by a factor $1 + \frac{k'}{d}$, where d is the current-density, and k' a constant not differing much from ·00002.[1]

CHEMICAL EQUIVALENT OF COPPER.

We have now to compare the results obtained for the ratio of the chemical equivalent of silver to that of copper with those obtained by purely chemical methods, in order to ascertain whether or not Faraday's law is strictly applicable in the case of silver and copper. If we take the results given in Landolt and Börnstein's 'Physikalisch-Chemische Tabellen,' we find the atomic weight of silver given as 107·66 by Meyer, and 107·675 by Clarke, and the accuracy is stated as being within ·05; that of copper is quoted as 63·18 from Meyer, and 63·17 from Clarke, with a possible error of ± ·5. This would give a value for the ratio of the chemical equivalents of silver and copper equal to 3·4086; or, allowing the fullest margin for error, the value lies between 3·38 and 3·44; so that the values obtained by the deposition of silver and copper seem to be all within the limits of error thus assigned; and we cannot, therefore, test the accuracy of Faraday's law until the

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[1] The values obtained by Lord Rayleigh with copper bowls (*Phil. Tr.* Pt. II. 1884, p. 458) are:

Current-density, about ·012; ratio of equivalent, 3·405
„ „ „ ·026 „ „ 3·408
„ „ 3·404

value of the chemical equivalent of copper can be assigned with greater accuracy than appears at present to be practicable. We may, however, notice that the value 3·4086 is that which would be obtained with comparatively very small current-densities, and occupies a place in the middle of a continuous series, and there seems to be no reason in the electrolytic behaviour of the cells for accepting that value as indicating a limiting result. We may therefore fairly approach the question the other way, and, using the observations to calculate the chemical equivalent of copper by Faraday's law, consider the results which follow. If we assume, as we seem fairly entitled to do, that the differences of the weights for different current-densities are due to the solution of the deposited copper, it follows (assuming Faraday's law) that we must get a nearer approximation to the true amount of copper equivalent to the amount of silver deposited the greater the current-density. The value would be affected by the correction discussed above; but it has been already stated that it is unsafe to apply the correction, or, at any rate, to assign to the value that of k' assigned above. But the consideration of that correction serves us to this extent, viz., to show that for current-densities above ·02 its value must be very small indeed, reaching, as a matter of fact, with the value of $k = {\cdot}00002$, to less than one milligramme per gramme. But in determining by Faraday's law as accurately as possible the chemical equivalent of copper from that of silver, the correction cannot be disregarded without sufficient reasons. Some reasons for that course have been given, but in order to test further whether or not the correction should be applied I have plotted the observations on sectional paper, taking as ordinates the ratios of copper to silver, and as abscissæ the reciprocals of current-densities. If the correction should be applied throughout, the grouping of the observations should show a straight line inclined to the axis of current-densities. I have adopted this method of combining the observations belonging to different experiments for this purpose, in preference to the arithmetical one of taking means, because the latter is liable to be seriously affected by a set of observations, each one of which is far from the mean in the same direction, but which does not extend throughout the whole range. In the estimation by eye of a mean result of plotted observations allowance can be made for the effect such observations produce, whereas they may give a false appearance of general law to a set of arithmetical means.

The observations included in the Table II. when plotted do not give any indication of the divergence of the mean ordinates from a straight line parallel to the axis of reciprocals of current-densities until the current-density is less than ·02, and the straight line passing through the 'centre of gravity' of the group of observations for highest current-densities, and inclined to the axis with the angle given by the value $k' = {\cdot}000025$, would leave all the rest of the observations except three on one side of it: but a very fair result is obtained if the value of k' be somewhat reduced, and the line be drawn at the corresponding less inclination through the point corresponding to the 'centre of gravity' of observations about the current-density ·02. If we must take a straight line inclined to the axis as representing the results, the one which must be selected has an inclination to the axis of about one-half that given by $k' = {\cdot}000025$, and even that leaves on one side of it nearly the whole group of observations whose current-densities have reciprocals between 50 and 30. Further, the values of the ratios obtained from the observations for current-densities above ·02 are remarkably close, except in two instances; in one the ratio is very high, with a high current-density, and differs widely from other observations at about the same current-density; the other is very low, and belongs to an experiment which gives a series of very low values; this has been rejected because the wire which gave it was marked in the note-book as 'discoloured,' *i.e.* oxidised, at the time of weighing.

In order, therefore, to obtain the value of the chemical equivalent by this method, I have taken all the values obtained for current-densities greater than ·025 ampère per square centimetre. They are included in the following table:—

TABLE V.

Current-densities	Ratios observed	Ratios with the correction ($k'=\cdot000012$)
·124	3·3968	3·3965
·104	3·4005	3·4001
·093	3·3984	3·3979
·072	3·3971	3·3965
·064	3·4004	3·3997
·062	3·3994	3·3987
·052	3·4035	3·4027
·051	3·3982	3·3974
·046	3·4009	3·4000
·036	3·3984	3·3972
·032	3·3990	3·3977
·031	3·3998	3·3984
·027	3·4014	3·3998
·026	3·4056	3·4040
·025	3·3982	3·3966
Mean . . .	3·39983	3·39888
Mean error . .	·00175	·00151

I have included in the same table the values obtained when the correction for the current-density ($k'=\cdot000012$) is introduced, in order that an opinion may be formed as to the magnitude of the difference produced: it will be seen that the amount of difference corresponds to an error in weighing of only 0·3 milligramme per gramme. I have given reasons for preferring the value as calculated without the introduction of this correction, and from the circumstance already pointed out, viz., that after the correction $k'=\cdot000025$ is introduced, the '2 wire' values are minima, it would seem likely that the deposit obtained with the highest current-density may be too great in consequence of the operation of some action which is not accounted for. To decide this point requires measurements to a degree of accuracy beyond that reached in the present observations, so that we may set down the ratio of the chemical equivalent of silver to that of copper, as obtained by this method, as being

$$\underline{\underline{3\cdot39983}},$$

with a mean error of ±·00175 in the observations.

THE ATOMIC WEIGHT OF COPPER.

It will be at once noticed that the value obtained for the ratio of the equivalent differs by only 17 parts in 300000 from the number 3·4000, and there is some indication that the observed value is too small; we may therefore accept the observations as showing the ratio to approach very nearly indeed to 3·4000. This gives for the ratio of the atomic weight of silver to that of copper the ratio of the whole numbers 17 : 10. If we take the atomic weight of silver as 107·66, the atomic weight of copper will be $\underline{\underline{63\cdot333}}$. This result gives some striking relations; it gives, in fact, for the atomic weight of silver the number $\frac{19\times17}{3}$, and for that of copper $\frac{19\times10}{3}$, and therefore gives both as one-third of whole numbers. The atomic weight of silver is one of the most accurately determined of all, and the number here assigned to copper is within the limits of error allowed by L. Meyer; so that these remarkable relations may perhaps offer some reason for considering the value of the atomic weight of copper deduced from Faraday's law as being worthy of consideration.

A number of speculations are suggested by the relations between the numbers thus arrived at; but it is not necessary to discuss them here. (See 'Phil. Mag.' Feb. 1887.)

On the application of Alternating Currents to the Determination of the Conductivity of Electrolytes. By T. C. FITZPATRICK, *Scholar of Christ's College, Cambridge. (Communicated by* W. N. Shaw.)

The work described in this paper was undertaken with the view of testing the method of the alternate current as applied to the measurement of the resistance and conductivity of electrolytes.

This method was first employed by Kohlrausch and Nippoldt in 1869, and an account of their work and their justification of the method is found in Poggendorff's 'Annalen,' cxxxvi. They found that above a certain rate of alternation of the current the electrolytic cell could be replaced by a metallic resistance, and that the value of this replaced resistance did not alter on increasing the rate of alternation.

Two things they considered were necessary for the complete removal of the polarisation effects:—

(*a*) A sufficient rate of alternation.

(*b*) Electrodes of considerable area; small platinised platinum electrodes were afterwards found to answer perfectly well.

The alternate current was produced by a sine inductor, and as indicator they employed a dynamometer.

In the October number of the 'Annalen' for last year there is a long paper on Kohlrausch's most recent work; the method is the same as that employed in the earlier work, only the dynamometer is replaced by a telephone as indicator.

A modification of this method was used by Ewing and Macgregor. They employed the Wheatstone bridge arrangement, the current being alternated by a rocker. They do not, however, appear to have obtained any satisfactory results.[1]

More recently Macgregor has replaced the rocker by a double commutator. By one half of the commutator the alternate current has been produced and by the other the current of the galvanometer circuit has been redirected, so that through the galvanometer there is a direct but intermittent current. It is a method similar to this latter that I have employed.

My commutator, which was very carefully made by the Cambridge Scientific Instrument Company, consists of a drum, on the two faces of which are eight sectors of brass separated by strips of ebonite; the alternate sectors are connected with two brass rings on the spindle of the commutator. The only difference between the two faces of the drum is that on the one side the sectors are smaller, and the ebonite pieces bigger. This is to permit of the galvanometer circuit being broken before the battery circuit, and made after it.

The two rings on the one side of the commutator are connected by brushes with the poles of the battery, and two brushes carry off alternate currents from the face of the drum to the two points on the Wheatstone bridge. The brushes are kept firmly pressed in contact by springs.

The two points in the bridge for the galvanometer are connected with two

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[1] *Note by Professor J. A. Ewing, in a letter to the Editor.*—'This reference is not quite accurate. The method we used was not properly an alternate-current method. The plates were allowed to depolarise first, then the circuit (a Wheatstone-bridge one) was completed—*i.e*, the battery key was pressed, the galvanometer key already being down, and the *initial* impulse of the galvanometer (a very light narrow one) was noted. The bridge was adjusted till this initial impulse was zero, as well as could be judged. Of course this plan is open to the self-induction objection to which alternate-current methods are liable; and I should not recommend it now. As a matter of fact, however, it gave much more consistent and apparently better results than one might expect. Some of these, on the resistance of mixtures (solution of sulphate of zinc mixed with sulphate of copper), were rather interesting The paper was published in *Trans. R.S.E.*, vol. xxvii., 1873. It was rather a boyish performance. Still, if reference is to be made to it, it may as well be made correctly.—J. A. E.'

brushes in contact with the other face of the commutator; and, lastly, two brushes in contact with the other two brass rings carry off the direct current to the galvanometer.

The resistance-box employed is one of Elliott's, being a legal ohm box; the galvanometer is a Thomson reflecting galvanometer, only the light mirror has been replaced by a piece of mirror-glass, which is loaded with several lead discs, and to the back is fixed a small magnet. The magnet has thus a considerable time of swing, and was found to answer much better than the usual light needle. The resistance of the galvanometer was about 268·8 ohms.

Two different cells were employed to hold the electrolyte. The first was similar to that of Kohlrausch—a strong glass beaker, in which the electrodes were kept in fixed relative positions by two small glass plates—a thermometer was inserted between the two plates to register the temperature.

Kohlrausch, to determine the resistance-capacity of his cell, measured its resistance when filled with pure mercury;[1] but he does not mention his having taken any precautions as to the difficulty of getting a good contact between his platinum plates and the mercury. Recent observers have stated that there remains a film of air between the platinum and the mercury, and that to get good contact the cell should be filled under greatly reduced pressure; and even then I have found that the resistance may vary. I have therefore not employed mercury to determine the resistance capacity of my cell, but a standard solution of copper sulphate, the absolute values of which I determined by means of my other cell.

This consists of a glass tube of considerable cross-section which fits into two glass end-pieces; the tube has been ground so as to enter about an inch into the end-pieces. This apparatus was made for me by Messrs. Powell, of Whitefriars Glass Works, and possesses the advantage of being entirely of glass, without any corks, &c. And the electrodes were firmly pressed against the ends of the tube, and so the resistance of a given column of the solution determined.

For electrodes, in the first instance, copper plates were platinised. For a long time no satisfactory method of platinising could be found; that which gave the best results was the electrolysis of a solution of platinum chloride and nitric acid: the deposit thus obtained was fairly adhesive.

It was finally found best to obtain some platinum electrodes, and for this purpose two platinum shoes were made by Messrs. Johnson and Matthey, into which fitted thick copper plates; thus a strong electrode of small resistance was obtained without the expense of thick platinum plates; these plates were slightly platinised as above described.

In the early experiments with this method no satisfactory results could be obtained. When the electrolytic cell was introduced into the fourth arm of the Wheatstone bridge, sometimes the galvanometer would not give any steady deflection, and it was impossible to get a balance. This was similar to Macgregor's experience; he states that by introducing another cell into one of the other arms of the bridge he readily obtained a steady deflection. In my own case this did not in the slightest diminish the effect; even with a metallic resistance in the fourth arm of the bridge the same value could not be obtained as when the commutator was not working.

Under these circumstances it became necessary to thoroughly investigate the action of the commutator. At first the commutator had been lubricated with a small quantity of oil; this was found to be partly the cause of the effects observed, and it was consequently thoroughly cleaned from all oil.

It was also found that the commutator did not run perfectly steadily; the commutator and its stand were therefore firmly fixed in position with wooden props, and driven by a water-engine, which was supplied with water from a tank at the top of the building, and thus a constant and steady speed was obtained.

Finally, as above described, the light needle of the galvanometer was replaced by one with a longer time of swing.

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[1] *Note by Professor Kohlrausch, in a letter to the Editor.*—'This is an error. I filled the cell with zinc-sulphate solution, whose resistance had been measured in the form of a cylindrical column.'

With these alterations it was found that the galvanometer gave a steady deflection, and the method appeared to be satisfactory.

This result having been obtained, the apparatus was tested for induction effects. For this purpose a metallic resistance was introduced into the fourth arm of the bridge, and its value determined when the commutator was not working; the value obtained was—

$$R = 19{\cdot}91 \text{ legal ohms.}$$

With the commutator working at varying rates of speed, the value remained the same, and was not altered by changing the battery power from that of 2 Leclanché cells to a tray of 10 Daniells. This seemed satisfactorily to show that there was no induction effect, though the sensitiveness of the galvanometer was diminished.

The diminution in the sensitiveness of the galvanometer when the commutator was working may be seen from the following series of observations.

The above metallic resistance being in the fourth arm of the bridge, a balance was obtained when the value of the resistance of the third arm was 1991, the value of the other two arms being 1000 and 10 respectively.

(1) Commutator at rest—

$$\left.\begin{array}{l}\text{Galvanometer zero } 28{\cdot}3 \text{ cm.}\\ \text{50 ohms in 3rd arm } 26{\cdot}7\end{array}\right\}\text{ deflection of 16 mm.}$$

$$\left.\begin{array}{ll}\text{Zero} & .\ .\ 28{\cdot}3\\ -100 \text{ ohms} & .\ 25{\cdot}1\end{array}\right\}\text{ deflection of 32 mm.}$$

(2) Commutator working—

$$\left.\begin{array}{ll}\text{Zero} & .\ .\ 28{\cdot}5\\ -50 \text{ ohms} & .\ 29\end{array}\right\}\text{ 5 mm.}$$

$$\left.\begin{array}{ll}\text{Zero} & .\ .\ 28{\cdot}5\\ -100 & .\ .\ 29{\cdot}4\end{array}\right\}\text{ 9 mm.}$$

Hence the sensitiveness of the galvanometer is decreased by about $\frac{2}{3}$ when the commutator is working, though the rate of driving did not appear to affect the sensitiveness. The apparatus was then tested for polarisation effects. For this purpose the two wires leading from the commutator to the battery circuit were connected with the galvanometer and an electrolytic cell with platinum plates containing copper sulphate; the commutator was started and the circuit completed, the battery consisting of 2 Leclanché cells; the commutator was allowed to run for two hours and a half, the rate of alternation being about 120 per second; at the end of this time the circuit was broken, and the platinum plates washed, treated with hot nitric acid, and ammonia added after neutralisation with ammonia carbonate. There was not, however, a trace of blue coloration; it was therefore clear that no copper had been deposited on either plate, and that there was no cumulative polarisation effect.

This test was again repeated, the platinum plates being replaced by platinum wires, and the Leclanché cells by a tray of 10 Daniells; the commutator was allowed to work for over three hours at the same rate of 120 alternations per second. At the end of this time the wires were treated similarly to the plates, but with the same result. This latter was a more severe test, and would tend to show that the method may be expected to be free from all polarisation effects, and to give satisfactory results.

So far therefore this method seems perfectly satisfactory, and with the arrangements as above described I have not found it in the least necessary to have a second cell in the bridge, as did Macgregor.

I find that the steadiness of the galvanometer depends—

(1) On the commutator being perfectly clean.

(2) On the commutator being driven at a steady speed, though permanent alteration in the rate of speed does not affect it.

Having thoroughly tested the method for polarisation and induction, I proceeded to examine into the question of contact resistance, a subject which has been raised lately by Dr. Gore, several papers on the subject being published in the 'Philosophical Magazine' for this year.

It seemed that if there was such an effect as contact resistance it was impossible to obtain the absolute values for the conductivities and resistances of different solutions, and that before proceeding to the measurement of these quantities it was necessary to test for contact resistance.

For this purpose I filled one of my cells with copper sulphate solution, and determined its resistance value with different pairs of electrodes.

These were—

(*a*) Platinum plates (slightly platinised).
(*b*) Platinised copper electrodes.
(*c*) Amalgamated copper electrodes, or copper electrodes with freshly deposited copper surface.

I found that the amalgamated copper electrodes left in a solution of copper sulphate became coated with a film of copper, mercury apparently going into solution; this of course was only to be expected from the chemical ideas of mass action.

The values obtained were—

(*a*) Platinum electrodes, 469·2 at 16·9°.
(*b*) Platinised copper, 469 at 17°.
(*c*) Copper electrodes, 471·95 at 16·7°.

These same copper electrodes gave after standing in air or copper sulphate solution a value much bigger than that of the platinum plates.

Another pair of copper plates, which had been prepared some days, gave the values with a different copper sulphate solution of—

(1) Copper plates, $R = 477$ at 17·6°.
(2) Platinum plates, $R = 465$ at 17·4°.
(3) Platinised copper, $R = 465$ at 17·4°.

It appears therefore that the platinum and platinised copper plates give identical values, and it would appear that the value given by copper electrodes with a fresh metallic surface is almost the same; but that, due to oxidation in air or in the solution, the surface is changed, and as a consequence the resistance value much increased.

This would tend to show that with clean metallic surfaces, and the same solution, the resistance value is the same, and that there is no contact resistance, or at least that it is the same in all three cases. To further examine this question I determined to experiment with a solution of zinc sulphate with

(1) Platinum plates.
(2) Amalgamated zinc electrodes.

Two zinc plates were freshly amalgamated, and left over night standing in a solution of zinc sulphate, and when introduced into the cell they gave a value

$$R = 312 \text{ at } 16{\cdot}4°.$$

The platinum electrodes gave the value

$$R = 280 \text{ at } 16{\cdot}5°.$$

After again standing in the zinc sulphate solution the value for zinc plates was

$$R = 318 \text{ at } 16{\cdot}5°.$$

These same electrodes were then washed with dilute sulphuric acid, to dissolve off the film of zinc or oxide, and after careful washing were introduced into the cell; the value now came down to

$$R = 286 \text{ at } 16{\cdot}5°.$$

In this case too it would appear that with a pure metallic surface the resistance value would be the same, whatever the electrodes used.

Such being the case, it becomes very necessary, in the determination of the conductivity of electrolytes, to take account of the character of the electrodes, and at the same time the above observation would point to the fact that with pure metallic surfaces the effect of contact resistance is constant, if it occurs at all.

Again to further test this point, the absolute value of a certain copper sulphate solution was determined by employing two distinct cells.

(1) Cell A, the tube of this cell had a length of 31·4 cm., its mean section being 10·66 square cm.

The copper sulphate solution placed in this cell gave a resistance value of 504·5 legal ohms at 18·1°.

(2) Cell B, the tube of this cell had a length of 24·16 cm. and a mean section of 13·21 square centimetres.

The copper sulphate solution placed in this cell gave the value 306·9 legal ohms at 18°.

The same platinum electrodes were used in both cases.

The values obtained for the resistance of a cubic centimetre of the copper sulphate solution differed by about 2 per cent.

The values being, with cell A

$$R = 171{\cdot}2 \text{ legal ohms.}$$

With cell B

$$R = 167{\cdot}8 \text{ legal ohms.}$$

These results would again tend to show that there is no effect due to contact résistance.

Another point, which seemed of importance, was the action of the solvent in the conductivity of electrolytes; and, with the view of experimenting on this subject, solutions were prepared containing the same salt, whilst the solvents were different.

In the first place equal quantities of copper sulphate were dissolved in distilled water and in glycerine, the resistance of the two solvents having been previously determined.

(1) The resistance of 500 cm. of water introduced into the cell gave a resistance of $R = 12{,}780$ legal ohms; in this water was dissolved 6·625 gms. of hydrated copper sulphate; the resistance value was now $R = 8{\cdot}87$ legal ohms at 17·2°.

(2) The glycerine, which was not pure, gave the value

$$R = 181{,}000 \text{ legal ohms.}$$

In this was dissolved 6·625 gms. of hydrated copper sulphate, and the resulting value was

$$R = 27{,}850 \text{ at } 16{\cdot}8°.$$

From these results the conductivity of a solution would appear to a large extent, and in fact mainly, to depend on the solvent employed. The comparison of solutions of copper sulphate in water and glycerine was not, however, continued, as there appears to be some slight chemical action whereby a very small quantity of copper oxide is precipitated; and hence it was thought that this would not be allowed perhaps to be a case of solution similar to that of the copper sulphate in water.

The case, however, of solutions of calcium chloride in water and absolute alcohol appeared to be in every way comparable, as a definite crystalline compound of calcium chloride and alcohol exists similar to the hydrated crystalline chloride. For this purpose equal quantities ($\frac{1}{10}$ of a gramme-equivalent) of pure anhydrous calcium chloride were dissolved in 500 ccm. of water, and also in 500 cc. of absolute alcohol (sp. gr. ·795), the resistance of the alcohol and also of the water having been previously determined. Then by dilution solutions were prepared of 250 cc., containing $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{40}$, &c., of a gramme-equivalent of the salt in 500 cc. of the solvent.

Two series of values were thus obtained for solutions of different dilutions in both alcohol and water, wherein we can compare the action of the two solvents.[1]

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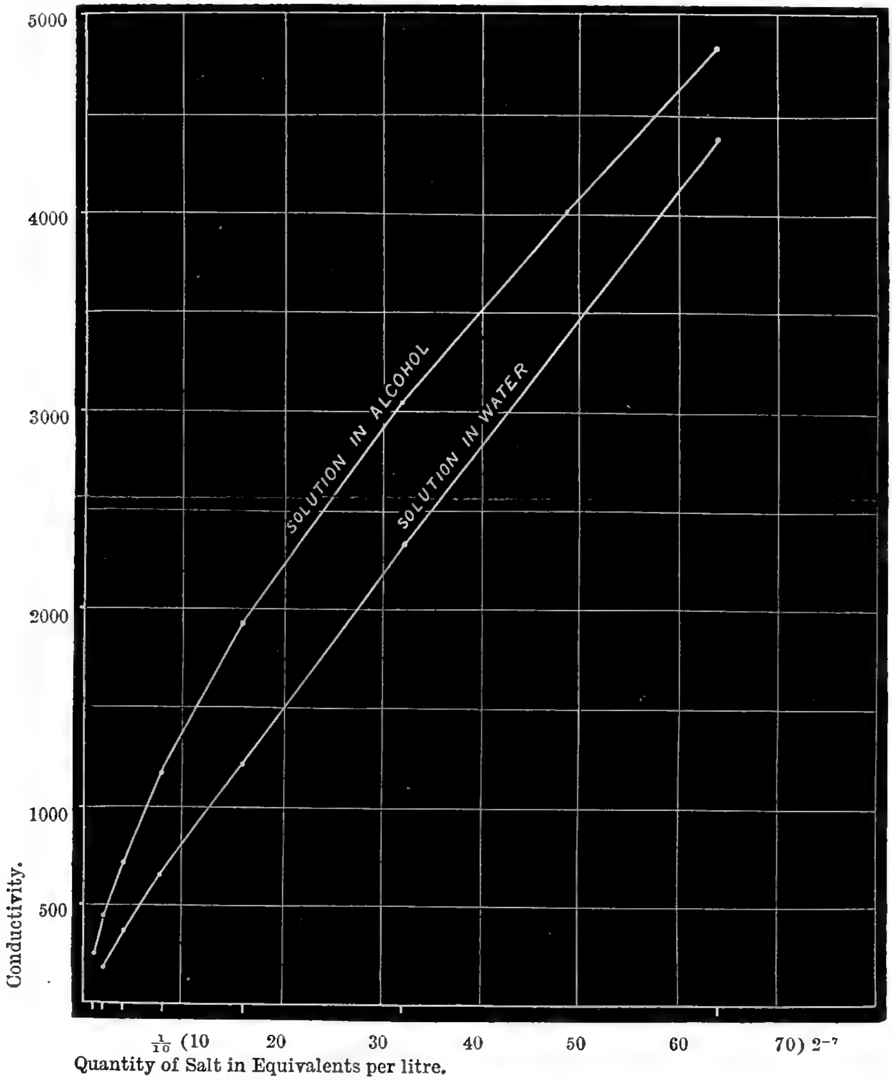
[1] In each case 250 ccm. of solution was introduced into the cell.

Solvent Alcohol.

(*Conductivity of Alcohol at* 17·8° = ·00000268.)

Amount of salt contained in 250 ccm.	Conductivity	Temperature
$\frac{1}{20}$ E.	·0007273	18·7°
$\frac{1}{40}$ E.	·0004820	18·7°
$\frac{1}{80}$ E.	·0003055	18·8°
$\frac{1}{160}$ E.	·0001939	18·6°
$\frac{1}{320}$ E.	·0001178	18·6°
$\frac{1}{640}$ E.	·0000729	18·6°
$\frac{1}{1280}$ E.	·0000430	18·6°
$\frac{1}{2560}$ E.	·0000259	18·5°



In curve for Water and $CaCl_2$ each division measured vertically represents ·0001 increase in conductivity.
In curve for Alcohol and $CaCl_2$ each division corresponds to ·000005.

Solvent Water.

(*Conductivity of Water at* 19·8° = ·00000848).

Amount of salt contained in 250 cc.	Conductivity	Temperature
$\frac{1}{20}$ E.	·015574	18·8°
$\frac{1}{40}$ E.	·008736	18·8°
$\frac{1}{80}$ E.	·004634	18·6°
$\frac{1}{60}$ E.	·002446	18·4°
$\frac{1}{320}$ E.	·001307	18·9°
$\frac{1}{640}$ E.	·000689	18·9°
$\frac{1}{1280}$ E.	·000364	19·3°

To determine the temperature coefficient of two comparable solutions, $\frac{1}{40}$ of an equivalent of dry calcium chloride was dissolved in 250 ccm. of alcohol and water respectively, and the values of the two were determined at two different temperatures.

(1) Alcohol solution:—

$\frac{1}{40}$ E. in 250 ccm. solution in cell gave a resistance value of

236 legal ohms, at 19·4°
250 „ „ 13·6°

Increase in resistance of 14 for a fall of 5·8° C.

This gives a temperature coefficient—·00102.

(2) Water solution:—

250 cc. in cell gave value

R = 14·0 at 18·3°
R = 15·4 at 14°

Increase in resistance 1·4 for a fall of 4·3°.

This gives a temperature coefficient—·0023.

The results obtained with the two series of solutions have been plotted on curves; that for the water solution is apparently a straight line, and would tend to show that for solutions of such strength the conductivity is proportional to the amount of salt in solution; the same does not, however, appear to be true in the case of the alcohol solutions.

This is a point which of course needs further investigation, and I intend to experiment further on this subject with different solvents and the same salt.

In conclusion, I have to thank Mr. W. N. Shaw for the kind help and advice he has given me in all this work.

Professor F. KOHLRAUSCH '*Ueber das Leitungsvermögen einiger Electrolyte in äusserst verdünnter wässeriger Lösung*' (Wied. 'Ann.' xxvi. p. 161). —*Abstract by* E. F. J. Love.

This memoir is an extension of previous work, and was undertaken for the purpose of verifying the following laws laid down by Kohlrausch in a former paper:—

1. If dilute solutions of various salts be prepared, having their strengths proportional to the chemical equivalents of the salts, then the specific conductivities of these solutions are all of the same order of magnitude.

2. In dilute solutions, under a given electromotive force, each of the ions moves through the liquid with a fixed velocity dependent on its own chemical nature, and independent of that of the other ion. This is termed the 'law of independent migration.'

3. The influence of change in temperature upon conductivity tends, as dilution

increases, to a limiting value; the temperature coefficient being the same, within narrow limits, for all neutral salts.

In his previous investigations Kohlrausch had determined the specific conductivities of solutions of varying strength, from saturation down to a few per cents., and from observations thus obtained had deduced the conductivity in more dilute solutions by extrapolation. In the present memoir he verifies and corrects the results thus obtained by the employment of solutions whose strengths vary from 1·0 to 0·00001 gramme-equivalents per litre. (The strength thus estimated is termed the 'molecular content.')

In measuring the resistances a Wheatstone bridge is used, with alternating currents and a telephone as indicator (the paper deals at some length with the advantages and difficulties of this method); the specific conductivities are expressed in terms of that of mercury, and calculated for a uniform temperature of 18° C.

In working up the results the conception of 'specific molecular conductivity' is employed, this being defined as the ratio k/m of the specific conductivity k of the solution to the molecular content m. As the specific molecular conductivities are all very small, Kohlrausch tabulates the values of $10^8 . k/m$, instead of k/m simply. The values of this ratio are exhibited graphically, by plotting in a curve, with $m^{\frac{1}{3}}$ as abscissa, this quantity being chosen because it expresses 'the reciprocal of the mean distance, or, in other words, the *mean relative proximity* of the molecules'—*i.e.*, the magnitude on which the specific molecular conductivity is most directly dependent.

The material thus obtained is amply sufficient to verify the three statements above mentioned, the very important law of independent migration in particular receiving a full confirmation. In addition a large number of interesting relations disclosed themselves, which may be summarised as follows:—

1. If the solution be sufficiently dilute the specific molecular conductivity k/m is, for all neutral salts, independent of the strength of the solution, or each molecule conducts the current independently of every other. In other words, the specific molecular conductivity has a limiting value. These limiting values are not the same for all salts, or even for those of the same base or acid; their magnitude depends on the nature of both ions.

2. The velocity with which the ions move past each other in extremely dilute solution, under an electromotive force of 1 volt per linear millimetre, is determined in millimetres per second by multiplying the specific molecular conductivity of the electrolyte by 11000[1] (or Kohlrausch's tabulated numbers by 0·00011). The numbers thus obtained for the various salts examined all lie between 0·14 and 0·10 *mm/sec.*

3. The specific molecular conductivity of a salt in dilute solution being proportional to the sum of the velocities of the separated ions, the values of these absolute velocities may, as Kohlrausch had shown previously, be determined from the experiments in the following way:—

Let u_1 and v_1 be the absolute velocities of K and Cl, u_2 and v_2 those of Na and Br; then the

$$\begin{array}{llllr} \text{Specific molecular} & \text{conductivity,} & k/m, & \text{of} & \text{KCl} = (u_1 + v_1)/11000 \\ \text{,,} & \text{,,} & \text{,,} & \text{,,} & \text{NaCl} = (u_2 + v_1)/11000 \\ \text{,,} & \text{,,} & \text{,,} & \text{,,} & \text{KBr} = (u_1 + v_2)/11000 \\ \text{,,} & \text{,,} & \text{,,} & \text{,,} & \text{NaBr} = (u_2 + v_2)/11000 \end{array}$$

and so on; hence the conductivities of KCl, NaCl, KBr, and NaBr, contain all that is necessary for determining the absolute velocities of K, Na, Cl, and Br; since the ratios u_1/v_1, u_2/v_2, &c., are known from Hittorf's migration experiments.

4. As the strength of the solution increases, the specific molecular conductivity slowly diminishes. For salts with monovalent ions it may be approximately represented by the formula

$$k/m = \text{A} - \text{B}m^{\frac{1}{3}};$$

and since $m^{-\frac{1}{3}}$ = the relative mean distance r of the molecules,

$$k/m = \text{A} - \text{B}/r,$$

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[1] [This appears to be necessary in order to reduce measures in terms of mercury to absolute measure.—E. F. J. L.]

or 'the specific molecular conductivity is equal to a constant diminished by a quantity inversely proportional to the mean distance of the molecules.'

5. The rate of diminution of k/m with increasing concentration is greater the higher the valency of the ions. This is ascribed to two possible causes—(*a*) a change in the constitution of the polyvalent ion, in virtue of which it approximates in behaviour to a monovalent ion, as the dilution increases; (*b*) the possibility that the current may be in part conveyed by the water of the solution.

6. The specific conductivity of a salt appears to be unaffected by its possessing, or being destitute of, water of crystallisation.

The above conclusions refer only to neutral salts; acids and alkalies (including alkaline carbonates) behave in a different manner. The chief facts collected by the author regarding these substances are—

1. The specific molecular conductivity of acids and alkalies is small if the dilution be very great, increases with the strength of the solution up to a certain maximum, and from this point diminishes as the concentration increases. The small initial value of k/m he considers (following Arrhenius and Ostwald) to be a secondary phenomenon—probably due to impurities in the water—and accordingly he neglects this part of the curve, and obtains the limiting value of the specific molecular conductivity by producing the second part backwards through the maximum to the line of ordinates. He thus obtains as the maximum limiting velocity of the ions 0·4 *mm/sec*, under an electromotive force of 1 volt per linear millimetre.

2. The alkalies KOH and NaOH have specific molecular conductivities differing by a small constant amount, as also have their carbonates.

3. The monobasic mineral acids have the same specific molecular conductivity. Phosphoric acid gives a not very different value if, instead of the equivalent $\frac{1}{3}H_3PO_4$, we employ the whole molecule H_3PO_4.

4. Acetic acid and ammonia in dilute solution exhibit a conductivity nearly proportional to $m^{\frac{1}{2}}$. In strong solution they conduct very badly.

5. Sulphuric acid is anomalous, showing, after an initial specific molecular conductivity like that of the monobasic mineral acids, a rapid decrease to an inferior value, about $\frac{2}{3}$rds of this. From former investigations by the author it is known that the conductivity of sulphuric acid during increasing concentration exhibits three maxima and two minima. The first minimum corresponds to the hydrate $H_2SO_4.H_2O$, and the second to concentrated H_2SO_4. One of the maxima occurs between this point and SO_3. This behaviour points to a chemical change in the structure of the molecule, depending on the concentration.

With regard to the problem of electrolytic conduction in general, Kohlrausch lays down the axiom that no electrolyte in a pure state is a good conductor, but only becomes such on admixture with other bodies, this admixture being necessary in order to set up the dissociation which Clausius looks upon as the cause of migration of the ions. In this connection the question is discussed as to whether the water of a solution conducts part of the current. This our author considers proved for dilute solutions of several sulphates by an old experiment of Faraday, which he has confirmed. Perhaps such a circumstance would explain various anomalies.

Kohlrausch discusses Bouty's 'law of equivalents,' which states that 'the electric conductivity of dilute salt-solutions of equivalent strengths is the same for different substances.' Bouty distinguishes between 'normal' salts, which obey the law, and abnormal salts, which do not; and defines an abnormal salt as one 'whose constituent ions in dilute solution travel with different velocities.' But Kohlrausch shows that some salts which would come under this definition obey Bouty's law, while some of the salts which disagree with it can be shown to be 'normal,' from observations on their migration-constants. He also objects to the law on the ground of its inherent improbability, and alleges further that Bouty's method of calculation in comparing his own results with those of the author is erroneous.

Among minor points of interest brought out by the investigation are the following:—

1. The low conducting power of nearly pure water, the smallest value obtained being $0{\cdot}25 \times 10^{-10}$.

2. The phenomenon of absorption by the electrodes. The conductivity of a

very dilute solution of HCl was found to slowly diminish, owing to the withdrawal of the acid from the solution. That this is due to the electrodes was shown by an increase in the resistance on sinking them in the fluid, the higher conductivity being restored by stirring. The phenomenon is not exhibited by solutions of neutral salts.

3. The specific molecular conductivity of a strong base or acid is diminished by gradual neutralisation, reaches a strongly defined minimum when neutralisation is complete, and thence increases. Phosphoric acid seemed to show several such points of discontinuity; acetic acid gives a curve of *gradually* changing curvature, the neutralisation point being apparently somewhat indefinite.

4. The behaviour of the tree-formed deposits on cathode, out of very weak solutions. The threads are less than ·001 centim. thick; they repel one another, while the current is passing, like a head of hair on an electrical machine, and with high E.M.F.'s they are continually in motion.

Addenda. By Oliver Lodge.

To this brief abstract of an important memoir it may be convenient to append a few of the numerical results, since they are interesting in themselves and important to Arrhenius' theory of chemistry (see below). Moreover, these determinations of Kohlrausch are probably a long way the most accurate at present made.

First comes a table of molecular conductivities $\left(\frac{k}{m}\right)$ multiplied by 10^8 for convenience. The top line of the table gives the strength of the solutions, in gramme equivalents of the substance per litre. For example, the first entry (1216) means that a solution of potassic chloride containing ·000746 gramme of the salt in each litre has a specific conductivity $1216 \times {\cdot}000746 \times 10^{-8}$ times that of mercury. A line is drawn across the table to divide the curiously behaving acid and other bodies from the more neutral substances.

Abridged Table of Molecular Conductivities for different substances at various concentrations, according to Kohlrausch's latest determinations. Tabulated Numbers, $10^8 \frac{k}{m}$, where m is gramme-equivalents per litre.

$m=$	·00001	·0001	·001	·01	·1	1	5	10
KCl	1216	1209	1193	1147	1047	919	—	—
AmCl	1205	1209	1190	1142	1035	907	752	—
NaCl	1024	1029	1008	962	865	695	398	—
LiCl	965	943	921	875	775	591	303	106
$\frac{1}{2}BaCl_2$	1142	1126	1092	1006	861	658	—	—
$\frac{1}{2}ZnCl_2$	1036	1029	994	915	768	514	180	60
KI	1207	1216	1203	1161	1069	968	770	—
KNO_3	1215	1207	1180	1122	983	752	—	—
$NaNO_3$	975	975	952	907	817	617	—	—
$AgNO_3$	1080	1078	1068	1017	886	635	351	—
$\frac{1}{2}Ba2NO_3$	1114	1096	1054	951	755	—	—	—
$KClO_3$	1141	1122	1101	1053	927	—	—	—
$KC_2H_3O_2$	939	934	919	879	784	594	240	30
$\frac{1}{2}K_2SO_4$	1275	1249	1207	1098	897	672	—	—
$\frac{1}{2}Na_2SO_4$	1054	1031	998	906	734	475	—	—
$\frac{1}{2}Li_2SO_4$	949	945	906	818	637	386	—	—
$\frac{1}{2}MgSO_4$	1056	1034	935	715	474	270	82	—
$\frac{1}{2}ZnSO_4$	1060	1023	919	685	431	249	82	—
$\frac{1}{2}CuSO_4$	1086	1062	950	675	424	241	—	—
HCl	1254	3171	3455	3416	3244	2780	1420	600
HNO_2	1144	3088	3427	3395	3225	2770	1470	610
$\frac{1}{2}H_2SO_4$	1413	3118	3316	2855	2084	1820	1270	660
KOH	747	1689	2110	2124	1986	1718	990	423
$\frac{1}{2}K_2CO_3$	865	995	1221	1083	879	660	403	169
$\frac{1}{2}Na_2CO_3$	697	874	1037	899	682	427	—	—
$\frac{1}{3}H_3PO_4$	402	837	968	790	430	200	160	148
NaOH	(130)	1070	1810	1870	1700	1490	652	190
$C_2H_4O_2$	1304	995	380	132	43	12	2·6	·5
NH_3	560	610	260	92	31	8·4	2·4	·5

The next little table contains the estimated limiting values of molecular conductivity for infinite dilution. First for fairly neutral substances, next for acid and alkaline bodies. The ionic velocities corresponding to these numbers are, for the first set, between ·0014 and ·0010, and for the second set between ·0040 and ·0013 centimetre per second, rate of travel of anions past cations, when urged by a slope of potential of 1 volt per centimetre.

Limiting Values of Specific Molecular Conductivity for extreme dilution.

(A). ORDINARY SALTS.

$\frac{1}{2}K_2SO_4$	128	× 10^{-7}	$\frac{1}{2}MgSO_4$	108	× 10^{-7}
KI	122	,,	$\frac{1}{2}ZnSO_4$	108	,,
KCl	122	,,	$\frac{1}{2}Na_2SO_4$	106	,,
AmCl	121	,,	$\frac{1}{2}ZnCl_2$	104	,,
KNO_3	121	,,	NaCl	103	,,
$\frac{1}{2}BaCl_2$	115	,,	$NaNO_3$	98	,,
$KClO_3$	115	,,	$\frac{1}{2}Li_2SO_4$	97	,,
$Ba_{\frac{1}{2}}NO_3$	112	,,	LiCl	96	,,
$\frac{1}{2}CuSO_4$	110	,,	$KC_2H_3O_2$	94	,,
$AgNO_3$	109	,,			

'These values are all of the same order of magnitude, but they are by no means equal to one another.'

(B). NON-NEUTRAL BODIES.

$\frac{1}{2}H_2SO_4$	370	× 10^{-7}	KOH	220	× 10^{-7}
HCl	350	,,	NaOH	200	,,
HNO_3	350	,,	$\frac{1}{2}K_2CO_3$	140	,,
$\frac{1}{3}H_3PO_4$	110	,,	$\frac{1}{2}Na_2CO_3$	120	,,

LAW OF SPECIFIC IONIC VELOCITY.

Taking into account the results of Hittorf on migration, Kohlrausch estimates as the relative velocities for the following ions in a solution of strength defined by $m = \cdot 1$:—

K	Am	Na	Li	Ag	H	$\frac{1}{2}Ba$	$\frac{1}{2}Mg$	$\frac{1}{2}Zn$
52	50	32	24	42	272	30	26	24

Cl	I	NO_3	ClO_3	$C_2H_3O_2$	OH
54	55	48	42	26	143

and with these numbers he proceeds to calculate the conductivity of solutions of this strength ($m = \cdot 1$) of the various substances, and to compare them with experiment.[1] The agreement between observed and calculated numbers for a large number of substances as regards both conductivity and migration is remarkable.

For instance, here are some calculated numbers to be compared with the column headed ·1 of the table just quoted, page 337.

KCl	1060	$AgNO_3$	900
AmCl	1040	$\frac{1}{2}Ba,NO_3$	780
NaCl	860	$KClO_3$	940
LiCl	780	$KC_2H_3O_2$	780
$\frac{1}{2}BaCl_2$	840	HCl	3260
$\frac{1}{2}ZnCl_2$	780	HNO_3	3200
KI	1070	KOH	1950
KNO_3	1000	NaOH	1750
$NaNO_3$	800		

But several substances remain intractable. For instance, acetic acid gives, calculated, 2980; observed, 43.

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[1] See table on page 215 of Kohlrausch's memoir.

The following remarks are taken from a criticism of the above abstracted memoir of Professor Kohlrausch, published by M. E. Bouty *in the 'Journal de Physique,' for September* 1886. (Translated by Mr. Love.)

'The object of M. Kohlrausch is to control the results of the experiments of Messrs. Lenz, Ostwald, and Vincenti, and my experiments of 1884, and to throw light on points left in dispute. To this end he works by the methods which he had previously pointed out, but with excessive dilutions, attaining to 0·00001 gramme equivalents per litre. These liquids conduct scarcely better than distilled water, and a thousand times worse than the water supplied to the town of Würzburg. Experiments of this kind raise a multitude of theoretical and practical difficulties which M. Kohlrausch points out in all good faith, if he has not always given them a decisive solution.

'In the first place come the difficulties due to the employment of alternating currents and the telephone. . . . Possibly graver difficulties arise from the employment of distilled water; and these will always present themselves, whatever method be employed, if the dilution be pushed to extreme limits. In the first place, it is very difficult to procure distilled water of constant composition. M. Kohlrausch used rain-water distilled in a tin retort with a silver condenser, and stored in large glass flasks. The conductivity of this water ranged from 1·1 to $1{\cdot}5 \times 10^{-10}$ (the conductivity of mercury being taken as unity), and was diminished rather than increased after keeping in the flasks.

'Let us admit this conductivity as accurately known. If a trace of saline matter be added to the water its conductivity increases. M. Kohlrausch supposes that the conductivity of the salt and that of the water simply add; and as this rule if applied to neutral salts assigns to them a molecular conductivity sensibly constant in very dilute solution he supposes it to be sufficiently justified by experiment. M. Kohlrausch admits, however, that the greater part of the conductivity attributed to the distilled water really belongs to foreign matter—neutral salts, acids, or bases—with which it is contaminated; if some saline particles be added to this water we then have to deal with a mixture of which we know only a single element—that which has been added—the nature and proportion of the other elements remaining unknown; it is possible that the conductivity we wish to measure may be modified by the presence of this unknown element in a manner altogether arbitrary, and which may vary from one salt to another. . . .

'M. Kohlrausch does not admit the division of neutral salts into "normal" and "abnormal," which I established on the basis of the inequality of the numbers relating to the transport of the ions. If we consider only anhydrous normal salts, the limiting values assigned by M. Kohlrausch are as follows:—

NH_4Cl	$k/m \cdot 10^8 =$	1205	$KClO_3$	$k/m \cdot 10^8 =$	1141
KCl	„	1216	KI	„	1207
KNO_3	„	1215	$AgNO_3$	„	1080
$\frac{1}{2}K_2SO_4$	„	1275			

. . . .

'M. Kohlrausch thinks himself in a position to enunciate the following conclusions:—

'1. *For a given neutral salt the molecular conductivity tends towards a definite limit, as the dilution is increased indefinitely.*

'2. *For the different neutral salts this number is always of the same order of magnitude.* The extreme values of $k/m \cdot 10^7$ are 128 for K_2SO_4, and 94 for $KC_2H_3O_2$ (an abnormal salt).

'3. *This limiting value depends on both ions*: they group themselves in the order of diminishing conductivity in the manner indicated by the following table:—

Kation	Anion
Potassium.	Sulphuric Acid.
Ammonium.	Iodine.
Barium.	Chlorine.
Silver.	Nitric Acid.

Kation
Copper.
Magnesium.
Zinc.
Sodium.
Lithium.

Anion
Chloric Acid.
Acetic Acid.

. . . ‘According to M. Lenz, *the kation alone would influence the conductivity in dilute solution*, a statement which M. Kohlrausch refuses to accept.

‘4. *With increasing concentration the molecular conductivity always diminishes*, and to a very unequal degree for different salts. In order to exhibit this variation conveniently to the eye, M. Kohlrausch constructed curves, taking as abscissæ the values of $m^{\frac{1}{3}}$, and as ordinates the molecular conductivities. These different curves present markedly different courses, but I observe that they all approach more or less to a common ordinate for $m=0$.[1] This peculiarity is especially well marked in the case of the normal salts if we reject the portion of the curve, often a little inflected, beyond $m=0{\cdot}006$; *i.e.*, if we produce as near as can be judged (*de sentiment*) the sensibly rectilinear portion which precedes this.

‘5. *For the salts of the monobasic acids the molecular conductivity in dilute solution is represented approximately by the formula*

$$k/m = \mathrm{A} - \mathrm{B}m^{\frac{1}{3}},$$

expressing that this conductivity differs from a constant value A by a term inversely proportional to the mean distance of the molecules of the salt. My latest researches[2] have led me to an analogous result.

. . . .

‘The limiting value of the conductivity of sulphuric, hydrochloric, and nitric acids is sensibly three times that of neutral normal salts, as I had previously pointed out. Sulphuric acid, moreover, exhibits peculiarities which would alone require a monograph.

‘Coming to the interpretation of the capital fact of the increase in the molecular conductivity of all salts in dilute solutions, M. Kohlrausch thinks that it must[3] be attributed to *a special conductivity acquired by the water when it contains other substances in solution*, but which is too small to be evident in strong solutions. Very small quantities of foreign matter may communicate to the water that state of dissociation which Clausius looks upon as the origin of the migration of the ions under the influence of electric forces, *and hence a considerable portion of the current might be diverted through the mass of the water*, which would itself then share in the electrolysis. This hypothesis, to which M. Kohlrausch declines to give greater precision, may be interpreted as a denial of the very principle which he applies to the calculation of molecular conductivity, as in order to obtain this he had already subtracted from the gross conductivity that part which belongs to the distilled water, more or less impure, *and therefore already possessing the special conductivity with which he deals*; unless this be capable of changing with the nature and proportion of the salt in solution, which implies the formation of hydrates, and that the conductivity of a solution is not equal to the sum of the separate conductivities of the salt and the solvent, the calculated numbers on which the discussion hinges would in that case lose all definite meaning.’

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[1] [I should imagine an examination of the curves is all that is needed to refute this criticism: compare the curves for KNO_3, $\frac{1}{2}BaNO_3$, $NaNO_3$.—E. F. J. L.]

[2] *Comptes Rendus de l'Académie des Sciences*, t. cii. p. 1375.

[3] [Kohlrausch gives another possible interpretation of the rapid diminution of the conductivity of salts of polyvalent radicles as concentration increases, viz.—that in extremely dilute solutions the more complete dissociation tends to assimilate such compounds in behaviour to those of monovalent radicles: ‘ein anderer Aggregationszustand, etwa eine grössere Dissociation in äusserster Verdünnung, welche die mehrwerthigen ähnlicher macht.’—E. F. J. L.]

Professor KOHLRAUSCH *has favoured the Committee with the following letter (in English) addressed to the Editor.*

Würzburg, January 6, 1887.

MY DEAR COLLEAGUE,—You have had the kindness to send me a proof of part of the Report on Electrolysis before finally going to press, and I must take advantage of your friendly permission to express my own views on the subject.

Since I consider it of great importance not to be misjudged in the reports of so prominent a body as the British Association, I cannot avoid making a personal remark. M. Bouty writes that the aim of my last published memoir was 'to control the results of the experiments of Messrs. Lenz, Ostwald, Vincentini and my (Bouty's) experiments of 1884.'[1] M. Bouty is mistaken, certainly with all good intention, as to the course of my research. I already in 1874 carried on a series of experiments with diluted solutions. Allow me to give, as a proof of the perfect independence of my research, a series of observations on sulphuric acid, made on January 30, 1875.

Per cent. H_2SO_4 $p =$	5·05	1·03	·339	·0992	·0324	·0098	·00306	·00099
Conductivity at 18° $k10^8 =$	1985	443	1645	55·1	20·45	6·77	2·06	0·57
$10^8\,{}^{k}/_{p} =$	393	430	479	556	631	690	673	580

Nitric acid (February, 1875)

Per cent. HNO_3 $p =$	6·32	2·05	·512	·100	·0152
Conductivity at 18° $k10^8 =$	2970	1045	275	55·8	8·65
$10^8\,{}^{k}/_{p} =$	470	510	537	558	570

These numbers have been written for more than ten years in my books. The same give, when calculated in reference to the molecular number m:—

Sulphuric acid

$m =$	1·06	0·212	0·0698	0·0202	0·00661	·00200	·000623	·000202
$10^6\,{}^{k}/_{m} =$	187	209	233	273	309	340	331	280

Nitric acid

$m =$	1·04	0·328	0·0813	0·0159	0·0024
$10^6\,{}^{k}/_{m} =$	286	319	338	352	360

The molecular conductivity ${}^{k}/_{m}$ of the sulphuric acid increases very rapidly by greater dilution, and very nearly reaches that of nitric acid. Extreme dilution causes again a decrease. This is the chief part of that research; it was published nine years later by Ostwald and then by me.

I discontinued these observations at that time, partly for the very reason that they gave such new results. The initial increase of ${}^{k}/_{p}$ for sulphuric acid, and the final decrease, made me suspicious; besides, the observations at that time were connected with difficulties, inasmuch as I could not so easily measure great resistances; also I could not obtain very pure water. At best the new object demanded a thorough research, which would draw me too far from my chief object. If one is working in an entirely new field he ought not to spend too much time on particulars.[2]

That dilute solutions are of very great interest has been emphasised in the first memoir by Grotrian and myself (1874), and later often enough in my publications. Indeed I limited myself then to combining those relations equally from the results which alone at that time were at my disposal, *i.e.* solutions of moderate dilution.

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[1] p. 339.

[2] In order to protect myself against the reproach of a too one-sided investigation, I would further remark that I early informed myself concerning mixtures of salts as well as acids in aqueous solutions, also concerning salts in alcoholic solutions, and finally, concerning mixtures of water and alcohol, many years before. After the publication of detailed researches of other authors I ceased to continue these investigations.

That this was no final solution of the problem I knew at once, and said so. And as soon as I had concluded with the stronger solutions at a time when of all other observations only those of Lenz were at hand, I recommenced with strongly dilute solutions. The specific difficulties of these experiments, the striving after accuracy and desiring to give absolute values, retarded the conclusion. But all my doubts, *e.g.*, as to whether sulphuric acid in great dilution did not conduct exactly like the monobasic mineral acids, were perfectly removed before any publication on the subject.

These remarks are only caused by the wish that a research to which I have given years may not be regarded finally as a mere repetition of someone else's work. My repulsion against publishing observations which I considered were open to improvement, was the cause of other investigators' earlier publications, they thereby gaining in many things the publisher's priority. On the other hand I can consider my research as of a greater experimental precision, and that you expressly recognise this for the later publication perfectly satisfies me.

M. Bouty reiterates his objections to my method of measuring resistances with alternating currents.[1] The empiric ground of this objection has been referred by me, and by you also, to an erroneous formula which M. Bouty used. The difficulties which Messrs. Bouty and Foussereau yet find will surely be overcome if these gentlemen will go through the same experiments which I 'at some length' described in my last treatise. M. Bouty's regret, that the water for solutions could not be obtained absolutely pure, must, of course, remain; but the same difficulty occurs in all observations of others addressed to the same object, and in most of them to a much higher degree than in mine. If the water which *I* used for solutions does not suffice for the explanation of the phenomena of dilute solutions, then this explanation is so far entirely unknown. I am also in this case obliged to you that you have emphasised my carefulness in this direction. M. Bouty says: 'Let us admit this conductivity as accurately known.' I measured the conductivity of the water every time shortly before the series of observations; those observations in which the characteristics of the solvent came into account at all were then made within a quarter of an hour. The telephonic method of measurement is so specially valuable on account of its very rapidity. That the conductivity of the solvent water must be subtracted from the conductivity of the solution, I have (for neutral salts) shown as probably very nearly correct. At present also I do not know how an observer could do otherwise. Finally, even an inaccuracy from this cause could only affect the most dilute of my solutions noticeably; considering the degree of dilution with which the other memoirs have to do, I cannot at all allow a possible inaccuracy proceeding from water in my observations.

Of course M. Bouty is correct in considering the use of quite pure (non-conducting) water as necessary, in order to explain with perfectly conclusive proof the relations obtaining in extreme dilutions. To consider his 'law of equivalents' thus far as an *axiom* cannot be denied him. Experience, however, in all observations (his own among them) disagrees with it, and I cannot see the necessity nor the probability of this axiom. It is indeed remarkable that the great differences of conductivity of strong solutions in the case of all salts reduce to about 30 per cent. Grotrian and I twelve years ago found this law, which is true for salts of monovalent acids even in moderate dilution, for the chlorides of the light metals. Lenz proved the same thing in a more general form, making use of more extreme dilutions. It is to the credit of Bouty that he set aside the yet remaining exceptions. It would certainly be heartily welcomed by every physicist if finally the equality of all molecular conductivities in extreme dilution should be proved. With Arrhenius one could then place this law alongside of the Boyle-Marriotte's law. I myself, since I first introduced the conception of the 'molecular conductivity,' would have an especial motive in agreeing to such a striking meaning of this conception. At times, however (as you yourself mention) the law, at common temperatures, does not agree with known facts.

Eight years ago I announced the following relation:—'The better a substance

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[1] pp. 339, 354, 356, 384.

conducts, the slower usually does its conductivity increase with temperature; in other words: 'the differences of conductivity of different substances usually diminish at higher temperatures.'[1] The supposition expressed by Arrhenius, that at high temperatures dilute solutions conduct equally well, does not lie beyond the bounds of possibility, but is at present only a hypothesis.

For common temperatures the law which I derived from Hittorf's numbers for migration of ions in connection with my observations in conductivity, which were independent of this migration, appears to me to contain a simple and natural hypothesis which has proved true for substances with monobasic acids. One must be blind to explain as an accident the systematic ordering of things under this view.

Now, just a remark concerning some things by Arrhenius, who through the introduction and consequent treatment of the conception of 'activity' in connection with Clausius's theory, has given us so important a point of view that his meaning must be carefully considered; especially do I regard as a decided advance the light which has been thrown by his and Ostwald's memoirs upon a hitherto theoretically dark group of bodies, viz., the bodies called by me, 'conductors of the lower order.'

I should, however, raise several objections to Arrhenius's radical meaning, that the theory which accepts a connection between internal friction and electrical conductivity ought to be rejected.[2] It appears to be a postulate *à priori* that besides activity some kind of friction must necessarily be accepted; through the work of Wiedemann and others, it has long been known that usually a lesser conductivity is connected with a greater internal friction. One cannot deny the nearly quantitative connection between the influence of temperature upon the so-called 'fluidity,' and upon conductivity, as shown by Grotrian. The proof which I gave,[3] that the supposition of a mechanical and electrolytic frictional resistance of about equal amount, allows the finding of an absolute size of molecules, which approaches the sizes found, by other methods, by Maxwell, Sir W. Thomson, van der Waals and others, seems to me of no little interest. In fact, the surprising phenomena in gelatinous substances[4] and 'solid' electrolytes must be supplemented by an accurate definition of the idea 'internal friction' before one can come to the conclusion that electrical resistance and internal friction are totally distinct.

Since, however, M. Arrhenius tells me that he intends to explain his remarks for himself,[5] I shall not enter into detail.

But I must draw your attention to something else. The supposition which Arrhenius makes in reference to the dissociation of solutions of $MgSO_4$ and related substances,[6] is really one special case of the possibility, expressed by me, that water, in extreme dilutions, can take part in the conduction. I have expressly left it an open question whether such a co-operation should consist in the formation of a hydrate. The hypothesis of Arrhenius is such a possible case. Should this be true, the possibility would thereby be strengthened that the rapid rise of the molecular conductivity of many salts, in extreme dilution, may be referred to a sort of secondary cause; $MgSO_4$ in solution conducts so much worse than H_2SO_4, and possibly also than MgO_2H_2, that a dissociation of the salt into these substances, even when only a small quantity of the decomposed substance is found, may cause the conductivity to increase considerably.

M. Bouty's fear[7] that by this means 'the calculated numbers on which the discussion hinges would in that case lose all definite meaning,' is a little strained. To my idea such an influence of the water, if it exists, comes only noticeably into consideration in extremely dilute solutions, and in this case perhaps also only in a limited group of compounds.

I conclude this letter assuring you of my real satisfaction that you, my dear colleague, have given the impulse to collect the newer results on electrolysis. My own conclusions, drawn from phenomena made known to me, did not dare to wander far from matters of fact, knowing myself to be not sufficiently well

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[1] *Wiedemann, Ann.* VI. 196. 1879.

[2] pp. 344 and 348.

[3] *Wiedemann, Ann.* VI. p. 207. 1879.

[4] p. 347.

[5] p. 387.

[6] p. 311.

[7] p. 340.

informed in theoretical chemistry. My old wish, that chemistry might make the interesting results of electrical conductivity of service for its theoretical purposes, has been realised in the recent memoirs of trained and clever chemists. Your own work and the present report, supported by the authority of the British Association, will, I am sure, bring forth other fruits in the field of electro-chemical theory.

Yours very truly,
F. KOHLRAUSCH.

Contribution to our Knowledge of the Action of Fluidity on the Conductivity of Electrolytes (Behaviour of Jelly). By SVANTE ARRHENIUS. *Translated from* 'Kongl. Vetenskaps-Akademiens Fördhandlingar,' 1885, *No.* 6, Stockholm, *by* Professor W. Ramsay.

From numerous researches of physicists[1] it has been held as proved that resistance to the passage of an electric current undergoes the same variations as the internal friction, *i.e.* that both increase or decrease simultaneously. This view is based on a considerable number of data regarding the conductivity of salts in aqueous solution. To obtain further knowledge on the subject it was necessary to test the action of solvents other than water. This has been done by C. Stephan,[2] who investigated the behaviour of alcoholic solutions, and found only an analogy between electric resistance and internal friction, but not complete proportionality; and this has been confirmed by other observers.[3] That proportionality exists, except in some exceptional cases considered by Stephan,[4] cannot be held. Unfortunately Stephan has only investigated alcoholic solutions containing from 0 to 70 per cent. of alcohol, *i.e.* those of which the internal friction is greater than that of water. Had he investigated solutions richer in alcohol, he would doubtless have found that an alcoholic solution of a salt has less conductivity than the corresponding more aqueous solution, in spite of the former having less internal friction than the latter. This has been clearly proved by Hittorf's work,[5] and has been completely confirmed by Lenz's[6] investigations, although Lenz's work was not directed to that point. I subsequently found on conversing with Professor Ostwald, of Riga, that he, like myself, disbelieved in any connection between internal friction and resistance, and he proposed that I should undertake the investigation of which an account follows. From a paper by H. de Vries[7] it follows further that the rate of diffusion of a solution of salt is nearly independent of internal friction; a result which Graham's experiments had already indicated. Lastly, Long's[8] work shows that the rate of diffusion of an aqueous solution of a salt is nearly proportional to its conductivity, whence it follows with high probability that the resistance must be nearly independent of internal friction under similar conditions. And should this prove to be true, the whole of our knowledge of the process of electrolysis would be much simplified.

The method of investigation was that proposed by Kohlrausch and Nippoldt.[9]

The resistance-vessels were of the same form as those I previously used. The platinised platinum terminals were 15·5 mm. apart, the diameter of each was 25·6 mm., and through each passed a glass tube 9 mm. in diameter. The solutions investigated were solutions of sodium chloride, zinc sulphate, and copper acetate, in

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[1] Among others G. Wiedemann; a detailed description of the work of others is to be found in his *Electricity*.

[2] Wiedemann's *Annalen*, 1882, xvii. p. 673.

[3] E. Wiedemann has proved this to be the case with solutions in glycerine (Wiedemann's *Annalen*, 1883, p. 20.

[4] Stephan's figures do not exhibit this proportionality. The ratio is not a constant one.

[5] Poggendorff's *Annalen*, 1859, cvi. p. 554.

[6] *Mém. Acad. Imp. St. Pétersbourg*, sér. 7, p. 30, No. 9.

[7] Beiblätter, 1885, p. 160.

[8] Wiedemann's *Annalen*, ix. p. 623.

[9] Poggendorff's *Annalen*, cxxxviii. pp. 280 and 370.

pure water, and also in water in which had been dissolved 4·2 per cent. of commercial gelatine.

The proportions taken were: (*a*) 20 cc. of the salt solution diluted to 25 cc. with water; (*b*) 20 cc. of solution, in which 1·05 gram gelatine was dissolved, diluted to 25 cc. The gelatine solutions were tolerably fluid at 30°, at 25° very thick and syrupy, at 24° the traces of fluidity were extremely small, and at 23·5° the whole had jellied.

The internal friction was determined by Sprung's[1] method for the gelatine solution containing 4·2 per cent. of gelatine, and was found to be, at 30·5° C., 2·271; at 27·7° C., 2·889, the internal friction of water at 0° being taken as unity. At 24° the internal friction was infinitely great, *i.e.*, the solution had gelatinised and blocked the capillary tube. At corresponding temperatures the internal friction of water is, at 30·5°, 0·4475; at 27·7°, 0·4547; and at 24°, 0·5171. The internal friction of the weak salt solutions employed can have differed but very little from these numbers.

The distilled water showed a resistance of 60,000 ohms, while the gelatine solution averaged 300 ohms. It was therefore considered unnecessary to introduce a correction for the conductivity of the distilled water present. Now as it is known that all organic substances which do not possess well-marked acid, basic, or salt-like properties have extremely small conductivity, it may be concluded that gelatine also, if free from salts, should manifest great resistance, and the high conductivity of the gelatine is evidently due to the salts which it contains.

Conductivity of Gelatine Solution.

t	m	l	Δt	Δl
14·5°	289·8	34·51		
			2·3	2·03
16·8	273·7	36·54		
			1·0	0·94
17·8	266·8	37·48		
			2·3	2·41
20·1	250·7	39·89		
			1·2	0·99
21·3	244·6	40·88		
			1·0	0·96
22·3	239·0	41·84		
			0·9	10·89
23·2	234·0	42·73		
			0·8	0·96
24·0	228·9	43·69		
			0·9	0·97
24·9	223·9	44·66		
			1·1	1·04
26·0	218·8	45·70		
			1·1	1·10
27·1	213·7	46·80		
			1·1	1·12
28·2	208·7	47·92		
			1·1	1·20
29·3	203·6	49·12		
			1·1	1·26
30·4	198·5	50·38		
			2·2	2·7
32·6	188·4	53·08		
			0·8	1·48
33·4	183·3	54·56		

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[1] Poggendorff's *Annalen*, clix. p. 1.

The gelatine solution was warmed in a water-bath to 35° C. Simultaneous measurements were made of temperature and resistance. As the water cooled the former fell, while the latter slowly rose.

The preceding table shows in the first column the observed temperatures, and in the second the resistance in British Association units. From these data the conductivity was calculated in arbitrary units (according to the formula $l = \frac{10000}{m}$, m being the resistance given in the second column); the values of l are given in column three. The fourth and fifth columns exhibit the differences of the temperatures and the conductivities.

The results with the gelatine solutions to which salt had been added are given below:—

Gelatine Solution with Sodium Chloride.

t	m	l	Δt	Δl
15·3°	43·6	194·1		
			5·1	23·4
20·4	38·8	217·5		
			4·4	23·6
24·8	35·0	241·1		
			3·4	17·1
28·2	32·6	258·2		
			4·2	22·3
32·4	30·0	280·5		

Gelatine Solution with Zinc Sulphate.

t	m	l	Δt	Δl
14·0°	61·6	128·3		
			3·9	12·4
17·9	56·1	140·7		
			3·8	8·2
21·7	52·5	148·9		
			4·3	16·8
26·0	47·3	165·7		
			4·0	14·3
30·0	43·5	180·0		
			1·5	8·3
31·5	41·7	188·3		

Gelatine Solution with Copper Acetate.

t	m	l	Δt	Δl
15·0°	62·0	126·3		
			4·1	11·5
19·1	56·6	137·8		
			3·0	9·2
22·1	53·0	147·0		
			3·5	11·8
25·6	49·0	158·8		
			4·4	13·5
30·0	45·0	172·3		
			2·6	12·7
32·6	42·0	185·0		

Here it is evident that the conductivity alters only uniformly with temperature, for had this been otherwise great variations in the neighbourhood of 24° should have been noticeable, for the internal friction increases about that temperature from a moderate value to an infinitely great one. But no sign of such a sudden variation can be deduced from the above figures. The calculated values of the coefficient of temperature are,

for gelatine solutions

Gelatine alone	Sodium chloride	Zinc sulphate	Copper acetate
0·0281	0·0244	0·0243	0·0248

and for aqueous solutions

	0·0238	0·0234	0·0213

Those for gelatine solutions are generally somewhat higher than for the corresponding aqueous solutions, but the difference is unimportant. If it be assumed that the coefficients of temperature for internal friction and conductivity are the same with aqueous solutions, it cannot be so with gelatine solutions, because for these the temperature-coefficient of internal friction must be infinity, while the conductivity-coefficient never exceeds 0·03. If the conductivity of pure aqueous solutions at 17·8°, which are very mobile, be compared with that of gelatine solutions of 4·2 per cent. containing the same amount of salts, which are solid at 24°, the following table results:—

	Sodium chloride	Zinc sulphate	Copper acetate
Aqueous solution . .	250·6	169·6	159·9
Gelatine solution . .	205·6	140·3	134·2
Difference	17·9 per cent.	17·3 per cent.	16·1 per cent.

The gelatine solution has accordingly about 17 per cent. less conductivity than the corresponding aqueous solution. The found difference of 17 per cent. is not of the magnitude which might be expected if internal friction had really the effect usually attributed to it.

Let us now examine the reasons for assuming parallelism between internal friction and conductivity. In most cases the molecular conductivity in aqueous solutions decreases with increase of concentration, and similarly with the fluidity. These relations hold with few exceptions for aqueous solutions, and it is therefore not remarkable that the fluidity and the molecular conductivity of aqueous solutions should vary at about the same rate. But it does not follow that they are interdependent or to be ascribed to the same cause. If very dilute solutions be employed the fluidity remains nearly constant, but the molecular conductivity of salts increases considerably with dilution, as I have shown in my former work, and my results have been confirmed by Kohlrausch.[1]

There cannot therefore be a complete parallelism between fluidity and conductivity in aqueous solutions. For very dilute solutions our present views of the nature of electrolysis lead us to conclude that the variation in conductivity is dependent on chemical change, such as the breaking down of complex molecules, the union of molecules of salt with molecules of water, and so on. And the difference between dilute and concentrated solutions is merely a relative one. We cannot draw any definite line between bodies in dilute and in concentrated solution. Thus strong acids in concentrated solution pass through precisely the same phases as weak acids in dilute solution. There is the same relation between alkali salts on the one hand and mercury salts on the other. The conclusion follows therefore that the molecular conductivity depends chiefly on chemical relations. And there appears no reason to connect internal friction with molecular changes of a chemical nature.

A similar relation holds between the temperature-coefficient for fluidity and the conductivity. These are for dilute solutions approximately comparable, and it

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[1] *Göttinger Nachrichten*, February 25, 1885.

might be expected that in extremely dilute solutions they should coincide. I have shown[1] that such a relation does not hold either for aqueous or alcoholic solutions. Bouty[2] who found complete correspondence between these two quantities, was misled by a coincidence in calculating his results, as Kohlrausch has shown.[3]

As all known cases can therefore be explained without assuming a connection between internal friction and conductivity, this theory, which serves only to complicate matters, must be abandoned.

As a final proof of the justice of the above conclusion I made a cell like an ordinary Daniell, but introduced gelatine into the solutions of zinc sulphate and copper sulphate. The resistance was 1·5 ohm, while that of a similar Daniell's cell was 1·3 ohm. But the resistance of the cell containing gelatine gradually increased after four days, owing to bubbles being deposited in the gelatine near the zinc and the copper.[4]

Sur la Polarisation des Électrodes et sur la Conductibilité des Liquides. *Par* M. E. Bouty.[5] *Abstract by* Oliver Lodge.

The author first describes Lippmann's method of measuring the resistance of electrolytes, viz. by tapping off and measuring the fall of potential between two points of the liquid contained in a cylindrical tube, and comparing this with the fall in a known length of wire included in the same battery circuit as the liquid. He proceeds to use it also for determining the polarisation of either electrode, by measuring the potential difference between one of the main electrodes supplying current to the liquid and one of the tapping electrodes; using the obvious relation

$$e = rC + p$$

in order to find p, the polarisation.

With platinum electrodes and acidulated water he thus reckons that with a current of average intensity about 8×10^{-8} ampères per square centimetre, the polarisation of the electrode rises as follows:—

	Polarisation of the cathode is	Polarisation of the anode is
In 5 minutes	·056 volt	·103 volt
„ 40 „	·063 „	·166 „
„ 60 „	·065 „	·175 „

He then applies a slightly stronger current, but as it is very variable I do not see that the numerical results obtained are very useful. However, the idea is that the polarisation of the cathode attains a maximum and begins even to diminish, while that of the anode goes on increasing.

He then measures the resistance of acid water in a long siphon tube, and considers that it is independent of current intensity, and asserts, '*A liquid has only a single way of conducting electricity, whatever may be going on at the electrodes. The expressions "metallic conductivity" and "electrolytic conductivity" ought to disappear from science.*'

ELECTROLYSIS OF MIXTURES.

A number of mixed salts are tried, one of them being always a salt of copper. Results are given for the electrolysis with copper electrodes of a mixture of sulphate of copper and sulphate of zinc, saturated in the cold, and are analysed thus: 'For current intensities from 5 to 12 ten-thousandths of an ampère per square centimetre the polarisation of the anode is constant and equal to ·0088 volt; but that of the cathode varies enormously. For an intensity 2·9 (ten-thousandths of an ampère as before) it is already ·02 volt; it increases slowly with the current and is sensibly

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[1] *Bihang till K. V. Akad. Handl.* viii. No. 13, p. 45 (1884).

[2] *Compt. Rend.* February 11, 1884.

[3] *Göttinger Nachrichten*, 1885, p. 86.

[4] For remarks on this paper see Prof. Kohlrausch's letter on page 343.

[5] *Journal de Physique*, 1882, 2e série, t. i. p. 346.

constant for the same current when prolonged. But at an intensity 8·6 a new phenomenon is produced: polarisation increases with time, first very slowly, then more and more rapidly, going from ·04 to ·65 volt; at the same time one notices that the metallic and brilliant deposit of pure copper which one had hitherto obtained is displaced by a ruddy and non-adhesive deposit. In proportion as it is produced the polarisation increases, and the deposit overspreads the electrode with increasing rapidity.

'Finally, augmenting the current still more, the deposit passes gradually from red to black, while polarisation increases in a continuous manner, and for a sufficient current-intensity the deposit acquires anew a certain adherence. It is then dark-grey, very rich in zinc, and recalls by its aspect deposits of zinc obtained from impure commercial sulphate of zinc.

'*As for the conductivity of the liquid it remains constant all the time, in spite of the variety of electrolytic actions,* to which a study of polarisation and aspect of deposit bear witness. . . . The same *kind* of thing happens with other proportions of $CuSO_4$ and $ZnSO_4$. . . .

'One may remark further that the specific resistance of the liquid passes through a minimum for a certain composition of the mixture; it is then inferior to the resistance of even a saturated solution of one of the two salts, and *à fortiori* to that of the same salt diluted down to the strength in which it occurs in the liquor. *So the molecules of two mixed salts take part in the transport of electricity, even when only one of the two metals is deposited on the cathode.*'

All the variations of polarisation in the above case are then simply and naturally explained by the fact of exhaustion, in the liquid near cathode, of the salt of the metal being deposited, except in so far as diffusion replenishes it. With strong currents it is therefore plainly necessary for zinc to be deposited as well as copper, and it is equally obvious that this zinc will tend to clear itself off again by local action.

The author then goes on to observe that very similar complications occur even when only one salt is intended to be present. Thus pure $CuSO_4$ almost always contains a trace of acid, and accordingly, in its solution, hydrogen plays much the same part as zinc has done in the above described experiment. For feeble intensities copper alone is deposited, but for stronger currents the deposit is red and contains some oxide [?]. Hydrogenised copper forms with copper, in fact, local couples in which copper is the attacked element. Evolution of heat by local action has been proved by the use of thermometer electrodes.

Even if $CuSO_4$ contained no acid to start with, it would soon get some by electrolysis;[1] for the solution of anode is never exactly equal to deposit on cathode.

In all these cases one may notice that *electrolytic reactions which go on for the most feeble currents absorb always less heat than those which occur with stronger currents.* This extension to mixtures of the beautiful law announced by Berthelot for the case of electrolysis of a single salt is confirmed by a study of particular cases. For instance, the following table sums up the author's observations on a mixture of $\frac{9}{10}$ by volume of a solution of Na_2SO_4, and $\frac{1}{10}$ of a solution of $CuSO_4$, both pure and saturated when cold. The polarisation of anode is so small as to be negligible; the polarisation of cathode is given for various intensities of current in ten-thousandths of an ampère per square centimetre.

Current Intensity	Polarisation of Cathode in Volts	
7	·042	Brilliant deposit of copper.
10	·044	
15	·045	
19	·051	
31	·068	
36	·100	
41	·162	
44·7	·298	
45·4	·859	Brown deposit.
77	1·366	
150	1·585	Abundant evolution of hydrogen.

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[1] Unless one artificially keeps it neutral: see D'Almeida, *Annales de Chimie*, 3e série, t. ii. p. 257.

The brown deposit of oxide appears as soon as the polarisation exceeds ·28 volt; the polarisation increases first very rapidly, then slowly, and its limit is very nearly the number (1·428 volt) which corresponds to the decomposition of Na_2SO_4 between copper electrodes. (It is slightly sophisticated by the extra resistance of gas bubbles then given off.) To sum up: first is decomposed $CuSO_4$, which theoretically consumes no energy (the electrodes being copper), then comes in the decomposition of acid water (·28 volt), finally that of sulphate of soda (1·424).

As for the conductivity of the mixture it remains perfectly invariable in spite of the variability of the electrolytic reactions.

M. Bouty then quotes a saying of Wiedemann, that from a mixture of any of the following metals, Zn, Cd, Pt, Cu, Ag, Au, any metal which follows in the list is deposited to the exclusion of any which precedes. This is manifestly in accord with the above law, for the metals are in order of thermal equivalents. But the fact is only true for feeble currents. With strong currents a mixed deposit is obtained.

To sum up: *liquids have, like metals, only one mode of conducting electricity. Also they have, like metals, only one contact E.M.F. with an electrode of invariable composition.* But the result of electrolysis being to modify both electrode and liquid round it, their contact E.M.F. alters in a variable manner—whence polarisation.

Sur la Conductibilité Électrique des Dissolutions Salines très Étendues. Par M. E. Bouty.[1] *Abstract by* Oliver Lodge.

I. *Historical.*

'The electric conductivity of salts dissolved in water varies with concentration in a manner extremely complex and differing for different salts. One possesses neither general law nor empirical formula, of however limited an application. One conceives *à priori* that this conductivity depends on the chemical nature of the salt, on the hydrates it can form, and on their stability; experience establishes also that it is not without relation to some physical properties of the solution, in particular its viscosity. But the separation of these circumstances has not yet been made. There seemed to me room first to simplify the problem by considering only solutions of identical physical properties. I have therefore chosen solutions so dilute that their density and viscosity are the same as pure water; their conductivity is yet relatively enormous, and can be measured easily by an electrometric method derived from that of M. Lippmann.'

In this method as now applied the tapping electrodes are zinc in sulphate of zinc, communication being established between the experimental fluid and the sulphate of zinc by a pair of capillary openings in the experimental tube. The difference of potential between these tapping electrodes is either measured by a Lippmann electrometer and compared against another difference taken at the ends of a known wire in the same circuit, chosen so as to be as nearly equal in resistance to the liquid as possible; or, what is plainly better, it is compensated by an auxiliary wire, and the electrometer brought to zero.

The author quotes Kohlrausch's views as expressed in his paper in Wiedemann's 'Annalen,' vi. pp. 1, 51, 145, 210; but he objects to them as founded too much on extrapolation, the conclusions being stated for extremely dilute solutions, while those experimented with contained $\frac{1}{20}$th of their weight of salt. 'So, although my results present a general agreement with those of M. Kohlrausch within the limits in which he has himself worked, I find myself led for their interpretation to conclusions absolutely different from that of the learned German professor.'

II. *Method of Measurement.*

The liquids to be compared are contained in two long vertical inverted U tubes

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[1] *Annales de Chimie et de Physique*, 6e série, 1884, t. iii.; also *Journ. de Phys.* 2e série, t. iii. p. 325. See also Foussereau, *Journ. de Phys.* t. iv.

dipping with their open ends into two pairs of porous pots, each pair full of the same liquid as is in its tube. The four pots, and also the two main (zinc) electrodes, are contained in six separate glass vessels, all full of sulphate of zinc solution, connected up by short stout siphon tubes, as shown in fig. 1. The tapping electrodes are zinc blocks, each in a Woulffe's bottle of sulphate of zinc, with a projecting and recurved full tube able to dip into any part of the liquid in the glass cells outside the porous pots, and so make connection (see fig. 2).

Fig. 1.

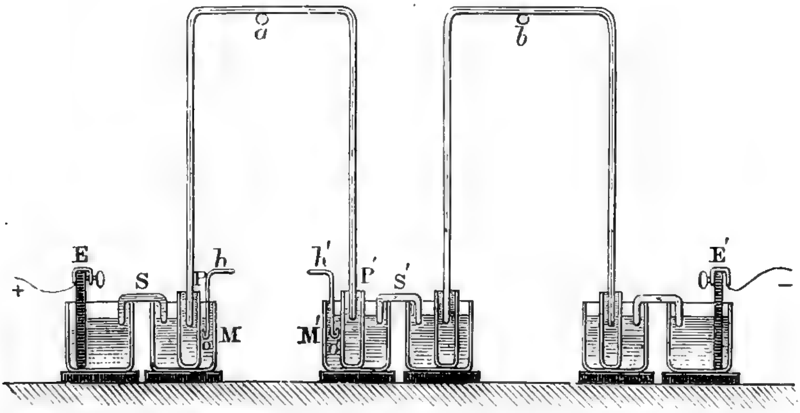
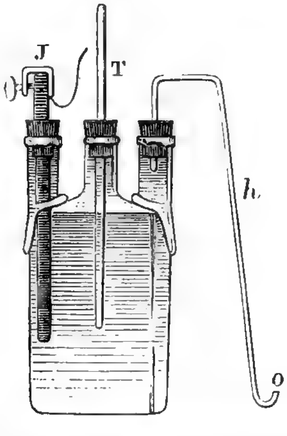


Fig. 2.



After taking readings for the two tubes filled with different liquids, they are both filled with the same liquid and fresh readings taken, so as to compensate for inequalities between the tubes.

III. *Conductivity of very dilute Neutral-salt Solutions.*

'When one takes a solution of a neutral salt, already pretty dilute, and doubles the quantity of water it contains, the specific resistance is in general far from being doubled, as one would *à priori* expect; it is multiplied by a coefficient λ, smaller than 2, which increases progressively with dilution and tends towards the limit 2, but only for excessive dilution. Here, for example, are some numbers furnished by sulphate of zinc:—

Initial concentration	Ratio λ[1]	Initial concentration	Ratio λ
$\frac{1}{10}$	1·684	$\frac{1}{160}$	1·752
$\frac{1}{20}$	1·712	$\frac{1}{320}$	1·805
$\frac{1}{40}$	1·721	$\frac{1}{640}$	1·845
$\frac{1}{80}$	1·739	$\frac{1}{1280}$	1·953

'Chloride of potassium gave in one experiment—

Initial concentration	Ratio λ	Initial concentration	Ratio λ
$\frac{1}{30}$	1·921	$\frac{1}{240}$	1·933
$\frac{1}{60}$	1·943	$\frac{1}{480}$	1·958
$\frac{1}{120}$	1·931	$\frac{1}{960}$	1·945

'Anhydrous salts behave in general like KCl, that is to say, the ratio λ is very near 2, even for moderate concentrations. Hydrated salts, on the other hand, are comparable to sulphate of zinc, and it is only for very great dilutions that their ratio λ approaches the value 2.'

M. Bouty considers that at sufficient dilution the molecular conductivity of all salts is the same. For salts without water of crystallisation a concentration of $\frac{1}{1000}$ or so may be permitted; but for hydrated salts it is necessary to go below these limits, a thing *which requires the possession of absolutely pure water*, and he is only able to show that they approach equality to the other class of salts when very attenuated. Two tables follow, showing ratios of resistances compared with ratios of concentration, first for anhydrous salts, and then for salts which crystallise with a definite amount of water, KCl being taken as the standard of reference.

IV. *On the Migration of Ions, and its Relation with the Conductivity of Salt Solutions.*

The author styles the case when the migration number of each ion is simply $\frac{1}{2}$ as 'normal electrolysis,' and he quotes results of Hittorf to show that the salts which thus behave are anhydrous salts, *e.g.*, AmCl, KCy, KCl, K_2SO_4, K_2CrO_4, KNO_3, KBr, $KClO_3$, $KClO_4$, Ag_2SO_4, KI, $AgNO_3$.

For all these Hittorf's number (n) is very near ·5 and scarcely varies with dilution. But for salts which definitely combine with water neither of these statements holds. Here are Hittorf's numbers. S represents the weight of water combined with 1 gramme of the salt; n expresses the loss of concentration at the cathode while 1 equivalent of electrolyte is decomposed.

It seems from the following table that hydrated salts approach normality as their solutions become very dilute. They then also tend to obey the law of equivalents ($k/m = \text{const.}$); so the two things are connected.

'When a salt obeys the law of equivalents, its electrolysis is normal (migration number $\frac{1}{2}$); when it does not obey, it is abnormal, and the divergence which the law presents to the law of equivalents is so much the greater as the number n differs more from the normal value ·5. . . . There is thus, between the resistance of salt solutions and the phenomenon of migration, a very close relation impossible to overlook.'

[[1] This 'ratio λ' is plainly the same thing as Arrhenius' 'exponent of dilution,' only more simply introduced. I have shown in remarks on Arrhenius' memoir (first part, see below, p. 360) that the meaning of this 'ratio λ,' in so far as it is constant, is that conductivity varies as a power of the concentration, $k \propto m^r$, where $r = \log \lambda / \log 2$.]

Salt	S	n
$CaCl_2$	1·6974	·780
	2·0683	·771
	2·3608	·765
	2·739	·749
	3·9494	·727
	20·918	·683
	138·26	·673
	229·2	·683
$MnCl_2+4H_2O$	3·306	·758
	190·41	·682
$MgCl_2+6H_2O$	2·48	·806
	3·7	·778
	22·2	·706
	128·3	·677
	241·3	·678
$BaCl_2+2H_2O$	3·5	·662
	8·4	·642
	100	·614
$MgSO_4+7H_2O$	5·3	·762
	309·6	·656
$CuSO_4+5H_2O$	6·35	·724
	9·56	·712
	18·08	·675
	39·67	·645
	148·3	
$ZnSO_4+7H_2O$	2·524	·778
	4·052	·760
	267·16	·636
$Na_2SO_4+10H_2O$	11·77	·641
	50·65	·634

A still more striking proof of this relation is afforded by some salts of which the electrolysis is not normal and does not tend to become so with increasing dilution. For instance nitrate of soda :—

	S	n
$NaNO_3$	2·066	·588
	2·994	·600
	34·76	·614
	128·7	·614

[The meaning of $n=·614$ is that when an equivalent of $NaNO_3$ is decomposed, ·614 of an equivalent is lost from neighbourhood of cathode and ·386 from neighbourhood of anode.]

The number n thus varies little with dilution, and appears rather to diverge from the normal value ·5 as dilution increases.

A comparison between $NaNO_3$ and KCl of the same concentration has furnished me with the following results :—

Concentration	Ratio of Resistance	Ratio of Equivalents
$\frac{1}{200}$	1·489	1·141
$\frac{1}{1000}$	1·476	

The specific resistance thus scarcely varies with dilution, and it is almost 1·3 time its theoretical value. The permanent anomaly of its electrolysis corresponds to a permanent departure from the law of equivalents. Salts which behave something like nitrate of soda are LiCl, NaCl, $CaSO_4$, $NaNO_3$, $NaClO_3$, $Ba2NO_3$, CaI, $Ba2ClO_3$; $Li_2SO_4+H_2O$, $Ca2NO_3+4H_2O$, $SrCl_2+6H_2O$, $NaI+2H_2O$.

V. *Discussion of the Results of M. Kohlrausch.*

Kohlrausch attributes to every ion a specific molecular conductivity which it preserves in every combination.

Bouty asserts that the molecular conductivity of all neutral salts in very dilute solution is the same ; and would thus consider that the numbers of ionic velocity given by Kohlrausch should be all equal, which they by no means are.

He proceeds to criticise Kohlrausch's experiments by saying that the solutions he used were too concentrated, the weakest containing 5 per cent. of salt, while Bouty's went as low as ·025 per cent.

'On the other hand Kohlrausch's tables are too comprehensive, they include electrolytes which cannot be directly compared : let us leave on one side for the moment, first, acids and basic hydrates; second, salts decomposed by water, double salts, &c.; third, neutral salts which remain abnormal even in very dilute solution; and consider only the salts I have called *normal.*'

The class of bodies most favourable to M. Kohlrausch's results are those relating to anhydrous and nearly 'normal' salts. Here are his numbers for the following ions. The numbers for Am, K, Cy, Cl, Br, I, and NO_3 differ very little from a mean value 50. But for Ag, SO_4, ClO_3, the atomic conductivity is 40, and for CO_3 it is 36.

'To compare these numbers with my own, this is what I have done. Consider, for example, K_2SO_4; its molecular resistance according to Kohlrausch is

$$\frac{1}{48}+\frac{1}{40}=\frac{88}{1920}.$$

That of KCl, which I have used as a standard, is

$$\frac{1}{48}+\frac{1}{49}=\frac{97}{2352}.$$

The ratio of these is

$$1{\cdot}1114.^{[1]}$$

I have measured this same ratio at different concentrations, viz. $\frac{1}{20}$, $\frac{1}{200}$, $\frac{1}{1000}$, $\frac{1}{4000}$, and find numbers which, divided by the ratio of equivalents, give respectively

1·288 1·144 1·074 1·011.

These evidently tend towards the limit 1, and not to the number 1·1114 proposed by M. Kohlrausch.'

Similarly with K_2CO_3 and $AgNO_3$.

'For sulphate of silver compared with KCl, Kohlrausch's table would give 1·21, which I find by experiment ·981.

'These divergencies are not enormous, but they get much bigger if one proceeds to study normal hydrated salts whose conductivity varies so rapidly with dilution.

'Kohlrausch's numbers for the following metals are very different from 50:—

Ca	26
Ba	29
Cu	29 and 12
Mg	23 and 14
Zn	— and 12

'When two coefficients are given, the former belongs to ordinary salts, the other to sulphates, which otherwise M. Kohlrausch cannot get to obey his law.'

Comparing these with KCl in the manner already explained, M. Bouty gets the following table, in which Kohlrausch's numbers are also inserted for comparison.

Concentration	$\frac{1}{20}$	$\frac{1}{200}$	$\frac{1}{1000}$	$\frac{1}{4000}$	Limit according to Kohlrausch	
					As given by Bouty	Corrected by O. L.
$CaCl_2$	1·437	1·339	1·251	1·181	1·428	1·29
$MgCl_2+6H_2O$	1·339	1·277	1·131	1·029	1·549	1·34
$BaCl_2+2H_2O$	1·290	1·133	1·081	·951	1·331	1·24
$Mg2NO_3+6H_2O$	—	1·323	1·249	1·163	1·581	1·4
$Cu2NO_3+6H_2O$	1·474	1·281	1·253	1·135	1·363	1·29
$MgSO_4+7H_2O$	2·777	1·879	—	1·249	2·834	1·80
$CuSO_4+5H_2O$	3·130	2·272	1·591	1·310	3·123	1·86
$ZnSO_4+7H_2O$	2·924	1·923	—	1·220	3·123	1·86

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[1] This is a mistake. The velocity numbers themselves must be added, not their reciprocals; so for K_2SO_4 $48+40=88$ is the conductivity, and for KCl it is 97; hence the ratio is 1·10. The difference being so small I have left the figures of M. Bouty unchanged, especially as the ground of his arguments is only partially affected, not removed. In a note to the September 1886 *Journal de Physique*, p. 428, M. Bouty admits his slip.

'It suffices to read the numbers in any horizontal row to see that they tend towards the limit 1, not towards variable limits according to the nature of the salt. The ratios deduced from the table of Kohlrausch agree very nearly with the numbers in my first column for concentration $\frac{1}{20}$.' Polarisation is so strong at the contact of metals with salts of Mg and Al that perhaps polarisation was not altogether avoided by Kohlrausch for the case of the magnesium salts above.

'To sum up: Molecular conductivities tend visibly to equality for hydrated as well as for anhydrous salts, and the disagreement of my results with those of Kohlrausch finds itself explained in the most satisfactory manner.'

VI. *Application of Faraday's Law to the Study of the Conductivity of Salt-solutions.*

'The law which I have just announced may be extended to a variety of salts. It suffices to know the manner in which the salt is electrolysed, and what quantity of salt is equivalent to KCl, for the application of Faraday's law.'

The author then gives figures for various salts, classifying them thus:—

a. Salts with several equivalents of acid.
b. Double salts decomposed by water (including alums).
c. Simple salts decomposed by water (tin salts and Fe_2Cl_6).
d. Stable double normal salts (K_4FeCy_6, &c.)
e. Double abnormal salts.
f. Phosphates and arseniates.
g. Bicarbonates.
h. Mercuric salts.
i. Tartar emetic and a couple of cobalt compounds.

He finds that $HgCl_2$, $HgBr_2$, and $HgCy_2$ are unique; they are insulators. Water containing 5 grammes of one of these substances to the litre conducts very little better than pure water: 200 times less than what the k/m law would give. Sal alembroth, however, conducts.

VII. *Organic Substances.*

Organic salts differ in no essential character from salts of which the acid and base are mineral. If the electrolysis is normal the law of equivalents rigorously applies, otherwise it does not, just as with mineral salts.

Bodies like alcohol, glycerine, glucose, urea, &c. are very bad conductors, and it is difficult to make sure that the feeble conductivity they show (when commercially pure) is not due to the presence of traces of salts.

VIII. *Conductivity of very dilute Acids and Bases.*

The author has been led to the following conclusions:—

'*Acids and bases which dissolve in water without combining with it furnish insulating solutions; on the other hand, when these substances combine with water in a manner more or less complete they conduct in the same way as salts.*

'But a given acid or a given base often forms with water several different combinations. These combinations are usually unstable in presence of excess of water; they are dissociated more or less by elevation of temperature and by dilution. It is only in a manner altogether exceptional that a monobasic acid can exist in dilute solutions in the monohydrated state, and without mixture with superior hydrates; its mode of electrolysis and its conductivity will vary in a corresponding manner. It is therefore not legitimate to liken acids and bases in aqueous solution to neutral salts; the law of equivalents cannot be directly applied to them.'

Then follows a twelve-page discussion of results, to establish these laws; from this I make a few extracts only.

The case of sulphuric acid is interesting, since it can crystallise with either one, two, or four, molecules of water, and it undergoes maximum contraction when combined with six atoms. It is known also to possess a maximum conductivity for sp. gr. 1·25. M. Bouty finds that the ratio λ attains a minimum for a concentration about 1/500, as the following table shows:—

Initial concentration .	$\frac{1}{30}$	$\frac{1}{60}$	$\frac{1}{120}$	$\frac{1}{240}$	$\frac{1}{480}$	$\frac{1}{960}$	$\frac{1}{1920}$	$\frac{1}{3840}$	$\frac{1}{7680}$
λ	1·917	1·894	1·867	1·856	1·849	1·854	1·881	1·942	2·002

'One does not see how to explain a variation of this kind except by a change in the nature of the electrolyte (*i.e.*, of the dissolved hydrate).'

By making the hypothesis, which Bourgoin made, that the hydrate really decomposed by the current was S_2O_6, $6H_2O$, M. Bouty considers that the anomaly of electrolysis as expressed by Hittorf's values of n, and also that of conductivity, is explained. These are Hittorf's values of n for dilute sulphuric acid.

[1] S = ·5574	1·4383	5·415	23·358	97·16	161·4
n = ·400	·288	·174	·177	·212	·206

Hydrochloric acid is in much the same condition as sulphuric acid: it conducts as if its molecule contained three equivalents of basic hydrogen. One does not know such a hydrate, but there is probably a mixture of hydrates present.

Oxalic and picric acids are the best conducting organic acids. Other acids conduct hardly at all when strong, and dilution has an enormous effect upon them—probably because they combine with water forming compounds analogous to salts.

IX. *Influence of Temperature.*—To study this, the U tubes of fig. 1 are turned upside down and immersed in a bath. The result is that for normal neutral salts the conductivity is a linear function of temperature.

$$k = k_0(1 + bt),$$

where b is the same constant for all the salts, and equal to about ·0337. This agrees with Kohlrausch also.

It is noteworthy that Poiseuille gives the quantity of water which flows through a capillary tube, under a given pressure, as proportional to—

$$1 + {\cdot}03365t + {\cdot}00021t^2.$$

It is impossible not to be struck with the identity of the principal coefficient in this formula, with b in the conductivity formula; showing that resistance is of the nature of a friction, as Wiedemann surmised.

For abnormal salts the coefficient b is a little greater, and a parabolic formula is required at higher temperatures. So, although these salts conduct worse than normal ones to begin with, they improve faster when heated, and accordingly their abnormality decreases with rise of temperature.

For acids and bases the temperature-coefficient is rather less, being only ·0119 for sulphuric acid, and ·024 for hydrochloric. Probably warming breaks up some good-conducting hydrate, and so spoils conductivity almost as fast as it otherwise improves it.

'To sum up: I believe I have established that the electrolysis of neutral salts is a simple phenomenon, and that there is only one elementary law of conductivity in harmony with the law of electro-chemical equivalents. Apparent exceptions only reveal to us the complexity of certain solutions which are not directly comparable with those of KCl or K_2SO_4.'

On the Employment of Alternating Currents for Measuring Liquid Resistances. By MM. BOUTY *and* FOUSSEREAU.[2]

The authors criticise the employment of alternating currents employed by Kohlrausch and many others in the hope of diminishing the effect of polarisation. They point out that self-induction in the resistance-box is fatal to silence in the telephone [naturally], and only succeed in getting good results when they replace wire in their bridge by liquid resistances, describing for this purpose a liquid rheostat. Even thus, however, they hardly get concordant results when they try to apply the method to extremely weak solutions.

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[1] S means weight of water combined with one gramme of acid.

[2] *Journal de Physique*, 2e sér. September 1885, t. iv.

On Mechanical and Thermal Effects accompanying Electrolysis. By M. BOUTY. *Brief Abstract by* Oliver Lodge.

A series of short memoirs have been published by M. Bouty in the 'Journal de Physique' on a branch of the subject not very immediately connected with that which at present concerns us. I had occasion to refer to part of them in a communication on the seat of E.M.F. in the voltaic pile. (See 'B.A. Report,' 1884, pp. 492 and 513–518, or 'Phil. Mag.' vol. xix. 1885, pp. 189 and 343 to 350.)

The references to them are as follows:—

1. *On some mechanical and thermal effects accompanying electrolysis* ('Journ. de Phys.' 1879, t. viii. pp. 289 and 341).
2. *Thermo-electric and electro-thermic phenomena at contact of metal and liquid* (1880, t. ix. p. 306).
3. *On the contraction of galvanic deposits, and its relation with the Peltier phenomenon* (1881, t. x.)

In the first of these papers, metals are deposited on silvered thermometer bulbs and the mechanical compression caused by the different deposits studied; Wertheim's results in elasticity being applied to them.

The effect of heat on such metallised thermometers is also discussed.

Metallised thermometers are then used as electrodes to examine the changes of temperature which occur while various ions are being liberated. During the electrolysis of $CuSO_4$ or $ZnSO_4$ the anode is slightly warmed, the cathode slightly cooled; inverting the current cools the new cathode distinctly. Electrolysing dilute H_2SO_4 with platinum coated thermometers, the anode is quite warm, the cathode scarcely at all. This is the permanent effect. Inverting the current cools the old anode, sometimes $\frac{1}{5}$ degree below the temperature of the surrounding liquid. The effect can be repeated seven or eight times, although with decreasing intensity, if one takes care to stir the liquid between the inversions.

Replacing H_2SO_4 by HCl, the permanent effect is very small, but both poles heat strongly at each inversion. With $PtCl_4$ one observes at each inversion a cooling of the old anode and a heating of the old cathode. In every case examined, anode is hotter than cathode in the permanent state.

In the second paper, metal-liquid junctions are warmed and cooled alternately so as to give thermo-electric currents, the E.M.F. of several circuits being measured. An attempt is then made to measure absolutely the coefficient of the Peltier effect at these junctions when a current passes; a method suggested by Maxwell ('El. Electricity,' p. 146) being used. The result is that the author believes the effects to be purely physical, without known relation to the heats of combination or the latent heats of solution, but connected exactly with the thermo-electric forces of couples corresponding. The thermo-electric laws of Sir W. Thomson are believed to apply without modification. Chemical effects are regarded as disturbances producing parasitic heats.

In the third paper, the author reconsiders the contraction of galvanic deposits in the light of the Peltier effect, and comes to the simple and satisfactory conclusion that the two phenomena are immediately connected. Each envelope being deposited at a rather higher temperature than it is able afterwards to maintain, a state of compression naturally results. This view he sustains by experiment.

Recherches sur la Conductibilité galvanique des Électrolytes (152 *pages*). *Par* SVANTE ARRHENIUS. *Mémoire présenté à l'Acad. des Sciences de Suède le* 6 *Juin* 1883. *Published at Stockholm, Konigl. Boktryckeriet.* Norstedt and Söner.

PART I.—*On the Conductivity of Extremely Dilute Aqueous Solutions, determined by means of the Depolariser* (63 *pages with plate*). *Critical Analysis by* OLIVER LODGE.

WHATEVER may have been the importance of the *first part* of this memoir at the date of its appearance (1883), the publication last October in Wiedemann's 'Annalen' of a masterly memoir by Prof. F. Kohlrausch on the same subject throws it into the shade; for there can be no doubt that while the ground covered by both is similar, the Kohlrausch memoir is greatly superior, both in the experiments made and in the discussion upon them.[1]

A brief abstract of this portion of Dr. Arrhenius's paper is all, therefore, that is now necessary; and if my criticisms on parts of it appear in any case caustic, I must express my regret to the author for the adverse opinion, and trust that my appreciation of a great deal in the second part will compensate for it to some extent. It sometimes seems as if the author allowed himself occasionally to indulge in an exploded type of reasoning, wherein, by manipulation of imaginary data, a confusion is produced, out of which emerge several laws more or less in agreement with experience, which are thenceforth labelled and referred to as theoretical deductions. It may be, however, that the italicised and numbered statements throughout the paper are not intended for strict statements of deduced law, but are merely summaries of more or less probable truth. In that case it is their form only which is misleading, and one would judge them by a different standard. I proceed to give an account of the contents.

§§ 1–8 are devoted to an account of the experimental method employed, and to a justification of it.

The method consists in the use of a differential galvanometer, one of whose branches consists of ordinary wire, while the other contains a current alternator in the shape of a wheel turned by hand, with alternate bars on its periphery rubbed by two springs (Edlund's 'depolariser'). The alternating current from this instrument is led to a switch, which is able at pleasure to throw into circuit either the experimental tube of liquid or a wire resistance box.

A battery is arranged so that its current divides fairly equally between the two branches of the galvanometer; and one portion of the current, after being rendered alternating by the above arrangement, is diverted by the switch either to the electrolyte or to the adjustable resistance-box. The resistances of the liquid and of the box are considered equal when the deflexion of the galvanometer is independent of the position of the switch.

I must confess to surprise that this can be a satisfactory mode of measuring resistance: self-induction and electro-chemical capacity being so mixed up in it,[2] and the so-called depolariser being a very unsatisfactory instrument. Apparently, however, results fairly comparable with each other can be obtained.

§ 9. *Calculation from the Experimental Data.*—First, the conductivity of the original water used as solvent is subtracted from that of the solution, and the result claimed to be the conductivity of the salt alone. For this rule, as an empirical process justified *à posteriori*, there may be something (not much) to be said. But as a corollary from a 'law' subsequently proved in this paper (§ 15, law 2) it is unreliable. Probably not much harm is done by using this rule in the special cases considered; at any rate, Kohlrausch does the same thing: but it is well to notice that the rule $k = k_1 + k_2$, for the conductivity of a mixture, if stated as a general and *à priori* law, assumes two things:

1st. That the law of divided circuit must hold whenever two conductors are intermingled; which is untrue.[3]

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[1] See § 6 of a letter by Dr. Arrhenius printed on p. 386.

[2] See § 1 of a letter by Dr. Arrhenius printed on p. 384.

[3] Dr. Arrhenius in his letter, page 385, naturally and justifiably objects to this statement as dogmatic. The reason it is here put so briefly is that the point was referred to in my last year's paper, see Aberdeen Report, top of page 728. Observe, I only object to the assumption that the law of divided circuit *must* be true: it *may* be true in some cases, but a possibility cannot be made the basis of a deduced law. In order that the combined resistance of two solutions when mixed may be the semi-harmonic mean of their separate resistances when alone, the following conditions are necessary and sufficient:

(1) The solutions must not affect each other's conductivity in any way; the fact of mixture must not increase dissociation or change viscosity, for instance.

2nd. That the conductivity of water itself remains unaffected by the presence of a foreign body; which is improbable.[1]

Effect of Dilution.—A great part of the paper is taken up with the effect on conductivity which dilution with an equal quantity of water causes to solutions of various salts. This mode of expression is a roundabout substitute for a straightforward expression by curve or formula for the relation between conductivity and concentration such as Kohlrausch attempts to give. However, as Dr. Arrhenius evidently prefers this mode of expression, I translate his introduction of it (page 25 of his memoir).

'Table A shows that when a saline solution is diluted in a certain ratio [1 : 6·08, for instance] its conductivity diminishes in a certain other ratio [not in general a very different one]. To render these numbers comparable among themselves in the different series a recalculation has been made, in which all dilutions are reduced to the ratio 1 : 2.

'This calculation is made in the following manner. If 1 : u is the proportion between the dilutions of two solutions of the same salt examined consecutively (*i.e.*, if one of the solutions is u times as dilute as the other), the proportion between the resistances in the two cases is, say, 1 : n (the value of n being taken from the table); that is to say, one of the solutions has a conductivity n times less than that of the other.

'If now 1 : x is the proportion between the resistances of two solutions when the dilutions are in the proportion 1 : 2, the following relation will hold good. If the dilution is $1 : 2^p$, the ratio of resistances (if the process is effected in a uniform manner) ought to be $1 : x^p$. In consequence we have $1 : 2^p = 1 : u$, and $1 : x^p = 1 : n$, which enables x to be calculated by the following formula:—

$$\log \log x = \log \log n - \log \log u + \log \log 2.$$

'The values of x calculated from this formula, which, according to what has just been said, signifies the proportion in which the conductivity of one salt-

(2) The current must divide itself accurately between the two constituents, so that whatever starts to go by one substance must keep to that all the way, and not go partly through one, partly through the other.

If these two conditions are not satisfied, the law can only be true in any particular case by some semi-accidental sort of compensation. True there is much to be said for the fulfilment of the second condition in many cases of electrolysis, perhaps in all; but it cannot be regarded as axiomatic; and it is certainly not true of intermingled conductors in general, which is all I say in the text. The point may be illustrated thus. Take a square sheet of tinfoil, send a current through it between copper strips on its opposite edges, and measure its resistance. Now make an arbitrary cut across the sheet from one of these edges to the other. The current will divide between the two portions, and the resistance of each portion can be measured. *The resistance of the uncut sheet will not in general be equal to the semi-harmonic mean of the two portions*; in other words, the law of divided circuit need not apply.

It *may* apply, but only for the special case of a cut along a stream-line. The statement, therefore, that the law of divided circuit *must* hold whenever two conductors are intermingled is untrue—Q.E.D.

As to the question whether the law *does* hold for any mixed electrolytes we have the experiments of Hittorf and of Buff on the conductivity of mixtures; with the result, I believe, that whereas all the mixed substances take part in conveying the current, no simple relation holds between the conductivity of the mixture and their separate conductivities except in the case of some haloid salts. For them the law of divided circuits does seem to hold.

To diminish the risk of misunderstanding, I may be permitted to point out that the remark made in the text is not a criticism of Dr. Arrhenius or of anybody. It relates to a general proposition or matter of fact, and is intended as a memorandum of a circumstance which it is very easy to see when pointed out, and rather easy to forget in practice when considering a special case; cf. Guthrie's Text-book of Electricity, sections 244–247, first edition, which are all wrong in principle as well as cumbrous in detail.

[1] See §§ 2 and 3 of letter on p. 385.

solution diminishes when it is diluted with water to double its volume, are laid down in table B. This quantity we name the *exponent of dilution.*'

B is a long table wherein, after all, x does not turn out a constant—though it is roughly so, several values of x being given for each substance according to its degree of dilution. The values of x for all the substances range from 1·7 to 2·3, and their average value would seem to be about 1·95.

The above introduction to the formula for calculating x loses all meaning unless x is intended to be constant; but, in so far as x is intended to be constant, the gist of the introduction may be paraphrased thus:—

The first approximation to the relation between k and m (conductivity and concentration) is that made by Kohlrausch, viz., that the two are proportional.[1] This is roughly true for very dilute salt (not acid) solutions, but it breaks down in a manner shown by Kohlrausch's experimental curves for more concentrated ones, so that he suggests the formula—

$$k/m = \mathrm{A} - \mathrm{A}m^{\frac{1}{3}}$$

as a closer, though still rough, approximation. Arrhenius, however, prefers to assume (*i.e.*, practically, though unconsciously, *does* assume by his reasoning) that k is nearly proportional to m^{r}, where r is an index to be determined by experiment. This is fair enough as an hypothesis, and should have been set forth clearly, and then negatived by the result of his experiments: or, as a clumsier and bulkier proceeding, the value of r might be tabulated for every substance at various strengths. Instead, however, of determining r, Arrhenius determines 2^{r}; which he calls x, and tabulates. This number x, his *exponent of dilution,* he calculates from the equation—

$$\frac{\log x}{\log 2} = \frac{\log m/m'}{\log m/m'} = \frac{\log n}{\log u} \; [=r].$$

I confess that it has cost me a good deal of trouble to disentangle the real meaning of this said dilution-exponent, and of the ideas involved in it.[2]

I ought here to say that in 1884 M. Bouty independently expresses his results in terms of this same number, which he calls the ratio λ; showing that it has some experimental convenience. Bouty, however, does give absolute concentrations, and he really doubles the dilution each time. Arrhenius gives no absolute concentration; he dilutes largely, and then calculates what would have happened if he had only doubled the dilution, by means of a formula which, after all, is not *really* correct.[3] Perhaps the idea in not giving absolute concentrations is that it is impossible accurately to tell them, unless absolutely pure water were available to start with. But the difficulty of impure water tells just as much at every dilution, for it is a medley of things you are really adding. A great part of the merit of Kohlrausch's work is that he takes such immense pains over the quality of his water.

§ 10. List of bodies examined.

§ 11. Table A, giving resistance and temperature of different strengths of solution of the various substances, but no absolute strengths are given; *ratios* of dilution are all that are specified. The columns, in fact, show $1/n$ and $1/u$.

Table B contains the 'exponents of dilution,' x, calculated for the different substances; it shows a slow increase in x as the solution becomes weaker.

Table B′ contains similar numbers, calculated from some experimental results of Lenz for stronger solutions.

The net result of these tables is that they help to confirm the later results of Kohlrausch. For all salts other than hydrates the value of x becomes practically equal to 2 as the solutions become very weak, *i.e.*, r becomes unity; and this means simply that k/m for such solutions is approximately a constant.

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[1] See § 4 of letter on p. 385.

[2] In his letter on p. 386 below, § 4, Dr. Arrhenius denies that he had any theoretical idea in introducing the 'exponent of dilution.' I accept his statement of course, and regret the time spent over the troublesome, and now apparently unmeaning, introduction quoted above.

[3] See § 4 of letter on p. 386.

For stronger solutions x diminishes; and this means simply that k/m falls off, just as Kohlrausch's curves more instructively show.

§§ 12 and 13. *Discussion of the Tables.*

§ 14. *Influence of Temperature on Conductivity.*—Dilution and heating exert a similar influence on molecular conductivity.

CHAPTER III.—THEORY.

§ 15. *On Conductivity considered as a Function of Concentration.*—Kohlrausch and most authors suppose that k/m is constant for extreme dilution; 'nevertheless he seems to make the statement with a certain reserve, for in another passage he says, "This number [gramme-molecules per cc.] can, according to all the experiments, be put proportional to the conductivity of attenuated solutions, provided *extreme* attenuation be excepted." Nevertheless it is not difficult to prove that such a proportionality follows from the principles postulated in his work: and that precisely for solutions of extreme attenuation.'

Then follows a proof, based on Kohlrausch's surmises and Hittorf's hypotheses,

(1) *That k/m is necessarily constant;*
(2) *That when two or more salts are dissolved, the conductivity of the whole is the sum of the separate conductivities;* and
(3) *That the conductivity of a solution equals the sum of conductivities of salt and solvent.*

To all this it is necessary and sufficient to remark that the surmises of a philosopher, which are to some extent upset by his own experimental results and accordingly by him stated 'with a certain reserve,' afford a very insecure basis for an elaborate proof, and for deductions therefrom.[1]

If it be once granted—1st, that the conductivity of the water in solution is, under all circumstances, nil, or extremely small; 2nd, that every atom of a salt added conducts equally, and independently of every other;—the laws stated are pretty obvious without further proof. But it is of little use attempting to prove these laws by begging the question.

§ 16 contains statements numbered (4) and (5), viz., *If the three laws are not true, it must be because of chemical action between the substances.*

§ 17. Hydrates (*i.e.*, hydrogen compounds, like acids and bases) are peculiar; either because they dissolve glass, or because impurities contained in distilled water act upon them chemically, and alter them.

§ 18. Statement No. 6.—*The 'exponent of dilution' is less than 2 for salts, greater than 2 for hydrates.*

§ 19. *Exceptions.*

§ 20. *Nature of the Resistance of Electrolytes.*—A hypothetical discussion of the friction between atoms, the mode in which ions rub against other molecules, and of the amount of rotation they produce in them; with three conclusions, numbered respectively—

(7) *The resistance of a solution is greater as the internal friction is greater.*
(8) *The resistance is greater as the ions are more complex.*
(9) *The resistance is greater as the molecular weight of the solvent is greater.*

§ 21. *Properties of Solutions of Normal Salts.*—Discussion of some results of Hittorf, and four statements—

(10) *Salts which are able to form double salts are most likely to form molecular complexes.*
(11) *Aqueous solutions contain the electrolyte dissolved, at least partially, in the form of molecular complexes.*
(12) *Dilution diminishes complexity towards an asymptotic limit.*
(13) *The limit toward which the complexity of a dissolved normal salt approaches at extreme attenuation is the same for all normal salts.*

I feel that this brief analysis is not quite fair to the contents of these last sections, which are ingenious and interesting; but I scarcely think a detailed

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[1] See § 5 of letter on p. 386.

abstract of them would repay perusal, inasmuch as the author allows himself rather too freely the use of hypothesis concerning wholly unknown molecular interactions.[1] Perhaps it will be fairer if I give the *résumé* in full.

Résumé.

'In the first six sections of the present work we have described a new method of measuring the resistance of electrolytic conductors. In this method we made use of rapidly alternating currents, produced by a depolariser constructed for the purpose by M. Edlund. We have tried to show the use of this method, and to make clear the practical advantages which it possesses.

'In the next part we have treated the process of making the observations, and of calculating the results. Then we have displayed the figures found for very dilute solutions of forty-five different bodies. Finally, we have discussed preliminarily the figures obtained, with regard to the exponent of dilution, the molecular conductivity, and the temperature-coefficient.

'In Chapter III. we have, guided by the data of MM. Kohlrausch and Hittorf, laid down the proposition of the proportionality between the conductivity and the number of electrolytic molecules of a dilute solution, as well as two other propositions, according to which the figures of the preceding part were calculated (1) (2) (3). Moreover, we have shown that if these propositions are not applicable, it is necessary to suppose that by dilution of electrolytic solutions chemical reactions are set up, (4) (5). Proceeding from these different propositions, we have shown that all salts, properly so called, in solution are composed of complex molecules, which are partly destroyed by dilution. We have also indicated the manner in which these complexes are formed.

'By aid of this conception the properties of salts at all dilutions have been explained, as well as the properties of all electrolytes at considerable concentration.

'On the other hand, hydrates,[2] and salts which partially transform themselves into hydrates, manifest other properties when much diluted. We have shown that this singularity can be explained by the action of impurities which accompany the water used to dissolve them.

'By some considerations as to the nature of galvanic resistance we have been brought to the conclusions numbered (7) (8) and (9), of which the two latter complete the first: these indicate the long-known relation between galvanic resistance and internal friction. The two propositions (8) and (9) are also in agreement with published data.'

Thus much is a meagre account of the first part of the complete memoir. I now pass to the far more striking second part, and shall find it necessary to give a much fuller, and in many places verbatim, report.

I am not able to judge as to how much is original and new, as I am but slightly acquainted with the work of previous writers on similar subjects, nor am I at all confident how far the hypotheses made by the author are perfectly legitimate. So far as I am able to judge, however, and making allowance for possible inadequacy of data and somewhat hasty generalisation, the paper seems to me to be a distinct step towards a mathematical theory of chemistry.

The title affixed to it is 'The Chemical Theory of Electrolytes,' but it is a bigger thing than this: it really is an attempt at *an electrolytic theory of chemistry.*

PART II.—*Théorie Chimique des Électrolytes. Par* SVANTE ARRHENIUS. (89 *Pages*). *Abstract and translation by* Oliver Lodge.

[Remarks by the abstracter are enclosed in square brackets.]

§ 1. Ammonia considered as an electrolyte.

Kohlrausch has shown that a solution of ammonia, as regards conductivity, behaves differently from all other bases. It is a much worse conductor than potash,

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[1] See § 6 of letter on p. 386.

[2] By hydrates the author always means hydrogen compounds like acids and bases.

and its exponent of dilution is not much bigger than 1 [*i.e.*, its conductivity, instead of increasing anything like so fast as concentration, scarcely increases at all]. Kohlrausch guesses that the cause of this is the prevalence of NH_3 in solution instead of NH_4HO. Probably dilution increases the supply of NH_4HO, and therefore assists conduction almost as much as it for other reasons weakens it. This would explain the peculiarly small exponent of dilution.

(14) *The conductivity of ammoniacal solution is caused by a small quantity of* NH_4HO, *which is increased by dilution.*

[Surely it is rash to make definite statements like this on such a slender basis of fact.] [1]

§ 2. Case of acids; activity.

Acetic acid has the same properties as ammonia; so has boracic acid. Tartaric and oxalic have small exponents of dilution. Probably the behaviour of these acids, as well as of ammonia, is analogous to that of HCl, which only conducts in presence of water. Sulphuric, nitric, phosphoric, behave in the same way. Hence—

(15) *The aqueous solution of any hydrate* [2] *is composed of two parts, besides the water, viz., an active (electrolytic) part and an inactive (non-electrolytic) part. The three constituent parts of the solution form a system in chemical equilibrium, such that dilution increases the active and diminishes the inactive portion.*

How the inactive and active portions differ is not certain, perhaps only physically; perhaps the active part is a compound of hydrate and solvent.

To fix ideas we can introduce the notion of a coefficient of activity, defined thus:—

The coefficient of activity of an electrolyte is a number expressing the ratio of the number of ions which are really in the electrolyte to the number of ions which it would enclose if the electrolyte were totally transformed into simple electrolytic molecules.

[This 'coefficient of activity' is evidently the same thing as what, in accordance with dissociation ideas of electrolytic conduction, I called [3] the 'dissociation ratio,' *i.e.*, the relation between the number of atoms taking part in conduction to the whole number present. It may turn out that this ratio is unity, but it is in any case well to determine it; and the idea of Arrhenius that it is upon this that chemical activity and rapidity of interchange depends seems to me important.]

§ 3. Hypothesis of Williamson and Clausius, and consequence thereof.

[The continual interchanges of atoms supposed to occur among the molecules on this view of conduction are here regarded as circular electric currents. References to the original statements of the hypothesis are given as follows: Williamson, Liebig's 'Ann.', vol. 77, p. 37 (1851); and Clausius 'Pogg. Ann.', vol. 101, p. 347 (1857)].

§ 4. Deduction of some electro-chemical laws (16)–(20).

[*E.g.*, Faraday's laws. I omit this section because it is not much use deducing laws like these from an hypothesis. The Williamson-Clausius hypothesis is of course in harmony with the fundamental laws of the subject, otherwise it would have been pretty soon abandoned. Probably the object of the author is to show how readily the known laws can be built up from one simple foundation.[4] One

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[1] See § 7 of letter on p. 386.

[2] For 'hydrate' always read *hydrogen compound, either base or acid.*

[3] On page 756 of last year's *B. A. Report,* Aberdeen.

[4] See § 8 of letter on p. 387.

statement deduced from this hypothesis is worth quoting (see also Wiedemann, 'Elek.', vol. ii. p. 924).]

(20) *Every body which acts chemically by double decomposition on an electrolyte is itself an electrolyte, as well as the products of the decomposition. Therefore water, alcohol, aldehydes, &c. &c., are electrolytes, and therefore conductors.*

[The *a priori* manner in which this statement is made is striking; so is the note immediately following.]

'On this subject people have disputed for some time. They often attribute the feeble conduction observed in these bodies to traces of saline impurity.'[1]

§ 5. Relation between conductivity and chemical power of acids and bases.

(21) *The molecular conductivity of the active part of an acid (in dilute solution) is constant, and independent of the nature of the acid.*

For if the chemical formula of an acid is HR, its molecular conductivity, according to Kohlrausch, is $h+r$. Now the molecular conductivity of dilute salts with the same metal, MR, MR′, &c., is the same; hence $r=r'=$&c. And therefore it follows that for acids also the molecular conductivity of HR, HR′, &c., is the same. A corollary is—

(22) *The more a dilute acid solution conducts, the greater is its active part.*

Similar propositions may be stated for bases.

[The author then goes on to consider the idea of coefficients of activity more particularly in the light of the Williamson-Clausius view, and he gives reasons for supposing *molecular conductivity* and *coefficient of activity* to be closely related, and indeed proportional, to one another. He then says, *let them be defined to be equal.* A list of molecular conductivities for acids, bases, and salts from the results of Kohlrausch is supplied, and it is pointed out that the best conducting acids are the strongest. Appeal is made to the results of Berthelot, Thomson, and Ostwald in support of this.]

'Thus we believe we have proved that for acids and bases galvanic activity is accompanied by chemical activity,' and probably non-electrolytes have no direct chemical action. *Cf.* Gore on the inactivity of anhydrous HCl.

§ 6. Double decomposition.

[This section is the key to the whole, and I had best translate it in full.]

Suppose two electrolytes, A B and C D, are dissolved in an inactive solvent. Circular currents pass in the solution [*i.e.*, Williamson-Clausius atomic interchanges occur], whereby the bodies A D and B C are formed. If the coefficients of activity of all four bodies A B, C D, A D, and B C were equal, they would all be present in the same quantity, viz., half an equivalent of each, provided the original substances were in equivalent proportions. And in any case an equilibrium would establish itself, the rate of formation of each substance being equal to its rate of destruction. Now the coefficient of activity of a body indicates that fraction of the body which at any one time participates in the circular currents [*i.e.*, is ready for interchange]. If then this coefficient for A B is a, and if m equivalents of A B exist in solution, am expresses the number of equivalents of A B which at any moment take part in the circular currents.

One could figure to oneself the process of double decomposition in the following manner. The ions of active molecules rotate round one another. Then, considering the molecules A B, the ion A moves with a certain velocity in the neighbourhood of B until it comes near another ion, B′, after which it follows B′. The molecule A B exists until this happens.

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[1] See § 9 of letter on p. 387.

As now, from the preceding, the conductivity of the active parts of all salts is the same—that is to say, according to M. Kohlrausch, the velocity with which the ions move relatively to each other is independent of the nature of the salt, and only depends on the strength of the current—it is natural enough to suppose that the said velocity is the same for all salts, even when the strength of current is zero. [This is rather an overstraining of Kohlrausch's results, but it may pass as a first approximation any way.]

Suppose, moreover, the mean distance at which A need find itself from B in order that it may abandon B and attach itself to B′ is the same for all B ions, whatever their nature (as is probably the case in gases). In this case M. Clausius has shown that the mean path of the cation A between the moments of encountering B and B′ is—

$$l = \text{const}/n,$$

where n is the total number of anions in unit volume.

True, M. Clausius has given this proof for the case where the paths are rectilinear, but according to the premisses of the demonstration it is equally valid if the path is a broken line or any other form. Suppose, for simplicity, that the B ions are motionless; then, from what precedes, the mean time of existence of the molecules A B is—

$$t = \frac{l}{v} = \frac{\text{const}}{n v},$$

v being the mean velocity of an A ion. So, in unit time, of m molecules A B, a number equal to—

$$\frac{m}{t} = \text{K}\,m n$$

are destroyed (v, being the same for all electrolytes, is included in the constant K). In reality the B ions are also moving, but since v is the same for all, the only effect will be to change the constant K in such a way as to leave it nevertheless the same for all salts.

In the same way we can show that if p is the number of A ions, and q the number of B ions in unit vol., the number of molecules A B *formed* in unit time is—

$$\text{K}pq.$$

Hence the number of A B molecules at the end of unit time in excess of those at the beginning—that is to say, the velocity of the reaction by which A B is being formed—is—

$$\text{K}(pq - mn).$$

If the hypotheses supposed in the foregoing are only approximately true, the above deductions are no more so. The effect would be to multiply the numbers p q m and n by different factors, so that the general aspect of the above-deduced expressions will be only slightly modified. The same thing can be said for the equations we deduce in the sequel. However, as in the actual state of science it is impossible to judge of the validity of these hypotheses, and as they have a certain degree of probability, and of all hypotheses are the simplest we can imagine, it is my intention to prove that the deductions which it is possible to draw from what has just been said are compatible with experimental facts—facts of which we thus give a certain explanation. With the progress of science it is possible that one may see the necessity of modifying these hypotheses; the general reasonings will persist nevertheless, as well as the conclusions drawn from them.

Now, suppose we have four electrolytes, A B, A D, C B, and C D, intermingled; let the number of equivalents of each, existing at a given moment, be m, q, p, n, respectively; and the corresponding coefficients of activity α, β, γ, and δ: the velocity of reaction will be, according to the foregoing,—

$$\text{K}\{(m\alpha + q\beta)(m\alpha + p\gamma) - m\alpha(m\alpha + q\beta + p\gamma + n\delta)\},$$

an expression which transforms itself into the following:—

$$\text{K}(q\beta \,.\, p\gamma - m\alpha \,.\, n\delta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

A state of equilibrium will be attained when the velocity of reaction is nothing. If then m originally equalled 1, and a quantity x of the body A B has been transformed, the final state will contain $1-x$, $n-x$, $q+x$, $p+x$, equivalents of the bodies A B, C D, A D, C B, respectively. The equation expressing equilibrium will thus be—

$$(1-x)(n-x)\alpha\delta = (p+x)(q+x)\beta\gamma \quad . \; . \; . \; . \; . \; . \; . \quad (2)$$

or, if p and q are zero, a case often realised in practice—

$$(1-x)(n-x)\alpha\delta = x^2\beta\gamma \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2\text{A})$$

Now introduce the following definition:— . . . Two electrolytes like A B and C D, which have no common ion, are to be called *conjugate*; and two like A B and A D, or A B and C B, are to be called *opposite*. Equation (2) expresses the fact that an equilibrium occurs between the system of two conjugates, AB and CD, and the system of their two opposites, AD and CB, which are conjugate to each other. From that system is formed this system, and *vice versâ*; wherefore equilibrium occurs, because the number of circular currents in which both systems are engaged is the same in the two cases. This is precisely the signification of equation (2). This equation immediately shows that,

> (23) *As soon as the relative quantities of the ions, A B C D, are given, the final result is independent of their original form of combination, whether A B and C D, or A D and C B, or any other form.*

This proposition is sufficiently natural to need no proof. Moreover, it has been verified by the work of MM. Guldberg and Waage and Ostwald.

Solving equation (2) we get

$$x = -\frac{\alpha\delta(n+1)+\beta\gamma(q+p)}{2(\beta\gamma-\alpha\delta)} \pm \sqrt{\left\{\left(\frac{\alpha\delta(n+1)+\beta\gamma(q+p)}{2(\beta\gamma-\alpha\delta)}\right)^2 + \frac{\alpha\delta \,.\, n - \beta\gamma \,.\, qp}{\beta\gamma-\alpha\delta}\right\}} \quad (3)$$

or for the special case when q and p are zero—

$$x = -\frac{\alpha\delta(n+1)}{2(\beta\gamma-\alpha\delta)} \pm \sqrt{\left\{\left(\frac{\alpha\delta(n+1)}{2(\beta\gamma-\alpha\delta)}\right)^2 + \frac{\alpha\delta \,.\, n}{\beta\gamma-\alpha\delta}\right\}} \quad . \; . \; . \quad (3\text{A})$$

The sign of the radical is always the same as that of $\beta\gamma-\alpha\delta$.

If it should happen that $\beta\gamma=\alpha\delta$ the above solution fails, but, returning to (2), we see that in this case—

$$x = \frac{n-qp}{q+p+n+1} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3\text{B})$$

so x is always unambiguously known.

Differentiating equation (2), we get—

$$dx = \frac{\dfrac{dn}{n-x}+\dfrac{d(\alpha\delta)}{\alpha\delta}-\dfrac{d(\beta\gamma)}{\beta\gamma}-\dfrac{dq}{q+x}-\dfrac{dp}{p+x}}{\dfrac{1}{q+x}+\dfrac{1}{p+x}+\dfrac{1}{1-x}+\dfrac{1}{n-x}} \quad . \; . \; . \; . \; . \; . \; . \quad (4)$$

If, now, α, β, γ, δ, are the coefficients of activity of four bodies, A B, A D, C B, C D, and if the product, $\alpha\delta$, for two conjugate bodies is much greater than that, $\beta\gamma$, for the two opposite bodies, one finds realised a case of very great importance—namely, the equilibrium of four bodies, acid, base, salt, and water. According to equation (2), if the original quantities mixed, of acid, base, and water, are 1, n, and p equivalents, there are formed x equivalents of salt and of water, where—

$$(p+x)x = \frac{\alpha\delta}{\beta\gamma}(1-x)(n-x). \quad . \; . \; . \; . \; . \; . \; . \; . \quad (5)$$

For strong acids and bases $a\delta/\beta\gamma$ is a number of several millions, while x is necessarily always less than 1 and n: hence to satisfy the equation it is necessary that $(1-x)(n-x)$ shall be very small (unless p is enormous); that is to say, x must be almost equal to 1 (if n is greater than 1), or to n (if n is less than 1).

> (24) *If one mixes a strong acid with a strong base, they unite for the most part to a salt, in such a way that there is formed a quantity of salt always a little less than that of the hydrate of which one has added the smallest equivalent portion.*

[This is rather an anticlimax.]

The clearest way to see this is to work some numerical examples. We have therefore made calculations on mixtures of a strong base (caustic soda) with a strong acid (nitric acid) on the one hand, and of a weak base (ammonia) with a feeble acid (boracic acid, supposed monobasic) on the other. The figures employed are taken from a previous section,[1] with the supposition that the molecular conductivity of ammonic borate is equal to that of ammonic carbonate (an hypothesis which ought to be approximately correct). We have thus calculated that if one mixes 1 equivalent of acid with n equivalents of base in 100 equivalents of water, the amount of salt formed (x) is given in the table below for several values of n.

1 *Nitric Acid and* n *Caustic Soda.*

n	x
$\frac{1}{2}$	·4999981
1	·998659
2	·999998

1 *Boracic Acid and* n *Ammonia.*

n	x
$\frac{1}{2}$	·245
1	·404
2	·634
3	·741

[The molecular conductivities used in this calculation are probably—

For HNO_3 . . $a = 3 \times 10^{-5}$
For NaHO . . $\delta = 1{\cdot}5 \times 10^{-5}$
For $NaNO_3$ . . $\beta = 6 \times 10^{-6}$
For H_2O . . . $\gamma = 10^{-12}$

For boracic acid . $a = 4{\cdot}4 \times 10^{-9}$
For ammonia . $\delta = 8{\cdot}4 \times 10^{-8}$
For ammonic borate $\beta = 4 \times 10^{-6}$
For water . . $\gamma = 10^{-12}$

so that $\frac{a\delta}{\beta\gamma}$ in the first case equals 10 , and in the second case equals 100, or thereabouts.]

What we have just said applies specially to the formation of salts of strong acid and base when the quantity of water is very considerable. From the above example (the formation of $NaNO_3$), as well as from proposition 24, we proceed to deduce the following observation, true for salts of strong acid and bases:—

> (25) *The quantity of salt formed when one adds a strong base to a strong acid is sensibly proportional to the quantity of base added, until the acid is saturated, after which the formation of salt sensibly ceases.*

An entirely different aspect is presented by the figures calculated for the formation of a salt from feeble constituents, such as borate of ammonium. In this case $a\delta/\beta\gamma$ is not excessively great, so that for considerable quantities of water (p) it is not necessary for either $1-x$ or $n-x$ to nearly vanish. That is to say, although the acid is in excess, the free portion of base is nevertheless sensible, and *vice versâ*. In this case we may apply equation (4), regarding all quantities contained in it except x and n as constant, and q (the original amount of salt) as zero. We thus find that—

$$\frac{dn}{dx} = 1 + (n-x)\left(\frac{1}{1-x} + \frac{1}{p+x} + \frac{1}{x}\right)$$

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[1] [§ 5, *i.e.*, from Kohlrausch's tables of molecular conductivity, as then published.]

[which may be written more symmetrically, though less usefully for present purposes—

$$\frac{dn}{dx} = \frac{n}{x} - \frac{n-1}{x-1} + \frac{n+p}{x+p}\Bigg].—$$

Differentiating again, we get[1]—

$$\frac{d^2n}{dx^2} = \frac{2(p+1)(n-x)}{x(p+x)(1-x)^2},$$

which is always positive, since x cannot be greater than n. This we can render into words thus:—

> (26) *If one adds a feeble base to a feeble acid, or* vice versâ, *there is necessary for the formation of a given quantity of salt* (dx) *a quantity of base* (dn) *so much the greater as the formation of salt has proceeded further.*

Moreover, equation (4) shows that if n is greater than 1, the denominator is not very great, because $1-x$ differs sensibly from zero; so $\frac{dx}{dn}$ will have a sensible positive value even for $n>1$, which means—

> (27) *If one adds a feeble base to a feeble acid, or* vice versâ, *the formation of salt continues sensibly, even after the number of equivalents of the body added has surpassed that of the other body.*

The figures calculated for boracic acid and ammonia exhibit this property clearly. Between the two examples cited are a crowd of transitions which are realised by mixing a strong acid with a feeble base, or *vice versâ*. Everything depends on the magnitude of the factor $a\delta/\beta\gamma$, and on p, the amount of water present. The laws deduced above have been long known by chemists. They are fundamental, and occur in most reactions—that is to say, in all reactions of electrolytes.

If in equation (5) the factor $a\delta/\beta\gamma$ is a small number, as is probably the case for alcoholates,[2] the quantity of salt formed is almost zero. So if one mixes alcohol with any base, it only forms a very little alcoholate. But, according to law (23), final equilibrium only depends on relative quantities of the ions present, so if one adds water to an alcoholate it is destroyed, and turns into alcohol and hydrates. Here the rôles are changed; water is an acid stronger than alcohol, so it is necessary that water shall displace most of the alcohol, as nitric acid displaces water from a hydrate, and this is in full agreement with fact. What is common to every case is the necessity of regarding water as an acid (or, if one likes it better, as a base), which concurs with other acids (or bases) in the equilibria.

As, according to equation (4), $\frac{dx}{dq}$ is always negative, one perceives that the presence of salt (q) has always an opposing influence on its formation, just as water has. However, the quantity of salt present in the reactions is generally small enough for this influence not to be noticeable.

§ 7. Important case of double decomposition.

From the simplified formula indicated above by an 'A,' one can at once deduce some important propositions. From (2A), viz.—

$$a\delta(1-x)(n-x) = x^2\beta\gamma$$

one finds, by a discussion like that preceding prop. 24, that if one mixes two bodies AB and CD, the bodies AD and CB will also form; and that the more as $a\delta/\beta\gamma$ is greater.

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[1] [Dr. Arrhenius's mathematical expressions are sometimes unnecessarily long, so I rearrange them whenever convenient without compunction.]

[2] According to all authors, alcohol is a conductor very inferior to water. On the other hand, the conductivity of an alcoholate is comparable to that of a hydrate. (See my work on the conductivity of alcoholic solutions.) [Author's note.]

According to (4A) [that is, (4) with $p = 0, q = 0$], $\frac{dx}{dn}$ is always positive, so—

(28) *The more one adds a body to a system in equilibrium, the more will the opposite bodies be formed.*

Then if the body is water, and one adds it to a salt, one has immediately the following consequence:—

(29) *Every salt dissolved in water partially splits up into acid and base. The quantity of these products of decomposition is so much the more considerable as acid and base are feebler and quantity of water greater.*

Let α and δ be the coefficients of activity of salt and water, β and γ the same for acid and base; then in the majority of cases $\alpha\delta$ is enormously smaller than $\beta\gamma$; consequently for small values of n[1] (in the case of strong acids and strong bases n can without inconvenience rise as high as 10,000) we can neglect the term $\alpha\delta\,(n+1)/(\beta\gamma-\alpha\delta)$ in comparison with the radical, and so—

$$x \bumpeq \sqrt{\frac{\alpha\,\delta\,n}{\beta\gamma-\alpha\delta}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

If, on the contrary, n is excessively great, one gets—

$$x \bumpeq 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

These two formulæ indicate that—

(30) *The amount of salt decomposed by moderate dilution is approximately proportional to the square root of the quantity of water used to dissolve it.*

(31) *A salt is completely split up if the water used to dissolve it is infinite.*

What is here said about water is evidently applicable to every other dissolving electrolyte.

On this subject (the decomposition of salts by water) one reads in the work of M. Berthelot (p. 199), 'The process of decomposition by water of the salts of feeble acids is not always the same. Sometimes it increases little by little, either indefinitely with each addition of water, or tending towards a certain limit. . . . . Sometimes, on the contrary, the decomposition of a neutral salt is accomplished almost wholly by the first dose of water.'

Thus, 1st. The salts of strong acids with strong bases are not decomposed. According to prop. 30 they ought to be. At the same time the example of the previous section shows that the salt $NaNO_3$ is only decomposed ·13 per cent. by 100 equivalents of water. Such quantities cannot be observed by any thermic means (at least, not by any that M. Berthelot employed). This is the reason for supposing that these salts are not decomposed at all. . . . On the other hand, the salts of strong acids with feeble bases are notably decomposed by water. Ammoniacal salts behave in this manner. In M. Berthelot's work there are a crowd of examples.

2nd. Salts of feeble acids are notably decomposed. For example, ammonic borate is decomposed 59·6 per cent. by 100 equivalents of water. Such quantities are well marked by thermal actions. Nevertheless, from what we have just said, the decomposition ought to be illimitable. The reason why M. Berthelot has in certain cases only found a limited decomposition is probably because his thermal experiments did not permit the employment of more than 1,000 equivalents of water, and because the decomposition is at first proportional to the square root of the quantity of water added (later still less); whence the first dose of water has an effect equal to that of the three following doses, &c.

3rd. As for salts which are almost wholly decomposed by the first addition of water, they are those for which $\beta\gamma$ is less than $\alpha\delta$ (alcoholates, for example).

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[1] n means the number of equivalents of added substance—for instance, water—for each equivalent of original substance—*e.g.*, salt.

§ 8. Systems more complex.

Concerning these salts we have already said enough. [Then follows a physiological application of law 29, and a reply to some feeble objections to the Williamson-Clausius hypothesis.]

In general the case in which four electrolytes alone establish a chemical equilibrium is rather rare. The most frequent case is that of six or nine electrolytes acting on one another. However, it is not difficult to establish general equations for a system of $n\nu$ electrolytes, composed of ν cations and n anions. Let them be the following:—

$$I_1 J_1, I_1 J_2 \; . \; . \; . \; . \; I_1 J_n ; \; I_2 J_1, I_2 J_2 \; . \; . \; . \; . \; . \; . \; I_2 J_n ; \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; ; \; I_n J_1 \; . \; . \; . \; . \; I_n J_n ;$$

with the respective coefficients of activity—

$$a_{11} \; a_{12} \; . \; . \; . \; a_{1n} ; \; a_{21} \; . \; . \; . \; . \; a_{2n} ; \; . \; . \; . \; . \; ; \; a_{\nu 1} \; . \; . \; a_{\nu n} .$$

Moreover, let the original number of equivalents in the solution be similarly—

$$m_{11} \; . \; . \; . \; m_{1n} ; \; . \; . \; . \; ; \; m^{\nu 1} \; . \; . \; . \; m_{\iota n} ,$$

and the extra number formed at the end of the process—

$$x_{11} \; . \; . \; . \; . \; x_{1n} ; \; . \; . \; . \; ; \; x_{\nu 1} \; . \; . \; . \; x_{\iota n} .$$

Further, let us call the quantity—

$$a_{ij} \, (m_{ij} + x_{ij}) = r_{ij}$$

the *active mass* of the electrolyte $I_i \, J_j$.

Then, in the same manner as in § 6 above, we find a set of equations analogous to (1) and (2), and they take this form:

$$r_{ij} \, . \sum_{i=1}^{i=\nu} \sum_{j=1}^{j=n} r_{ij} = \sum_{i=1}^{i=\nu} r_{ij} \, . \sum_{j=1}^{j=n} r_{ij} .$$

These equations may be written—

$$\frac{(r)}{\Sigma_{(j)}(r)} = \frac{\Sigma_{(i)}(r)}{\Sigma_{(i)}\Sigma_{(j)}(r)} = \text{constant as regards } i ;$$

that is,

$$\frac{r}{\Sigma r_{1j}} = \frac{r_{2j}}{\Sigma r_{2j}} = \; . \; . \; . = \frac{r_j}{\Sigma r_{\nu j}} ,$$

which we may split up into—

$$\frac{r_{1j}}{r_{2j}} = \frac{\Sigma r_{1j}}{\Sigma r_{2j}} = \text{const.} ; \; \frac{r_{2j}}{r_{3j}} = \text{const.} ; \; . \; . \; . \; ; \; \frac{r_{(\nu-1)j}}{r_{\nu j}} = \text{const.}$$

And so finally we write down—

$$\left.\begin{array}{l}
\dfrac{r_{11}}{r_{21}} = \dfrac{r_{12}}{r_{22}} = \dfrac{r_{13}}{r_{23}} = \; . \; . \; . \; \dfrac{r_{1n}}{r_{2n}} \\[2ex]
\dfrac{r_{21}}{r_{31}} = \dfrac{r_{22}}{r_{32}} = \dfrac{r_{23}}{r_{33}} = \; . \; . \; . \; \dfrac{r_{2n}}{r_{3n}} \\[2ex]
. \quad . \quad . \quad . \quad . \quad . \quad . \\
. \quad . \quad . \quad . \quad . \quad . \quad . \\[1ex]
\dfrac{r_{(\nu-1)1}}{r_{\nu 1}} = \dfrac{r_{(\nu-1)2}}{r_{\nu 2}} = \; . \; . \; . \; \dfrac{r_{(\nu-1)n}}{r_{\nu n}}
\end{array}\right\} \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (A)$$

which are $(n-1)$ $(\nu-1)$ independent equations.

But there are $n\nu$ unknown quantities (x_{ij}) to be determined. So it is necessary to have $n+\nu-1$ fresh equations. These are not difficult to get. We notice that the quantity present of each ion, I_i or J_j, is not altered by the reactions; hence it follows that—

$$\Sigma_{(i)} x_{ij} = 0, \text{ and } \Sigma_{(j)} x_{ij} = 0.$$

These are $n+\nu$ fresh equations, one more than is required, but one of them is not independent.

Thus we have all the equations necessary for the solution of the problem.

The general equation of the system (A) is—

$$\frac{r_{ij}}{r_{i'j}} = \frac{r_{ij'}}{r_{i'j'}},$$

or—

$$r_{ij}\, r_{i'j'} = r_{i'j}\, r_{ij'}.$$

This equation contains the following proposition:—

(32) *When equilibrium is established among any number of electrolytes, the product of the active masses of two conjugate electrolytes is equal to the product of the active masses of their two opposites, just as if no other electrolytes were present.*

This extremely simple proposition contains the solution of the general problem —if one mixes a number of electrolytes together in any proportion, what reactions will occur? By a discussion similar to that preceding prop. 24, one recognises easily that—

(33) *Bodies possessing the smallest coefficients of activity are most likely to be formed at the expense of opposite bodies.*

§ 9. Applications of the foregoing paragraph.

In practice the case which most often presents itself is that of two electrolytes, whose four ions are different, put to react on each other in a slightly active solvent (most commonly water). We will consider some important special cases.

CASE 1. The two electrolytes are a very active acid, and the salt of a less active acid. Let the initial quantities be n and 1. If no water were present, the equation of equilibrium would be—

$$(n-x)\,(1-x)\,a\delta = x^2\,\beta\gamma \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad 2\text{A}$$

But, by reason of the presence of water, the salts, of which the quantities will be $1-x$ and x, get into equilibrium with the water and their respective acids and bases. So minute quantities are decomposed by the water, and the quantities $1-x$ and x will be a little diminished—especially $1-x$, the salt of the less active acid. Let us write these so reduced quantities—

$$\frac{1-x}{\chi} \text{ and } \frac{x}{\psi}.$$

Similarly the quantity of reacting acids $n-x$ and x will be a little increased, especially the latter. Call the actual quantities—

$$\lambda\,(n-x) \text{ and } \rho x.$$

Calculation indicates that the greatest of the quantities χ and ψ, λ and ρ, does not differ appreciably from 1 unless $a\delta$ is excessively great in comparison with $\beta\gamma$. So, writing $\psi\lambda/\rho\chi = \tau$, we have proved that $\tau \overset{\frown}{=} 1$ if $\beta\gamma$ is comparable to $a\delta$. If, on the other hand, $a\delta/\beta\gamma$ is very big, τ will differ from unity, but still $\tau \cdot a\delta/\beta\gamma$ will be enormously great, and hence in the equation—

$$(n-x)\,(1-x)\frac{a\delta}{\beta\gamma}\,\tau = x^2$$

it is still necessary to suppose x almost equal to n or to 1, whichever is least. The rôle of the water consists in delaying the process a little, and can, from a broad point of view, be neglected. The same can be said of any other solvent of very small 'active mass.' We are, then, in a position to assert the following proposition :—

> (34) *More active acids displace less active acids from solution of their salts.*

This is the proposition which, valid for bases also, is found in § 5 to agree so well with reality.

[To avoid the appearance of verbal obviousness in this statement, we can remember that by 'more active' the author means 'having a higher molecular conductivity.']

CASE 2. Both electrolytes are salts very little decomposable by water. In this case the water may of course be neglected, and $\alpha\beta$ nearly equals $\beta\gamma$; so from equation (2A) one perceives that x has a magnitude comparable to $n-x$ or $1-x$. Thus a sensible partition of the bases among the acids will be effected.

> (35) *If two salts, of which the four ions are different, are dissolved in water (or any other solvent), the two other salts possible will form to such degree that their amounts will be comparable to the amounts of the primitive salts, when the four salts are not notably decomposed by the solvent.*

This proposition, very often verified, expresses a general opinion accepted by chemists. (*See* Berthelot.)

CASE 3. If, on the other hand, one of the four possible salts—say that with the coefficient β—is to a high degree decomposable by the solvent (which is the case if it be composed of a feeble acid and a feeble base), but none of the others, an equilibrium will establish itself between this salt, its acid, its base, and the solvent, in such a way that only a certain fraction, $\frac{x}{\rho}$, remains as a salt in the system, of the quantity which would be found if the salt were not decomposed. (2A) takes the form—

$$(n-x)(1-x)\,\alpha\delta = \frac{x^2}{\rho}\beta\gamma.$$

So x will increase with ρ, that is to say—

> (36) *In solutions of two salts, of which one is composed of strong acid and feeble base, the other of feeble acid and strong base, the strong acid unites by preference with the strong base, leaving the feeble base to the feeble acid. This latter salt is naturally in great part decomposed by the solvent.*

This proposition has been experimentally proved by M. Berthelot (p. 712).

CASE 4. If two feeble acids have the same base, M. Berthelot believes he has proved that a sensible partition is effected. According to what has just been said, this ought to be a special case of 1, so that if the acids are almost equally strong a partition occurs; if, on the other hand, one of them is much the stronger, it seizes on a portion of base incomparably the larger. The work of M. Berthelot gives examples of both cases. Thus a partition occurs between hydrocyanic and boracic acids; while the phenol of the phenate of potassium is displaced by boracic acid.

§ 10. Influence of acid salts.

Salts called 'acid' are in general completely decomposed by water in sufficient quantity. According to M. Hittorf, acid phosphates are exceptions. Nevertheless, we have proved that NaH_2PO_4 is partly decomposed by great dilution (see Part I. § 19).

The ions of acid salts are on the one hand a metal, and on the other the rest of the molecule. If, then, one mixes sulphuric acid with, say, sulphate of soda, a portion of $NaHSO_4$ is formed. But $NaHSO_4$ behaves as any other salt, *i.e.*, its H is not an ion. So that the part of H_2SO_4 contained in $NaHSO_4$ has no effect, *i.e.*, is totally inactive. Thus equilibrating systems are set up which do not agree with calculations based upon the coefficient of activity of H_2SO_4 above given. And an equivalent of an acid-salt-forming acid (such as sulphuric, oxalic, &c.) cannot completely displace an equivalent of a more feeble acid from its salt, as prop. 33 asserts. [References to Berthelot.]

The calculation of the relative quantities of electrolytes contained in a system where acid salts occur goes on in the manner indicated above. Only it is necessary to observe that if the acid is τ-basic, and if an acid salt is found in which σ hydrogen atoms of the acid are replaced by a metal radical, it loses, for each equivalent of acid salt formed, τ/σ equivalents of acid. So equation (2) becomes—

$$(1-x)\left(n-\frac{\tau x}{\sigma}\right)a\delta = (q+x)\,(p+x)\,\beta\gamma,$$

where n is the number of equivalents of acid added since the commencement, and $1, p, q$ are the corresponding quantities for base, water, and salt.

If several salts (acid and neutral) form simultaneously, the calculation will be more complicated, as is seen most clearly by an example. Suppose one has at the beginning $n\,.\,H_2SO_4$ and $1\,.\,KCl$; let there be formed $x\,.\,K_2SO_4$, $y\,.\,KHSO_4$, and some HCl; the equation (2A) will take the form—

$$(1-x-y)\,(n-x-2y)\,a\delta = (x\beta+y\beta')\,(x+y)\gamma,$$

where $a, \beta, \beta', \gamma, \delta$ are the coefficients of activity of KCl, $\frac{1}{2}K_2SO_4$, $KHSO_4$, HCl, and $\frac{1}{2}H_2SO_4$ respectively.

Between x and y there is a relation which is also a function of the quantities present in the equilibrium of free acids, neutral salt, and solvent, a relation of which the form still remains to be determined by experimental methods.

§ 11. Equilibrium of heterogeneous systems.

[By 'heterogeneous,' Arrhenius means systems out of which one constituent is separated from solution in either the solid or gaseous form, and so removed from action to whatever extent it is insoluble. He quotes from Berthelot and Williamson about the formation of precipitates by double decomposition, and the continual postponement of equilibrium by the dropping out of one constituent.

He then considers a system of four bodies, I_1J_1, I_1J_2, I_2J_1, I_2J_2, of which one (say the last) is but slightly soluble. A constant quantity, c, of this remains in solution, however much of it is formed or destroyed (time being allowed for precipitate to re-dissolve *ad lib.*).

Then, a, β, γ, δ being the respective coefficients of activity, and x the amount of I_1J_2, and of I_2J_1, formed from an original one equivalent of I_1J_1 and any amount of I_2J_2, the equation (2A) is—

$$a(1-x)\,c\delta = x^2\beta\gamma.$$

So x has a magnitude depending on c, and if c happen to be zero, x vanishes.]

We have thus given an analytic proof of the law of Berthelot,

> (37) *If of four bodies,* (1,1), (1,2), (2,1), (2,2), *one of them* (2,2) *has such physical properties that it separates wholly or nearly so from the system, this body* (2,2) *and its conjugate* (1,1) *are formed, to the exclusion more or less entire of the opposite bodies,* (1,2) *and* (2,1).

If *more* than one substance is insoluble the equation may be, either

$$x^2\beta\gamma = cc'a\delta,$$

or

$$c'x\beta\gamma = c(1-x)a\delta.$$

§ 12. Consequence of the variation of the activity-coefficient in homogeneous systems.

[Since provisionally Arrhenius supposed the coefficient of activity to be identical with molecular conductivity, he goes on to consider the effect of its varying with pressure and temperature as conductivity does. Pressure-variation he considers nil, or unknown. Temperature-variation he considers linear, $1+bt$. So he writes (2A)—

$$(1-x)\,\alpha\,(1+b_1t)\,(n-x)\,\delta\,(1+b_4t) = x^2\beta\,(1+b_2t)\,\gamma\,(1+b_3t),$$

but then says that the b are about equal for all salts and for all bases, and fairly equal for all monobasic acids; so the temperature terms cancel each other in pairs nearly; and he states the laws.]

(38) *The equilibrium of a homogeneous system is independent of pressure.*

(39) *The relative quantities of four bodies, like two acids*[1] *and two salts, or two bases and two salts, or four salts, in a system in equilibrium, only vary very slightly with temperature.*

The first is in accord with Bunsen and Berthelot; the second with Ostwald, who has verified it between 20° and 100° for HCl, HNO, and two salts of these acids with a single base. He has further shown that these two acids have the same activity between these temperatures by letting them act on calcic oxalate.[2]

M. Ostwald has also determined the relative coefficients of affinity of different acids with regard to the same base.

He let two acids act simultaneously on a given base—as, for example, KHO, MgO, &c. The acids employed were HCl, HNO_3, and H_2SO_4. The term 'relative coefficient of affinity' expresses the ratio between the fractions of the base which the two acids seize. If one mixes KNO_3 with HCl, one equivalent of each, there will be formed x equivalent of KCl and x of HNO_3, and there will remain $(1-x)$ equivalents of KNO_3 and of HCl. The coefficients of activity being β, γ, α, δ, respectively, x is given by the equation—

$$(1-x)^2\alpha\delta = x^2\beta\gamma,$$

and so the relative coefficient of affinity of HCl : HNO_3 is—

$$Q = \frac{x}{1-x} = \sqrt{\left(\frac{\alpha\,\delta}{\beta\,\gamma}\right)}.$$

If instead of potassium one uses sodium, γ and δ remain, but α and β change. Q, however, need not change unless α'/β' is different from α/β.

(If acid salts are formed, a modification is necessary.)

Molecular conductivities given above (§ 5) make one suspect that changing a base from KHO to ZnO or MgO will diminish the value of Q for $HNO_3 : H_2SO_4$ and for HCl : H_2SO_4.

For the rest: because the activity-coefficients of HNO_3 and HCl are about equal, and the same for salts formed from these acids, their relative coefficient of affinity ought to be nearly 1, whatever the base on which they are allowed to act.

Here are Ostwald's numbers:—

Table of Relative Affinities.

Base	$2HNO_3 : H_2SO_4$	$2HCl : H_2SO_4$	$HCl : HNO_3$
K	2·00	1·94	·97
Na	2·00	1·92	·96
NH_4	1·88	1·81	·96
Mg	1·76	1·74	·99
Zn	1·61	1·53	·95
Cu	1·44	1·40	·97

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[1] Except H_2SO_4 and H_3PO_4.

[2] Ostwald, *Journal für praktische Chemie* (1877), T. 16, p. 385.

In a word, we believe experiment has verified the following rule deduced from the present theory :—

(40) *If an acid HR acts on a salt MR′, and if* α *and* β *are the activity-coefficients of the salts MR′ and MR, the coefficients of relative affinity between the acids HR and HR′ vary almost proportionally to the square root of the quotient* α/β.

In § 13 of the first part we remarked that the molecular conductivities of different salts approach each other, in such a way that they would seem for extreme attenuation to advance towards a common limit. It follows that the quotient α/β approaches more and more to unity, and that the different values of α/β become equal.

This is why *the relative affinity Q becomes more and more constant as dilution increases*—a relation Ostwald thinks he has already perceived with dilutions less extreme.

The activity-coefficients of acids and bases also approach equality as dilution increases.

(41) *Consequently the coefficients of relative affinity of acids approach more and more to unity as dilution increases.*

M. Ostwald has also on this subject made some measurements which confirm the justness of the above proposition. His researches on the magnitude of the coefficient of relative affinity of H_2SO_4 indicate that at extreme dilutions this coefficient is ‘almost equal to that of HNO_3, at least it rises to ·9’ (that of HNO_3 being 1), while at moderate dilutions it is ·5 or less.

To the invariability of Q for acids and bases M. Ostwald adds a fact of great importance. The molecular conductivities of feeble acids and bases increase rapidly with dilution, *i.e.*, the value of δ' in weak solution is much greater than that of δ in strong; so Q increases also, if we compare either of them with a strong acid or base, which is nearly unaffected by addition of water, for—

$$Q = \sqrt{\frac{\alpha\delta}{\beta\gamma}} \text{ for small dilution,}$$

$$Q' = \sqrt{\frac{\alpha\delta'}{\beta\gamma}} \text{ for large dilution.}$$

Hence—

(42) *The relative affinities of feeble acids and bases (compared with a strong acid or a strong base) increase considerably as dilution goes on increasing.*

This is the reason for not attributing to these ‘coefficients of relative affinity,’ or ‘*avidities*,’ as M. Thomsen calls them, a too great importance. By believing them constant one may seem to incline strongly towards regarding them as fundamental numbers. Besides, the determinations of them by different workers do not agree well with each other.

(43) *As the activity coefficients of different acids change a little unequally with temperature, the relative affinity of two acids ought also to vary with temperature.*

Thus the activity-coefficient of H_2SO_4 increases more slowly than that of monobasic acids (HCl or HNO_3), whence it evidently results that its affinity, relative to either of these acids, diminishes as the temperature rises. We can give only a rough calculation. The temperature-coefficient of conductivity for HCl or HNO_3 exceeds by 4 per cent. that of H_2SO_4 at 20° C.; so Q, which is proportional to square root of conductivity, will vary by about 2 per cent. per degree at this temperature.

The temperature-coefficient for H_2SO_4 is still less at higher temperatures, so its relative affinity ought to diminish faster at these temperatures. Experience agrees with this as well as one can expect.

M. Ostwald has found the following figures for the relative affinity of HCl to H_2SO_4:—

At 0° C. $Q = 1·90$
„ 20° C. $Q = 2·00$
At 40° C. $Q = 2·02$
„ 60° C. $Q = 2·37$

Between 0° and 40° Q varies about ·15 per cent. per degree, while rough calculation indicated ·2 per cent.; at higher temperatures the variation is greater, as expected.

On the other hand, for HCl : HNO_3, Q is almost constant, only varying from 1·00 to 1·02 between 0° and 60°.

A great part of the cited observations (those on H_2SO_4) have been explained by Ostwald as due to the formation of acid salts at moderate dilution. We do not wish to deny this as a *vera causa*. We have already, in § 10, shown that the coefficient of activity diminishes for this reason. So naturally Q diminishes too. Nevertheless, it is difficult to explain thus the variation of Q with temperature. It seems much more reasonable to admit the explanation given above.

Finally, we will consider what ought to happen to a salt solution if its temperature rise. For this it is necessary to observe that the temperature coefficient of a concentrated hydrate is much greater than that of a weak solution. Thus, according to M. Kohlrausch—[1]

For sulphuric acid,	at 99·4	per cent. concentration,	$b = \cdot0426$
”	” 7·73	” ”	$b = \cdot0121$
For phosphoric acid,	” 87·1	” ”	$b = \cdot0374$
”	” 4·92	” ”	$b = \cdot0099$
For tartaric acid,	” 49·53	” ”	$b = \cdot0263$
”	” 4·95	” ”	$b = \cdot0186$
For caustic potash,	” 41·7	” ”	$b = \cdot0282$
”	” 4·19	” ”	$b = \cdot0188$
For soda,	” 12·72	” ”	$b = \cdot0710$
”	” 2·61	” ”	$b = \cdot0195$
For ammonia,	” 16·15	” ”	$b = \cdot0303$
”	” 0·1	” ”	$b = \cdot0247$

As this rule is without known exception, it seems permissible to attribute to water, which is also a hydrate, a coefficient much surpassing the coefficients of dilute compounds (which latter coefficients are almost equal among themselves). Some figures of Ayrton and Perry (*Proc. Phys. Soc.*, II. 178 [1877]) tend to confirm this. Similarly, the coefficient of a salt solution is sensibly greater than that of a hydrate. Looking, then, at the equation of equilibrium of a saline solution—

$$(p+x)\,x\,a\,\delta\,(1+b_1t)\,(1+b_4t) = (1-x)^2\,\beta\,\gamma\,(1+b_2t)\,(1+b_3t),$$

we see that b_1 and b_4 are bigger than b_2 and b_3, and therefore that the value of $1-x$ obtained from it will increase with t. But $1-x$ signifies the amount of salt decomposed, so—

(44) *The quantity of salt decomposed in a solution is increased if the temperature of the solution rises.*

This will be true also for other electrolytic solvents, according to the law of Hittorf (see § 4). One may imagine that this important law can be otherwise deduced from the idea of a dissociation of salt molecules. True, physics show that at high temperatures the movements of molecules are more vigorous. But this does not point out why water then attacks salts more strongly. One often slurs over these difficulties by saying that heating (as well as dilution) brings to the solution a foreign energy opposed to chemical action. But what then is the import of chemical laws if they can be annulled by causes which never disappear completely, and of which one does not know how to calculate the effect?

The above law is so generally adopted, and verified by a crowd of cases so enormous, that it is not necessary to cite any of them.

§ 13. Consequences of the variation of the coefficient of activity and of solubility in heterogeneous systems.

The influence of the variation of the coefficient of activity is much greater for heterogeneous systems in equilibrium than for homogeneous ones. The equation (2A) has the form—

$$(1-x)\,a\,.\,c\,\delta = x^2\,\beta\,\gamma,$$

where c is the quantity dissolved of a slightly soluble or gaseous body, $(1-x)$ the

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[1] *Pogg. Ann.*, T. 159, p. 233; and *Wied. Ann.*, T. 6, p. 1 (1876 and 1879).

quantity of its conjugate body, and x the dissolved quantity of its opposite. The coefficients of activity are δ, a, β, and γ, respectively.

Let us first examine the influence of pressure.

If the body whose mass is c is a solid, one may reckon that pressure affects nothing, and so—

(45) *A system heterogeneous with regard to a solid is independent of pressure.*

This proposition is in full agreement with fact, according to the researches of M. Bunsen (Liebig's *Ann.*, T. 65, p. 81, 1848).

If, on the other hand, the c body is a gas, c will be approximately proportional to the pressure *of the gas in question* on the surface of the solvent. So if this pressure is zero, $x = 0$. This case is realised if one lets the gas escape from the solvent as fast as it is produced. If the pressure increases, c increases also. For this reason the opposite bodies (whose masses are $x\beta$ and $x\gamma$) will increase, and the conjugate bodies will diminish. Such a phenomenon has been observed in a lot of cases.

If, for instance, one of the opposite bodies is also a gas, as (for instance) when H_2S acts on an alkaline carbonate, one has the equation—

$$(1-x)\,a\,.\,c\,\delta = c'\beta\,.\,x\gamma.$$

By giving to the pressure of H_2S a sensible value, and by separating the carbonic acid which is liberated [*e.g.*, by means of a continuous stream of H_2S], one finally arrives at the result that c', and therefore also $1-x$, are zero, *i.e.*, that all the carbonate will be transformed into sulphide. *Vice versâ*, by leaving to c' a sensible value, and decreasing c, one could displace the H_2S of an alkaline sulphide by CO_2.

Nevertheless, in the majority of cases the mass of gas dissolved is small in comparison with other matter dissolved. In this case x, that is the quantity of opposite bodies formed, will be insignificant, so that the influence of the gas on the system is not notable. Thus, we cannot in general observe changes of equilibrium produced by the presence of gas, unless the dissolved quantity of the opposite body is very small. This case is realised if the body is either gaseous or but slightly soluble, and it has been considered. But in the second case, one *could* perceive the influence of the gas, for the products due to its presence would precipitate themselves and disappear from the system. The precipitations of metallic salts by H_2S is a well-known example.

An influence, analogous to this of pressure, is exerted by temperature if the body with regard to which the system is heterogeneous is solid. The solubility of solids increases with heating. So c and x increase, while $1-x$, the quantity of conjugate body, diminishes. This conclusion has been verified by numerous experiments. One finds many in the works of M. Ostwald, who has studied the phenomena accompanying the solution of some oxalates (CaC_2O_4 or ZnC_2O_4) by an acid. M. Ostwald expresses the said conclusion thus:—

(46) *The effect of a rise of temperature on the quantities dissolved by a given acid at constant dilution is always to increase them.*

Another way of increasing the dissolved quantity, c, of a slightly soluble body is to increase the volume of the solution (*i.e.*, to add solvent). In this case one increases β and γ also, as well as a. At the same time solubility can be diminished by diminution of concentration, as we shall soon see. But in most cases these disturbing influences cannot compensate the increase of c by augment of volume. So—

(47) *An increase of solvent increases the body opposite to, and diminishes the body conjugate to, the solid with regard to which the system is heterogeneous* (if the perturbing influences are not too great).—Ostwald, *J. für pract. Chemie* (1881), T. 23, p. 517, and T. 24, p. 486.

[The author then goes on to consider these 'perturbing causes.' He quotes examples where the solubility of one substance in water has been shown to be increased by the addition of some other salt. He explains this phenomenon on his theory, and holds that the theory of Guldberg and Waage is insufficient to account for it, and, moreover, that it is not in agreement with the numerical results of Ostwald.]

§ 14. Action between liquids and solids.

[The author claims even for solids a certain electrolytic conductivity, and hence a certain, though very small, coefficient of activity. It is thus necessary for completeness to consider the action between liquids and insoluble solids. But inasmuch as the activity of even a trace in solution is much greater, because spread all through a liquid, than the action of a limited area of surface can be, he says the latter may be safely neglected, and states the law]—

(48) *If a system is heterogeneous with respect to a solid body, of which, nevertheless, a very small part is dissolved in the surrounding liquid, one can neglect the reactions which occur at the surfaces of contact between liquid and solid.*

§ 15. Velocity of the reactions.

[In accordance with a previous section the velocity with which $I_1 J_1$ and $I_2 J_2$ are formed (or with which $I_1 J_2$ and $I_2 J_1$ are destroyed), *i.e.*, the velocity of the reaction, is—

$$K(q\beta \,.\, p\gamma - ma \,.\, n\delta).$$

The author applies this to etherifications, where the water, alcohol, and ether have insignificant coefficients, the acid being the only active body. In this case the velocity is proportional to $\beta\gamma$, and so simply to the activity of the acid used, being quicker with nitric than with acetic.]

§ 16. Calculation of numerical examples.

The coefficients of activity being not quite constant, according to the first part, slightly different numbers must be used for higher concentrations.

§ 17. Conservation of the type, and predisposing affinities.

[Remarks on reactions among non-electrolytes, and on the behaviour of K_4FeCy_6 with reference to Berthelot's hypotheses on 'conservation of type' and 'predisposing affinities.']

§ 18. Molten electrolytes

should behave just like others.

§ 19. Cases to which Berthollet's laws are not applicable.

M. Berthelot cites some of these cases. They can be put under two general heads. Either a feeble hydrate is unable to displace a stronger hydrate, although one of the products of displacement is but slightly soluble, or a volatile acid (HCl and HNO_3) partially displaces another acid (H_2SO_4), although this acid is not volatile.

The first case is represented by the formula—

$$(1-x)^2 a\delta = x^2\beta\gamma < c^2\beta\gamma,$$

where the feeble hydrate and the salt of the strong hydrate are present in equivalent quantities (originally 1), and where c is the soluble quantity of the slightly soluble substance. x is the quantity of this substance formed, but as x is less than c none is precipitated.

One may write the inequality, *à fortiori*,—

$$(1-c)^2 a\delta < c^2\beta\gamma,$$

or—

$$\frac{c}{1-c} > \sqrt{\frac{a\delta}{\beta\gamma}};$$

so if this inequality is satisfied there is no precipitate. a belongs to the feeble hydrate, β to the strong, δ to the salt of the latter, γ to the salt of the former (the slightly soluble substance). $a\delta/\beta\gamma$ is in general pretty small, so c may be very small and yet no precipitation occur.

As to the second case, no HCl escapes, and so the system is really homogeneous, and a straightforward partition occurs.

We believe we have proved that objections made to the theory of Berthollet are avoided by the theory here presented.

§ 20. Production of heat in chemical reactions.

As we know, M. Thomsen considers that all bases, if they exist in the form of dissolved hydrates, generate the same quantity of heat when dissolved in the same quantity of an acid. This he calls 'saline thermo-neutrality.' On the other hand, all acids do not generate the same heat when united to a given base—a circumstance which has appeared very odd to thermo-chemists. After what we have just said, however, it appears to me possible to explain it. It is evident that the thermo-chemical parity between two hydrates cannot obtain unless both are in the active state. In the inactive state analogous compounds do not play the rôle of hydrates (acids or bases), since they cannot unite to a hydrate of any other nature (of contrary sign) and form water and salt. So instead of supposing, as M. Thomsen does, that the hydrates are in a 'forme dissoute,' we suppose them to be in the active state. After that we put forth the following very natural hypothesis:—

The chemical process, by reason of which a system of one equivalent of acid (active) and one equivalent of base (also active), transforms itself into a new system, consisting of a salt (not complex) and water, is accompanied by the same heat-production independent of the nature of the acid or base.

The different processes which go on during the neutralisation of an acid or a base (both supposed partially inactive) are the following:—

1. Neutralisation of the active parts.
2. Transformation of inactive parts into active ones.
3. Neutralisation of these new active parts.
4. Formation of molecular complexes of the salt produced.
5. Possible solidification of the salt.

Between these five processes it is the sum of the heats produced in 1 and 3 per equivalent of salt formed which ought to be constant, according to the above hypothesis.

The existence of the processes 2, 4, and 5 explains how it happens that the actual heat-production can be different in different cases.

[Omitting 5, and considering 4 as small, the author points out that No. 2 process is of least importance for strong acids and bases, and accordingly that for these the heat-production may really be nearly constant. But for weak acids and bases a good deal of heat is consumed in the No. 2 process. For remember that 'strong' means, in his view, 'having a high percentage of active molecules,' and 'weak' means 'having very few active molecules.' Moreover, since a molecule's activity is allied with, or equivalent to, its dissociation, it is very natural that its production should be a heat-consuming process. Slight residual differences he explains by No. 4 process, considering sulphates and acetates as more complex than chlorides, nitrates, &c., and makes the following statement:—]

(51) *Increase of complexity is accompanied by production of heat.*

(52) *Transformation from the inactive to the active state is accompanied by absorption of heat.*

(53) *During neutralisation a feeble acid or base generates in general less heat on the whole than a strong one.*

Since now for salts it happens that the activity is smaller as the complexity is greater (see § 2), and the formation of molecular complexes is (by 50) followed by a generation of heat, it is necessary that for salts also the transformation from inactive to active state shall be accompanied by heat-absorption. But, by prop. 33, bodies endowed with the smallest activity have the greatest chance of being formed. Thus it follows that—

(54) *In chemical reactions among electrolytes those bodies are* in general *formed in greatest quantity, the formation of which is accompanied by the greatest heat-production.*

This is the 'principle of maximum work,' modified. It is valid *in general,* not always.

[Neglecting now the above process 4, the author points out that process 2 has two parts, one concerned with the acid only, the other with the base only. Call these 2_a and 2_b. Processes 1 and 3 he considers all along as giving a constant thermal effect; and so he splits up the total heat-production H, by all the processes, thus—

$$H - h_5 = (h_1 + h_3) + h_{2a} + h_{2b},$$

and states—]

(55) *The heat produced by the neutralisation of an acid A by a base B (less heat of possible solidification) is equal to a constant,* plus *a term depending on the nature of the acid only,* plus *another depending only on the nature of the base.*

This has been verified by the experiments of M. Thomsen. A table of the heats of formation of some salts from the results of Berthelot and Thomsen are given. It is on such numbers as these that the rule of Thomsen is founded.

Heats of formation of some salts in dilute solutions.

	HCl	HNO_3	Acetic	Formic	½Oxalic	½ H_2SO_4	½ H_2S	HCy	½ CO_2
$NaOH$	13·7	13·7	13·3	13·4	14·3	15·85	3·85	2·9	10·2
KOH	13·7	13·8	13·3	13·4	14·3	15·7	3·85	3·0	10·1
NH_3	12·45	12·5	12·0	11·9	12·7	14·5	3·1	1·3	5·3
½ $CaHo_2$	14·0	13·9	13·4	13·5	18·5	15·6	3·9	—	9·8
½ $BaHo_2$	13·85	13·9	13·4	13·5	16·7	18·4	—	—	11·1
½ $SrHo_2$	14·1	13·9	13·3	13·5	17·6	15·4	—	—	10·5

§ 21. Heat of activity.

This is the name given to the heat used in transforming a body from inactive to active state.

Now if an acid unites with a base, one can regard the process as the displacement of a feeble acid (water) from its salt (basic hydrate) by a stronger acid. Then, if every substance concerned were perfectly active, the heat of neutralisation of water ought to be the same as that of the strong acid, according to the hypothesis at the beginning of last section, and so no heat-production should result from the interchange. But if the water, as fast as formed, passes into an inactive state, its heat of activity will be set free. In fact, it is necessary to suppose that water immediately after its formation is perfectly active, for it is formed by the collision of two ions H and OH, endowed with movement. But this activity is instantly lost, and almost inactive ordinary water results. Thus we have shown that—

(56) *The heat of neutralisation, set free by the transformation of a perfectly active base, and perfectly active acid, into water and simple salt, is only the heat of activity of the water.*

One might call this *the thermoneutrality of perfectly active electrolytes.* It is intimately connected with the Williamson and Clausius hypothesis. For as it is reckoned, by this hypothesis, a fair chance whether an ion encounters a similar or a dissimilar one, no work can be done by mere interchanges of ions.

Inactivity of salts is founded on complexity, and to make them more active one must split up molecular complexes. Inactivity of hydrates is caused by more or less disaggregating the molecule into its ions. Either process consumes energy. Elevation of temperature partly effects the process and does the necessary work in liquids, though not in solids, for solids have no appreciable activity even when warm. So it is natural to expect that the specific heat of a substance in the liquid state should be decidedly greater than in the solid state, at least for electrolytes.

For elements and non-electrolytes one would expect the difference to be less marked.

Table of atomic heats in liquid and solid states, to confirm this:—

Atomic Heats.

	Solid	Liquid		Solid	Liquid
Bromine . . .	13·3	18·1	Tin	6·6	7·5
Iodine . . .	13·7	27·5	Bismuth . . .	6·4	7·5
Phosphorus . .	11·8	12·7	Water . . .	9·0	18·1
Sulphur . . .	12·8	15·0	KNO_3	24·2	33·5
Mercury . . .	6·4	6·7	$NaNO_3$ . . .	23·7	35·9
Gallium . . .	5·5	5·6	$CaCl_2$ . . .	37·6	60·1
Lead . . .	6·5	8·3	Phosphate of Soda .	14·7	26·7

(The iodine figure seems to need revising.)

Again, when a body melts, if an electrolyte, it becomes partly active, and more energy is thus required than if it were non-electrolytic; so we may expect the latent heat of fusion to be in general higher for electrolytes than for elements.

[Table of latent heats of fusion to show this follows, but the difference is not exceedingly well marked, and there are exceptions.]

Most chemists are inclined to imagine a force between different bodies called that of affinity.

On this view the heat produced by chemical processes is the transformation of a potential energy into heat energy. Berthollet, who adheres to such an opinion, was thus conducted to the necessary consequence that chemical compounds have not a constant composition—a result generally admitted to be erroneous (see § 23). Besides, there are other circumstances in favour of the contrary opinion, viz., that the heat produced by chemical processes is analogous to latent heat. Thus nobody can deny the complete analogy between dissociation (*e.g.*, of $CaCO_3$) and the vaporisation of a liquid; after the researches of Deville, Debray, Troost, Isambert, Ditte, Naumann, and other noted investigators.

But the above-given theory conducts of necessity to the latter opinion. So it is from this point of view also in agreement with experimental fact.

§ 22. Comparison between some found and calculated numbers.

M. Ostwald has drawn up a table of the values of the coefficients of relative affinity for different acids, taking that of HNO_3 as 1. The definition given by Ostwald of this coefficient coincides perfectly with that of 'avidity' given by Thomsen, who has likewise given a table. We reproduce below both these tables together. . . . Sulphuric and oxalic acids are liable to form double salts which complicate matters a little (§10), but at extreme dilution not much, so their numbers vary with concentration (see § 12).

The coefficients quoted are, for want of better, those applicable when no other body is present; but other bodies, if present, diminish them, just as concentration of the same body does. And feeble hydrates, being most affected by concentration, are probably most affected by foreign bodies. These feeble hydrates, therefore, may be expected to be really a little weaker than calculation shows.

The determination of avidity was made by permitting an equivalent of each to share an equivalent of base (usually NaOH) between them; the ratio of the fractions of the base seized by each acid is their relative avidity. Two numbers are calculated for H_2SO_4, one if it does not, the other if it does, form an acid salt. As for phosphoric acid, we have supposed that its acid salt has only one H replaced by a metal—a supposition which ought not to be pressed, seeing the great excess of free acid present in a reaction. The following are the only acids for which there are data enough to calculate from. The base supposed in the calculation is NaHO for HNO_3, HCl, HI, and HA; for the others, KHO.

The formula used is that of § 10—

$$(1-x)\,(1-\tau x)\,a\,\delta = x^2\,\beta\,\gamma,$$

where $\tau = 1$, except for H_2SO_4, when $\tau = 2$, and for H_3PO_4, when $\tau = 3$. The following table gives the results:—

Relative Avidity of Acids.

	Ostwald experimental	Thomsen experimental	Arrhenius calculation
HNO_3	100	100	100
HCl	98	100	92
HBr	—	89	86
HI	—	79	92
H_2SO_4	50 to 90	49	47·6 to 85
H_3PO_4	—	13	21·7
$C_2H_4O_2$	1·23	3	8·2

Ostwald specially says that his numbers involve considerable uncertainties, so the agreement is sufficient.

§ 23. Review of anterior theories.

Finally, the author reviews the theories of Berthollet, Berthelot, and Guldberg and Waage. He points out that many objections to views expressed in Berthollet's essay of 1803 are met and removed by his own theory. He regards these views as true, but as requiring amplification and additional statements which he supplies.

The theory of Berthelot is based on this principle—'Every chemical change, accomplished without the intervention of foreign energy, tends towards the production of that body or system of bodies which liberates most heat.' The 'energy of dissociation,' however (which it is necessary to postulate), deranges conclusions from this principle, especially at high temperatures. On this ground M. Lothar Meyer and M. Ostwald state that there are a great number of cases to which Berthelot's principle cannot be applied, and that it is of but small value in predicting results.

As to Guldberg and Waage, he says their theory develops itself slowly from 1864 to 1879 in three distinct stages. In the first two memoirs they postulate 'forces of action' acting between substances, and in the first they give the equation—

$$a\,(p-x)^a\,(p-x)^b = a_1(p_1+x)^{a'}(q_1+x)^{b'},$$

where the indices may be quite different; and they oppose the view of Berthollet that affinity is proportional to mass.

In their second memoir they put all the indices $= 1$, and so abandon this ground. But they still continue the hypothetical 'forces of action.' Arrhenius objects to these forces as uncalculable and unnecessary.

In their third memoir G. and W. introduce the idea of a portion only of each body taking part in the reaction, and think of the number of encounters between such active molecules, and so of the velocity of the reaction, much the same as Arrhenius does.

For heterogeneous systems G. and W. think the surface of the solid present exerts an influence; but A. says it cannot, or it would vary with the extent of surface, which it does not. In § 13 (p. 377), he says, is cited an experiment fatal to the theory of Guldberg and Waage, according to M. Ostwald, but not inexplicable by the new theory.

Résumé.

'In the present part of this work we have first shown the probability that electrolytes can assume two different forms, one active, the other inactive, such that the active part is always, under the same exterior circumstances (temperature and dilution), a certain fraction of the total quantity of the electrolyte. The active part conducts electricity, and is in reality the electrolyte; not so the inactive part. Moreover, we have proved that the necessary consequence of the hypothesis of

Clausius and Williamson is that there exist circular continuous currents. In these currents the active parts alone participate.

'The molecules participating in such currents are necessarily decomposed, according to the scheme of double decomposition, and the result is that new electrolytes are formed. On this basis we have built a chemical theory of electrolytes which, deduced from very probable sources, possesses also a high degree of probability. This theory leads to formulæ applicable to chemical processes, formulæ very conformable to those proposed by MM. Guldberg and Waage,[1] which have been verified by a great number of experiments. We have also pointed out that the results of this theory agree very accurately with the opinions of Berthollet.

'As a provisional hypothesis we have supposed the coefficient of activity equal to the molecular conductivity. The figures calculated on this supposition, and the reactions thus foreseen, agree very well with experimental facts. We have also from this theory deduced a number of electro-chemical laws, among others the laws of Faraday and Hittorf; as well as, by aid of the hypothesis that every electrolyte has a constant composition, we have proved the necessity for the existence of equivalent weights of every substance playing the part of an ion (law of Richter). From data on the variations of conductivity and of solubility we have indicated the reason of a number of phenomena which are set up in equilibrating systems, by dilution, by heating, and by addition of foreign bodies. Finally we have, by aid of an hypothesis very probable in the present state of thermo-chemistry, deduced the principal propositions of thermo-chemistry (among others the "principle of maximum work"); propositions which, however, by reason of the mode of their deduction, are not valid in every case, but only "in general." Also we have indicated the nature of chemical energy, as analogous to that of latent heat; an indication with which specific heats, latent heats, and the phenomena of dissociation, correspond.

'All these propositions, and all these laws, are taken from the most different departments of chemical science; but as the theory agrees so well with reality in these different points, it seems probable that it ought to do so also in intermediate regions. Moreover, we have tried to prove that the differences between this theory and that which, after the examination of M. Lothar Meyer, is now the most probable, relate to opinions of the authors of the said theory, which to a deeper examination show themselves unsustainable either from the theoretical or the experimental point of view. We have thus approached the theory of Berthollet more nearly than MM. Guldberg and Waage have done. And this circumstance speaks, we believe, in favour of the above-developed theory. But there are considerations of greater importance. The theory of Guldberg and Waage (still less any other theory) cannot in its present state deduce more than a fraction of the propositions and laws given above. The constants necessary for the prevision of reactions can, according to the new theory, be approximately deduced from other constants known in other branches of science. Some of the propositions given above, and agreeing with fact, are contrary to the views of MM. Guldberg and Waage. The difficulty inherent in every theory of electrolysis, and also in the hypothesis of Clausius and Williamson in its primitive form, is totally removed by the new theory. Since, moreover, the theory given above is built on a substantial foundation, and is totally free from every hypothesis of an affinity different from physical forces, it is not doubtful, we think, that it will be preferred to all chemical theories hitherto published.

'True, one might object that this theory is only applicable to electrolytes, while previous ones have embraced all substances.

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[1] The probability of the correctness of the theory is increased to a high degree by the fact that in deducing the formulæ given above we ignored completely those of MM. Guldberg and Waage, formulæ of whose existence we had no knowledge before obtaining the work of M. Lothar Meyer (which only happened after the greatest part of this memoir had already been written). Thus we have found these formulæ without any occasion to construct them in some preconceived manner, and guided solely by the theory of Clausius and Williamson, and by the notion of an active and an inactive state of electrolytes. [Author's note.]

'Against this we remark that chemical knowledge is mainly based on the reaction of electrolytes, which seem in chemistry to play the same rôle as gases do in the mechanical theory of heat. For the rest, the idea of an electrolyte has an application much wider (according to the law of Hittorf) than one is accustomed to attribute to it. And reactions in general seem to manifest a considerable analogy to those of electrolytes, so that one could perhaps in the future enlarge the theory given for electrolytes, until it becomes, with some modification, applicable to all substances.'

REMARKS ON THE ABOVE MEMOIR.

The criticism of the first part of Dr. Arrhenius' memoir given above being somewhat stringent, I thought it best to send a proof copy to the author in case he might wish to reply. He has favoured me with a letter touching on various points, and in order to assist in the elucidation of them it seems most satisfactory to print it here, numbering its paragraphs so as to make it easy to connect them with the parts of my criticism to which they refer (see pp. 357–364). It would seem that I have been misled by the form in which the paper is written, especially by the italicised and numbered statements with which it abounds, into criticising parts of it from rather too elevated a stand-point, as if the statements were intended for rigorous laws. O. L.

Translation of a letter received from Dr. Arrhenius respecting the above Criticism.

'DEAR SIR,—Yesterday evening I received your friendly postcard and a copy of your criticism on my work. For both I thank you, and at once proceed to give an answer thereto as the subject requires.

'1. To your remarks against my experimental method ("I must confess to surprise, &c. . . . self-induction and electro-chemical capacity being so mixed up in it") I wish to observe that self-induction in the galvanometer coil has no effect. Self-induction possibly occurs in the rheostat, as well as electrochemical capacity in the liquid. Quite the same sources of error, however, occur in Kohlrausch's method also, to the same or even a higher degree; and on consideration you will hardly deny this.[1] The alternating currents used by him have just about the same total intensity as mine, so polarisation is about the same in the two

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[1] This opens a large question, viz., how far it is advisable to depend on the use of alternating currents as a device for avoiding polarisation difficulties. At first sight it might seem as if the mere fact of alternation was a sufficient safeguard; but when the extreme rapidity of rise and decay of polarisation is remembered, confidence in alternating currents is much diminished. In his early experiments Kohlrausch used a sine inductor, and in his later researches carefully considered the effect of the disturbing elements (see Jubelband, *Pogg. Ann.*, page 290). With a simple harmonic current of small period it is possible for self-induction and polarisation capacity to neutralise each other's effect; and in any case it is comparatively easy to take them into account. The equation to the current is—

$$\mathrm{L}\frac{d\mathrm{C}}{dt} + \mathrm{RC} + p\int_0^t \mathrm{C}\,dt = \mathrm{E}\sin nt\,;$$

or

$$\mathrm{C} = \frac{\mathrm{E}\sin(nt-\phi)}{\sqrt{\left\{\mathrm{R}^2 + \left(n\mathrm{L} - \frac{p}{n}\right)^2\right\}}}.$$

where $\mathrm{R}\tan\phi = n\mathrm{L} - \frac{p}{n}$.

p is calculable from the following data: the decomposition products of $\frac{1}{70}$ milligramme of water on two platinum plates, each one metre square, give an E.M.F. of one Daniell; consequently, knowing L, p, E, and measuring C^2 with a dynamometer, it is possible to calculate the true value of R. Or, by arranging that the polarisation coefficient p is equal to $n^2\mathrm{L}$, all disturbance vanishes, and the resistance can be measured quite simply by a bridge method. Unless the question of electro-chemical capacity be thus considered, and either eliminated by calculation or proved to be negligible by experiment, the presumed advantage of alternating currents in dealing with electrolytic resistance is illusory. O. L.

cases; on the other hand, he had six times as many alternations of currents per second, so the self-induction of his rheostat must be greater than that of mine (§ 3). On quite other grounds, Kohlrausch's method is preferable. I may also say that Kohlrausch used a galvanometer for measuring higher resistances.

'2. Secondly, concerning your remark on subtracting the conductivity of the water in order to find that of the dissolved salt. This mode of calculation I use, not only because it corresponds with later established "laws," but also on true *à posteriori* grounds (which indeed the reader of your critique cannot guess; cf. Pt. I. § 9). It would, however, to my mind, be little logical not to show that the rule corresponds also with the general laws, according to my apprehension of them. So I cannot understand your objection to this paragraph. The law of divided circuit is, so far as I know, really true when two electrolytes are mixed. According to my hypothesis, the conductivity of a solution is equal to the sum of the number of ions, each divided by the friction it experiences against the fluid. This view leads necessarily to the law in question, and it is also a necessary consequence of the Williamson-Clausius hypothesis. I regret I cannot enter fully into this here. I have, moreover, applied this rule throughout my memoir on conductivity of mixed solution with, so far as I see, complete success. You say quite simply, "which is untrue." I wish you would tell me of any well-established fact against it. I am of opinion that there exists no basis for the opinion that the law of divided circuits does not apply to dilute solutions.[1]

'3. Thirdly, "that the conductivity of water itself remains unaffected by the presence of a foreign body; which is improbable."

'It appears as if you meant that the conductivity which Kohlrausch and I have proved to exist in our distilled water is really the conductivity of water. That my experiments contradict this is indubitable, and Kohlrausch also attributes it to traces of saline impurity. Reaction-velocities give a pretty safe judgment on this subject. I have thus pretty clearly shown that there are salts which cause the greatest part of this conductivity (Part I. § 11). The probable effect of the foreign body is to take much of the water from the said salts (cf. my memoir on conductivity of mixtures). The salts, however, change their molecular conductivity very little with great dilution; and so the apparent conductivity of water does remain very nearly unaffected by the presence of a foreign body in very dilute solution. I could say much more on this if time permitted.

'4. Fourth, "The first approximation to the relation between k and m is that made by Kohlrausch, viz., that the two are proportional. This is roughly true for very dilute salt-solutions."

'For example, copper acetate (see Part I. p. 40) has the following:—

$$m = \frac{1}{276}, \ \frac{1}{200}, \ \frac{1}{1254}, \ \frac{1}{6586};$$

$$\frac{k}{m} = 320, \ 512, \ 671, \ 740, \text{ times } 10^{-8}.$$

'Again, copper sulphate has, according to Kohlrausch (p. 196 of his last memoir), the following:—

$$m = \cdot 5 \quad \cdot 1 \quad \cdot 05 \quad \cdot 01 \quad \cdot 001 \quad \cdot 0001 \quad \cdot 00001;$$

$$\frac{k}{m} = 288 \quad 424 \quad 479 \quad 675 \quad 950 \quad 1062 \quad 1086.$$

'You can find still better examples among mercury salts!

'These numbers, according to Kohlrausch's formula, should be the same; so the correspondence between formula and fact seems to me not "roughly true," but altogether futile. (The dilution-exponent is in every case much more constant; though I build nothing upon the fact.)

'That for extremest dilutions, under $\frac{1}{10000}$, the molecular conductivity is fairly constant, although even then probably not for mercury salts, I also have shown; since in these cases the dilution exponent rises to 2.

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[1] See footnote on pp. 358, 359. If Dr. Arrhenius did not mean that the law was deductively proved by him (in § 15) for all cases, my criticism does not apply; except, indeed, to his mode of statement. O. L.

'I set myself the problem to find out how much the resistance actually increased when a dilute electrolyte had its volume doubled by addition of water. (If Kohlrausch's formula were true, it would be simply doubled.) Thus I started free from hypothesis. The observed ratio of increase of the resistance I called "the dilution-exponent." Since it changes very slowly with concentration, one need not ascertain it by making every dilution from 1 to 2, but can quite well obtain a mean value of it for a greater range (say 1 : 6·08); and the calculation of the mean number then proceeds on purely arithmetic grounds without any special hypothesis. I hold strongly, therefore, that my method of calculation is absolutely correct for mean values; and that I have always meant mean values is quite clear from page 34 *et seq.* The number is by no means a constant. I speak continually of its variation, and have tabulated the variations in Table B. I could not make its variability clearer than I have done. I have taken conductivity as the fundamental quantity instead of concentration, because one is always much safer in determining its absolute value by ordinary means. You think it would have been better to tabulate r instead of 2^r; this is a matter of taste. The dilution-exponent is easy to define physically; r is not. Besides, one can more easily form a mental image of its meaning. Not only Bouty, but Lenz also, and Ostwald, have discussed the change of resistance on doubling dilution.

'5. "Kohlrausch and most authors suppose that k/m is constant for extreme dilution." This he does without reservation for solutions of no extraordinary weakness, and he thence calculates k/m for extremest dilution, whereby he several times gets incorrect values (too small).[1] The hypothesis is, however, quite natural, and I have always regarded this idea of Kohlrausch as most valuable; and I sought consequently to apply this idea, and to show how to explain apparent exceptions to it. I never sought to "label" the statements (1), (2) and (3) as laws of nature, but say definitely: "The above conclusions are deduced from ideas which are in full accord with all known facts, and consequently they have the same degree of exactitude as those ideas accepted by all the world" (Part I. § 15). It is quite certain that the conductivity of water is very feeble, and there is no reason for denying that molecules may be independent of one another in very weak solutions, since they collide so seldom. I have sought to explain why in practice the molecular conductivity is not constant even in utterly weak solutions. I have given two explanations:—1st, that the water used contains traces of ammonium salts (especially Am_2CO_3, not dissolved glass as you write; a fact more lately proved by Ostwald), which explains the decrease of molecular conductivity of hydrates; and 2nd, that molecular complexes are formed; a hypothesis which is introduced into so many other subjects that one need feel no difficulty in employing it. (This view a reader of your exposition will hardly attain.)

'6. That the last work of Kohlrausch contains as you say incomparably better experimental data (especially more accurate) is true enough. But without my data I could not have formed a coherent picture of the whole. Besides, Kohlrausch's work has in no way caused me to alter any theoretical views, but has fully confirmed me in them.

'It is the highest problem of the natural philosopher to link together facts into a connected chain. I had expected a criticism from you to take this view. I concluded that you were of this opinion from your essay on the seat of voltaic E.M.F.; yet you abandon it in your criticism of the first part of my memoir.

'As to the second part, I am very glad that you have everywhere appreciated my views, and represented them in a more complete manner than I could have hoped. Just a few notes.

'7. With regard to your remark on (14), I may say, in explanation, that almost all chemists attribute the reactions of ammonia to a small portion of NH_4HO in it, which so soon as consumed is generated anew by equilibrium between $H_2O\,NH_3$ and NH_4HO, so that ammonia behaves chemically just as if it consisted of nothing but NH_4HO. In Thomsen's and Kohlrausch's experiments, on the other hand, the properties of the chief quantity, which consists of NH_3, play the greatest part.

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[1] These remarks refer to my 1879 essay.—F. K.

'8. To § 4 you say that the Williamson-Clausius hypothesis would have been soon abandoned if it had not corresponded with the fundamental laws of Faraday, Richter, &c. So far as I know, no one has hitherto raised the question; besides it is of very great importance to deduce various laws from a single point of view.

'9. As to law (20), which is still very discussable, I have had no opportunity of going off into digressions in the treatise, but refer to Hittorf and Bleekrode. I treat the whole question as open, and share also the view that the conductivity of these bodies has been proved to be mainly, though not exclusively, due to the presence of saline impurities. One is only able at present to decide matters like this on a chemical basis.

'With compliments, &c.,

'SVANTE ARRHENIUS.

'*Würzburg, November* 1886.'

Viscosity and Conductivity.

[*The following letter from* Dr. ARRHENIUS, *though of late date, so directly bears on subjects referred to by* Prof. Kohlrausch (p. 343) *that it is best inserted now.*

O. L.]

WÜRZBURG: *January* 4, 1887.

Some time ago I thought of publishing the numbers given below, which may have a certain amount of interest in elucidating the question as to the connection between conductivity and internal resistance. In discussing the question with Prof. Kohlrausch I have been confirmed in my hypothesis, and, in accordance as much with his desire as with my own, I send the following communication.

In the subjoined table the names of the solutions examined (all of normal strength) are set forth in the first column; in the second column the conductivity (λ) of these solutions (from Kohlrausch's last memoir); and in the third column the viscosities (ρ) determined by myself. The fluids I investigated are identical with the solutions employed by Kohlrausch in his conductivity determinations. The numbers for the internal friction are given for 17·6° C., reduced to the internal friction of distilled water at 17·6° as unit. I cannot here describe the method of investigation, but may refer to the paper which I have communicated to Wiedemann's 'Annalen.'. The errors of observation probably do not amount to 0·5 per cent.

—	λ (Kohlrausch)	(Arrhenius)	ρ (Kreichgauer)
KI	968 10^{-7}	·912	·93
KNO_3	752	·956	·97
$NH_4 Cl$	907	·977	·98
K Cl	919	·978	—
$Na NO_3$	617	1·051	1·06
Na Cl	695	1·093	1·08
$\frac{1}{2} K_2 SO_4$	672	1·101	1·09
$\frac{1}{2} Ba Cl_2$	658	1·107	1·11
$\frac{1}{2} K_2 CO_3$	660	1·142	1·15
Li Cl	591	1·147	1·15
$\frac{1}{2} Zu Cl_2$	514	1·189	1·18
$\frac{1}{2} Na_2 SO_4$	475	1·230	1·23
$KC_2 H_3 O_2$	594	(1·258)	—
$\frac{1}{2} Li_2 SO_4$	386	1·299	1·28
$\frac{1}{2} Zu SO_4$	249	1·362	1·35
$\frac{1}{2} Cu SO_4$	241	1·368	—
$\frac{1}{2} Mg SO_4$	270	1·379	1·37

The numbers entered in the fourth column are some further experiments by Kreichgauer, assistant to Prof. Kohlrausch; they may be in error to the extent of one or two per cent. The number for potassium acetate was not observed directly, but was calculated from that for a half normal solution on grounds which I cannot here set forth; it may be affected by a somewhat greater error than the other numbers, though not so great as to make the succession irregular or to account for the irregularity of the succession.

As may be seen from these numbers, there appears to exist a certain relation between the internal friction and the conductivity of normal solutions, so that to a great extent the higher the conductivity the smaller is the internal friction. A detailed carrying out of this law is, however, impossible, since marked exceptions occur. Of the seventeen salts examined five are exceptions, viz., KNO_3, $NaNO_3$, K_2CO_3, $KC_2H_3O_2$, and $MgSO_4$. The exceptional behaviour of NH_4Cl as compared with KCl may be only apparent. (It is not unlikely that when salts of lower conductivity are examined the exceptions may become more numerous and more strongly marked.)

In the hope that my note, though inconclusive, may add a little to the material for discussion of a difficult subject, I subscribe myself

Yours, &c.,
SVANTE ARRHENIUS.

Electrochemical Thermodynamics.

[*Since submitting proof sheets I have been favoured with the following most interesting letter from* Professor J. WILLARD GIBBS.—O. L.]

NEW HAVEN: *January* 8, 1887.

DEAR SIR,—Please accept my thanks for the proof copy of your Report on Electrolysis in its Physical and Chemical Bearings, which I received a few days ago with the invitation, as I understand it, to comment thereon.

I do not know that I have anything to say on the subjects more specifically discussed in this report, but I hope I shall not do violence to the spirit of your kind invitation or too much presume on your patience if I shall say a few words on that part of the general subject which you discussed with great clearness in your last report on pages 745, ff. (Aberdeen). To be more readily understood, I shall use your notation and terminology, and consider the most simple case possible.

Suppose that two radicles unite in a galvanic cell during the passage of a unit of electricity, and suppose that the same quantities of the radicles would give $\theta\epsilon$ units of heat in uniting directly, that is, without production of current; will the union of the radicles in the galvanic cell give $J\theta\epsilon$ units of electrical work? Certainly not, unless the radicles can produce the heat at an infinitely high temperature, which is not, so far as we know, the usual case. Suppose the highest temperature at which the heat can be produced is t'', so that at this temperature the union of the radicles with evolution of heat is a reversible process; and let t' be the temperature of the cell, both temperatures being measured on the absolute scale. Now $\theta\epsilon$ units of heat at the temperature t'' are equivalent to $\theta\epsilon\frac{t'}{t''}$ units of heat at the temperature t', together with $J\theta\epsilon\frac{t''-t'}{t''}$ units of mechanical or electrical work. (I use the term equivalent *strictly* to denote reciprocal convertibility, and not in the loose and often misleading sense in which we speak of heat and work as equivalent when there is only a one-sided convertibility.) Therefore the *rendement* of a perfect or reversible galvanic cell would be $J\theta\epsilon\ \frac{t''-t'}{t''}$ units of electical work, with $\theta\epsilon\ \frac{t'}{t''}$ units of (reversible) heat, for each unit of electricity which passes.

You will observe that we have thus solved a very different problem from that which finds its answer in the Joule-Helmholtz-Thomson equation with term for reversible heat. That equation gives a relation between the E. M. F. and the reversible heat and certain other quantities, so that if we set up the cell and measure the reversible heat, we may determine the E. M. F. without direct measurement, or *vice versâ*. But the considerations just adduced enable us to predict both the electro-motive force and the reversible heat without setting up the cell at all. Only in the case that the reversible heat is zero does this distinction vanish, and not then unless we have some way of knowing *à priori* that this is the case.

From this point of view it will appear, I think, that the production of reversible heat is by no means anything accidental, or superposed, or separable, but that it belongs to the very essence of the operation.

The thermochemical data on which such a prediction of E. M. F. and reversible heat is based must be something more than the heat of union of the radicles. They must give information on the more delicate question of the temperature at which that heat can be obtained. In the terminology of Clausius they must relate to entropy as well as to energy—a field of inquiry which has been far too much neglected.

Essentially the same view of the subject I have given in a form more general and more analytical, and, I fear, less easily intelligible, in the closing pages of a somewhat lengthy paper on the Equilibrium of Heterogeneous Substances ('Conn. Acad. Trans.,' Vol. III., 1878), of which I send you the Second Part, which contains the passage in question. My separate edition of the First Part has long been exhausted. The question whether the 'reversible heat' is a negligible quantity is discussed somewhat at length on pp. 510–519. On page 503 is shown the connection between the electromotive force of a cell and the difference in the value of (what I call) the *potential for one of the ions* at the electrodes. The definition of the *potential for a material substance*, in the sense in which I use the term, will be found on page 443 of the synopsis from the 'Am. Jour. Sci.,' vol. xvi., which I enclose. I cannot say that the term has been adopted by physicists. It has, however, received the unqualified commendation of Professor Maxwell (although not with reference to this particular application—See his lecture on the Equilibrium of Heterogeneous Substances, in the science conferences at South Kensington, 1876); and I do not see how we can do very well without the idea in certain kinds of investigations.

Hoping that the importance of the subject will excuse the length of this letter, I remain

Yours faithfully,
J. WILLARD GIBBS.

NOTE BY THE EDITOR.—It is perhaps hardly wise to comment on the letter of so great an authority without further consideration, but it naturally occurs to one to ask provisionally whether he is not regarding a galvanic cell as too simply a heat engine? Surely if the union of certain elements can generate $\theta\epsilon$ units of heat when heat-production is all that is allowed, they can, under favourable circumstances, do $J\theta\epsilon$ units of (say) electrical work instead, quite independently of any considerations of entropy or of the temperature at which the heat might have been generated? In other words, is Professor Gibbs not assuming that in a cell the union of elements primarily produces heat, and secondarily propels a current, instead of (as may well be the case) primarily generating a current, and secondarily producing heat when that current is given nothing better to do? To this Professor Gibbs will doubtless reply: No, the highest temperature at which the heat could reversibly be produced, viz., the temperature of complete dissociation of the compound formed, is of the essence of the question, whatever be the mode of exciting the current. It is needless to point out the extreme interest and importance of such a view. O. L.

On the Migration of Ions and an Experimental Determination of Absolute Ionic Velocity. *By* DR. OLIVER LODGE.

What may be considered as the greatest step in advance since the time of Faraday in the subject of electrolysis is due to Professor F. Kohlrausch. His idea of specific ionic velocity is obviously most important. The bases of it are his own experiments on conductivity, and those of Hittorf on 'migration' or unequal concentration.

Up to the present time the numbers given by Kohlrausch for the absolute velocity of different ions in centimetres per second have been deduced from theoretical grounds only, and the sole verification to which they have been subjected has been by showing that from them the observed conductivities and migration coefficients of a considerable number of solutions can be calculated (see, for instance, page 337 above). In a paper published last year[1] I indicated reasons for doubting the complete truth of the Kohlrausch theory as it stood, *i.e.*, for supposing it deficient in generality, and also initially suggested an experimental method suitable for examining the question, and for giving a direct determination of the absolute velocity of various ions, in a form apparently free from any hypothesis.

The method consisted in passing a current through an electrolyte contained in a uniform glass tube, and arranging some form of test substance to detect the position to which the ions had at any instant attained in their journey along the tube. The speed of any ion which lent itself to this mode of chemical detection could thus obviously be measured, provided disturbing causes could be excluded.

The experiments I have made on this plan hitherto, though numerous, can hardly be regarded as more than preliminary—a good many difficulties, some expected, some unexpected, having turned up in the course of the investigation, as usual. Nevertheless, a fair approach to a satisfactory and accurate result has been in some of the later instances obtained, and, besides the experience, some of the results themselves are worth having.

Let me first rapidly obtain the theoretical values of ionic velocity, in a complete manner, in order to distinguish the parts of the theory which are manifestly true from the parts which may require modification and development.

Consider a unit cube of electrolyte, containing n^3 *active* molecules, *i.e.*, n^3 molecules actually engaged in conveying a current, and ignoring any inert molecules such as those of the solvent have (perhaps without reason) usually been supposed to be. Let q be the total charge of each kind of electricity possessed by the constituent ions of each active molecule, and let U be the velocity with which the two oppositely charged ions are being sheared past one another by the applied slope of potential $\frac{dv}{dx}$. Then, if k is the conductivity of the unit cube, we have the following couple of expressions for the intensity of current (*i.e.*, quantity of electricity conveyed per second through unit area normal to the flow) :—

First $n^2q \cdot n\mathrm{U}$, from simple notions of convection;

second $k\frac{dv}{dx}$, from Ohm's law.

Writing N for the number of monad gramme-equivalents *of the active substance* present in the unit cube, and η for the E.C.E. of hydrogen (that is, $1/\eta$ for the quantity of electricity corresponding to any monad gramme-equivalent), it is plain that

$$\mathrm{N}\,.\,\frac{1}{\eta}=n^3q.$$

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[1] *Aberdeen Report*, p. 754.

So, equating together the above two expressions for intensity of current, we get

$$\gamma = k\frac{dv}{d} = n^3 q\mathrm{U} = \frac{\mathrm{NU}}{\eta};$$

or,

$$\mathrm{U} = \frac{k}{\mathrm{N}}\eta\frac{dv}{dx} = \frac{\eta}{\mathrm{N}}\cdot\gamma; \quad \ldots \qquad (1)$$

γ being the intensity of current.

Whence the arithmetic sum of the opposite velocities of anion and cation (u and v), when urged by a slope of potential of one volt per centimetre, through a solution containing N monad gramme-equivalents of active substance per cubic centimetre and of specific conductivity k seconds per square centimeter, is

$$\mathrm{U}_1 = u + v = \frac{k}{\mathrm{N}} \times \cdot 00010352 \times 10^8;$$

$$u + v = 10352\frac{k}{\mathrm{N}} \text{ centimetres per second} \quad \ldots \qquad (2).$$

So far the ground seems to me to be perfectly firm.

We now proceed to apply this to special cases. To do this we *assume*, with Kohlrausch, first, that $\mathrm{N}=m$, the quantity of salt in unit volume of the solution; second, that the ratios of the anion and cation velocities, u/v, are known for a number of substances from Hittorf's classical migration experiments. On these two assumptions a table of velocities can be constructed. They vary, it is true, with k/m, but this number is fairly constant for very dilute solutions of many substances; if it is not, the concentration must be specified.

The latest determinations of Kohlrausch[1] give the following numbers for specific ionic velocities (in centimetres per second) in an aqueous solution containing one-tenth of a gramme-equivalent of salt per litre, the applied E.M.F. being 1 volt per centimetre.

Cation . . .	H	K	NH_4	Na	Li	Ag	$\frac{1}{2}$Ba	$\frac{1}{2}$Mg	$\frac{1}{2}$Zn
$v=$	·00300	·00057	·00055	·00035	·00026	·00046	·00033	·00029	·00026

Anion . . .	OH	Cl	I	NO_3	ClO_3	$C_2H_3O_2$
$u=$	·00272	·00059	·00060	·00053	·00046	·00029

Radicles omitted from this table, like SO_4, PO_4, &c., are intractable or anomalous.

Now in the above calculation what is there hypothetical? Accepting for the present the direct Hittorfian view of migration, the assumption that $\mathrm{N}=m$ involves two hypotheses, viz.:—

(1) That the added salt alone is the active substance, the solvent conducting none of the current.

(2) That the whole of the added salt is equally active.

On any dissociation view of electrolysis it could hardly be expected that when two substances are mixed one should be wholly inert, the other wholly active. It would seem much more probable, without evidence to the contrary, that the two substances should dissociate *each other* in some ratio or other, and that the conduction should be shared between them.

If this be so, equations (1) and (2) still remain perfectly true, but it is not so easy to determine N, the amount of active substance per cc. It

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[1] See memoir abstracted above, p. 337.

may indeed turn out to be *proportional* to m, the amount of salt added, but it is hardly likely to be exactly *equal* to it.

Moreover, if two substances are active, we shall have to split up u into u_1 and u_2, v into v_1 and v_2, as well as N into N_1 and N_2.

If m is the mass of salt contained in every gramme of solution, $\frac{N_1}{m}$ is the 'dissociation-ratio' or 'activity-coefficient'[1] of the salt, and $\frac{N_2}{1-m}$ the dissociation-ratio of the water. And equation (1), written out fully, becomes—

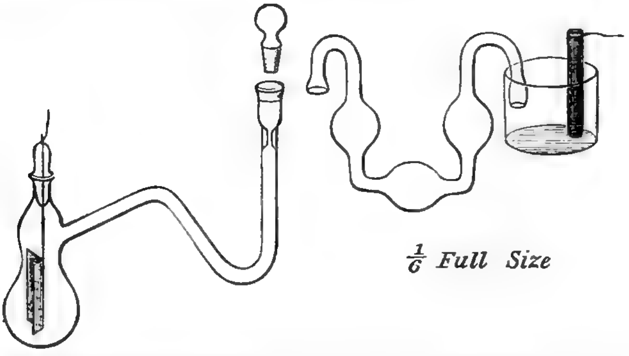
$$N_1(u_1+v_1)+N_2(u_2+v_2)=k\eta\frac{dv}{dx} \quad . \quad . \quad . \qquad (3).$$

The value of k to be used here is the simple straightforward conductivity of the whole solution. There is to be no subtracting of hypothetical water-conductivity in order to get at an inaccessible salt-conductivity; the distinction between known and unknown quantities is perfectly definite.

By a complete quantitative electrolytic experiment, such as Hittorf first made, and Wiedemann and others have followed up, the four quantities N_1u_1, N_1v_1, N_2u_2, N_2v_2 can all be obtained; but it is not possible thus to obtain the values u_1, v_1, u_2, v_2, separately, unless the dissociation-ratios N_1/m and $N_2/1-m$ are known too.

The mode in which I have begun to make complete determinations of electrolysis may be stated for the case of copper sulphate. The cathode vessel is in the form of a specific gravity flask with a long horizontal tube neck, which has a constriction at one place, to which it can be accurately filled, and an open mouth above the constriction for the anode vessel to dip its beak into. The cathode can be a piece of platinum fused through the glass, or, more conveniently, passed through a stopper. The anode vessel may be like a tobacco-pipe with the anode immersed in its bowl, and its stem recurved so as to dip into the mouth of the cathode vessel. Only one of the two vessels is to have measurements made upon it, and the cathode vessel is perhaps generally the more convenient. It can be kept immersed up to its neck in a bath of water at constant temperature, as in fig. 10.

FIG. 1.



The course of the experiment is as follows:—Fill the cathode vessel with a standard solution, adjusting its level exactly to the mark at a known temperature; then weigh it. Pour a little more solution into its mouth. Fill the anode vessel also with the same solution; arrange as suggested in figure 1, and pass a measured current for a known time, with a silver voltameter in circuit. Then remove the anode vessel, re-adjust the level in the other, and weigh again. Finally analyse the contents of the solution in the cathode vessel, and weigh the cathode deposit or voltameter plate. The necessary and sufficient data are these:—

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[1] See memoir of Arrhenius below, p. 364.

1. Proportion of ingredients in original solution.
2. Initial weight of cathode vessel.
3. Final weight of ditto.

4 and 5. Any *two* of the following three things: the amount of Cu, or of SO_4, or of free H_2SO_4, in the final solution.

The object of the long tube is to be sure that the current shall have to travel through the unaltered original solution in some part of its course; also to preserve uniform some liquid near the constriction.

I was under the impression that this scheme of experiment was more complete than any that had been previously attempted, but I have since looked up Hittorf's papers,[1] and found them very admirable. I do not say that nothing better can be done, but I have done nothing better yet, and therefore shall not at present rehearse the mode of treating the above data in order to extract from them their meaning, especially as it is long enough for a separate paper.

DIRECT EXPERIMENTAL DETERMINATION OF ABSOLUTE IONIC VELOCITIES.

Let us pass now from this rather laborious method of determining N_1u_1, N_1v_1, &c., to a simple and direct mode of experimenting on the velocities u_1, v_1, &c., themselves. It is manifest that if one can determine for any substance, Nu by one method of experiment, and u by another, its dissociation-ratio N/m, which must be a very important chemical constant, is known instantly.

One of the early forms of experiment for observing u and v was arranged thus:—

Two vessels, containing fairly strong sulphate of soda and baric chloride, respectively, adjusted to equal density, were joined by a longish tube full of dilute hydrochloric acid of small specific gravity (fig. 2).

FIG. 2.

A current from some twenty storage batteries was then applied, and the tube examined from time to time for the first appearance of a precipitate of baric sulphate.

When everything went well the precipitate appeared as a fine ring inside the tube, which rapidly filled up into a beautifully sharp thin disc or complete partition, and then grew in thickness, spreading out slowly both ways till it formed a solid plug and rather obstructed the current.

The locality of the disc and the time of its appearance after starting the current were noted; but I do not here record these first results, because they were very variable, owing to disturbing causes.

One obvious disturbing cause is that of slight differences of level, produced either by earth-warpings and local pressures, or by evaporation. To diminish mechanical changes of level the two vessels were next arranged side by side, and the tube was bent double so as to have its ends close together and yet to afford a good length for observation.

The level of the vessels was accurately adjusted, and the tube introduced with as little disturbance as possible, various devices, such as super-

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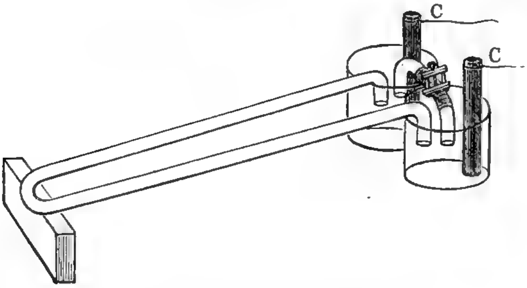
[1] *Pogg. Ann.*, vols. lxxxix., xcviii., ciii., cvi.

numerary tubes and stopcocks, being sometimes employed to assist this (fig. 3).

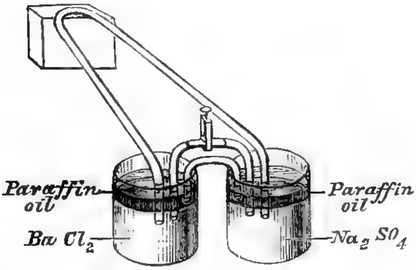
To diminish evaporation a layer of paraffin was sometimes put on each vessel, and my assistant, Mr. Robinson, hit on the happy device of connecting the two layers of paraffin by another and a much shorter and stouter siphon tube full of paraffin, so as to equalise the levels and, if possible, to keep them equal, and yet not to tap off any of the current by this supernumerary but almost infinitely resisting path (fig. 4).

FIG. 3.



We now got much more consistent results, and for a long time thought things were pretty satisfactory, so we proceeded to make numerous observations, varying the character and length of the tubes, the number of volts applied, the strength of the solution, &c.

FIG. 4.



The difficulty of electric endosmose is an obvious one, and it may be owing to this that the results of these experiments are not very concordant. Omitting minor corrections, however, and taking the measured ratio of the distances of the ring precipitate, from the $BaCl_2$ vessel end, and from the Na_2SO_4 vessel end of the tube, for all those experiments where a paraffin levelling tube was used, we get the average result that the ring forms 3·2 times as far from the $BaCl_2$ end as from the Na_2SO_4 end (see p. 400).

This may be recorded by saying that the Ba travels three times the distance that the SO_4 travels in the same time, or that Ba travels three times as quickly as SO_4; a result which, though simple and definite, is probably incorrect. But it is possible to argue that what we are measuring is not this simple ratio of speeds but a more complex ratio depending on all the substances. Thus, consider the substances in action,

$$Na_2\,SO_4 \mid HCl \;\; HCl \;\; HCl \mid Ba\,Cl_2,$$

and pass the current from right to left.

On Hittorfian principles, H travels to meet the SO_4, and journeys the greater part of the distance between them; Cl also travels to meet the Ba. Call the true velocities of these four ions, h, s, c, b respectively; then the position of the precipitate of the meeting Ba and SO_4 may be thought to really measure, not $b : s$, but

$$\frac{b}{c} : \frac{s}{h}.$$

Now, on Kohlrausch's calculation, $h=29, b=3·3, c=5·3$, s is not certain, but from Hittorf we may take it as roughly equal to the velocity of K, viz., 5·1; in which case

$$\frac{bh}{cs}=\frac{3·3\times 29}{5·3\times 5·1}=3·5.$$

I by no means press this probably accidental agreement; and the true meaning of any results obtained by such methods as I have described I leave for the present open.

On my cursorily mentioning these very preliminary results in a circular to the committee on Electrolysis, Professor S. P. Thompson suggested using a jelly, and we at once tried it. One cannot use any strong acid with gelatine, for it seems to spoil it, but acetic acid serves; and the siphon tube was accordingly filled with an acetic acid gelatine jelly, which went stiff when cold. Agar-Agar jelly, suggested, I think, by Prof. Clowes, can be used with stronger acids.

The use of jelly makes the experiment much less troublesome, because there is now no difficulty in the manipulation, no special need for adjustment of the solution densities, nor danger from changes of level.

One objection to it is, that, supposing the ionic velocities were determined in jelly, they could not easily be compared with Kohlrausch's numbers, which apply to weak aqueous solutions. There is of course no difficulty in determining the conductivity of the jelly and the slope of potential, as required in formula (1); but it is difficult to assign a value to N. The hypothesis that the solvent does none of the conduction, even though it be true for water, can hardly be pressed to include the case of a jelly of unknown and complicated constitution; especially as we found that the conductivity of plain jelly was actually considerably greater than that of dilute acetic acid [1] (see p. 406).

The endosmose difficulty is not got over by the use of jelly—in fact, it may perhaps be accentuated; and another and unexpected difficulty presents itself. Gelatine swells under the action of the current and exudes from the tube; but always in one direction only, viz., against the current. A cylinder of jelly an inch or two in length was ultimately protruded from the anode end of the tube; and cracks appeared in the substance of the jelly, of curious serpentine form, which underwent noteworthy metamorphoses.

The position of the precipitate in these jelly tubes was not far from the middle of the tube, indicating that Ba and SO_4 travelled at nearly equal rates (see pp. 401 and 411).

Second Series of Experiments.

I next proceeded to another form of the experiment, where a detecting substance was placed in the tube so as to be able to follow the motion of the ions along their journey, instead of only noting their time and place of meeting.

Various detectors were tried, but a simple and obvious one, able to show both anion and cation, is sulphate of silver.

A jelly tube containing, besides acetic acid, a solution of sulphate of silver, was arranged to join two vessels, each full of baric chloride solution. When the current passes, the barium travels with it and causes a precipitate of $BaSO_4$, which may be watched creeping on from point to point; the Cl at the same time travels against the current and causes a precipitate of AgCl, which may be likewise watched. The poor solubility of Ag_2SO_4 is of no consequence, because it is only wanted to *detect* the ions, not to absorb them and stop their motion; hence, however soluble a

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[1] In this connection see Dr. Arrhenius' previous experiments on conductivity of jelly as detailed above, p. 344.

detector is used, the amount of it put into the tube ought to be almost infinitesimal, or it will cause disturbance and prevent the full velocity of the ion being observed.

There is some slight difficulty with a solid precipitate, as detector, when free liquid instead of jelly is employed: for its settling causes currents and convective disturbances—especially in the vertical ends of the tube. Fluid detectors, whose colour the ions change, are therefore in some respects better.

Roughly examining the results obtained by the methods just described, one may say that they give the velocity of Ba through jelly, for a fall of 1 volt per centimetre, as about ·00012 centimetre per second; the velocity of Sr is about ·00015. The speeds of Cl, Br, and I are not very different from each other, and about ·00024. This rough statement is merely to give a notion of the order of magnitude of the velocities obtained, and by no means represents the full deduction from the tabulated numbers.

Experiments on Speed of Hydrogen.

To detect the motion of *Hydrogen* Mr. Robinson devised the following arrangement:—We happened to have been using phenol-phthallein as a detector of alkali in some other quite distinct experiment, and so it was a handy substance. The jelly tube contains a little phenol-phthallein and a trace of common salt, just made alkaline enough with soda to bring out the colour. The solution in the anode vessel is H_2SO_4; in the cathode vessel the same, or sometimes $CuSO_4$. (For details see below, under date August 17, p. 407.)

The result is that SO_4 travels one way, and H_2 the other. As the H travels, it liberates HCl, and decolorises the solution. As the SO_4 travels, it also decolorises the solution by forming neutral Na_2SO_4. The velocity of hydrogen, for 40 volts applied to a 40-centimetre tube, came out from the very first observation thus made

·0029

centimetre per second. Kohlrausch's theoretical number, deduced from conductivity and migration data, is

·003.

Later experiments gave respectively ·0026 and ·0024. SO_4 seems to travel at about one-third this speed.

Another experiment was made with NaHO in the cathode vessel, and $CuSO_4$ in the anode, and with NaCl and phenol-phthallein in the tube, as before, but colourless (p. 409). HO now travels against the current and produces colour as it goes. It seems to travel nearly as quickly as hydrogen.

The following abbreviated excerpts from Laboratory Note-books will sufficiently illustrate the results so far attained.

Specific Gravity Data.—11·73 grammes of crystallised baric chloride added to 88·27 grammes of water give a solution of sp. gr. 1·095, containing about 10 per cent. of the salt itself. One-thirtieth of its bulk of water added reduces it to 1·093. 22·68 grammes of crystallised sodic sulphate added to 77·32 grammes of water give a solution of specific gravity 1·093, likewise containing about 10 per cent. of the salt itself. 19·98 grammes of hydrochloric acid added to 80·02 of water make sp. gr. 1·098, and is a 25 per cent. solution. This also was reduced to 1·093.

Experiment made of inverting a test-tube containing one of these liquors into a pneumatic trough containing another. In each case pretty rapid mixture resulted.

The hydrochloric acid solution was then diluted with an equal volume of water, making its sp. gr. 1·030. A test-tube was filled with this and inverted over the baric chloride solution. There was no visible mixture; the place where the two liquids met remained quite sharp.

October 30, 1885.—A tube of uniform cross section and ·41 centimetre internal diameter was taken and bent as shown in fig. 3. Its total length was 84·2 centimetres. This tube was marked No. I.

It was filled with hydrochloric acid solution, of specific gravity 1·030, slightly tinged with litmus.

Two vessels containing the 1·093 solution of Na_2SO_4 and $BaCl_2$ respectively were arranged with vertical sticks of electric-light carbon as electrodes, and their levels as carefully adjusted as possible. The final adjustment was performed by a short siphon tube with a pinch-cock in the middle, and full of hydrochloric acid of sp. gr. 1·093 (see fig. 3). The experimental tube No. I. was then introduced very carefully at xiv. hrs. 58 min. At xv. hrs. 2 min. the pinch-cock of the levelling tube was closed, and the current started, flowing from $BaCl_2$ vessel to Na_2SO_4 vessel. Current strength ·01 ampère.

October 31.—Noon: ring beginning to form

22 centims. from Na_2SO_4 end, and
62·2 „ „ $BaCl_2$ end.

November 2, 1885.—Another similar experiment with same tube. Levelling tube started at xi. hrs. 49 min. Experimental tube put in xi. hrs. 55 min. Levelling tube closed at xii. hrs. 2 min., and current started of strength ·01 ampère.

By November 3, at ix. hrs. 47 min., ring formed; and at xiv. hrs. the current was stopped. Strength, ·007 ampère.

Solutions then tested and found all right; apparently a satisfactory experiment.

Distance of ring

from Na_2SO_4 end 24·6;
„ $BaCl_2$ „ 59·6.

November 3.—Another experiment started with the same tube; fresh liquids still with density 1·093 for $BaCl_2$ and Na_2SO_4, the HCl (coloured with litmus) of density 1·030. Levelling tube put in at xiv. hrs. 30 min.; experimental tube at xiv. hrs. 34 min. Levelling tube closed and current started at xiv. 36 min. Strength of current, ·009.

On November 4 at x o'clock the ring was formed.

Distance from Na_2SO_4 end 31·8 centims.
„ $BaCl_2$ „ 52·4 „

November 4.—Similar experiment, except that the tube is filled with an uncoloured solution of HCl of ordinary testing strength, that is, one centigramme molecule in 5 cc. Average current strength, ·009.

Distance of ring from Na_2SO_4 end 16·8 centims.
„ „ $BaCl_2$ „ 67·6 „

November 6.—Another experiment with the ·01 HCl is 5 cc. Current strength ·009.

Distance of ring from Na_2SO_4 end 16·4;
„ „ $BaCl_2$ „ 68·0.

November 7.—A blank experiment arranged purposely with no current. Tube put in and levelling tube closed at xiii. hrs. 35 min.

By November 16 *there was no ring formed and no deposit anywhere in the tube.*

November 24.—Two other similar tubes prepared, each of the same internal diameter—·41 centims.—but of lengths, No. II. 87 centims., No. III., 88·4 centims. The three tubes were then filled with the HCl solution (·01 in 5 cc.), and arranged with three pairs of vessels in multiple arc. The result was that, while the precipitate occurred in tube I. in about its usual position, in tubes II. and III. it occurred quite at end of the tube where it dipped into the Na_2SO_4 vessel, and accordingly most of it fell out of the tube.

December 1.—Another experiment started; tubes I. and II. as before, but a layer of paraffin over the vessels of tube III., and a siphon levelling-tube full of paraffin dipping into it and left open, as shown in fig. 4. The current strength decreased steadily from ·01 to ·005.

In tube II. the chief precipitate occurred again close to the Na_2SO_4 end.

In tube I. the distances were 16·5 centims. from Na_2SO_4 end.
67·8 " Ba_2Cl end.
In tube III. they were 20·2 " Na_2SO_4 end.
68·3 " Ba_2Cl end.

Precipitates appeared on Dec. 3.

December 3.—Paraffin levelling-tubes now provided for both tubes II. and III. The ring formed well in all three now, and quite blocked the tube. The distances were—

In tube I.	15	centims. from	Na_2SO_4 end.
	69	"	$BaCl_2$.
In tube II.	21	"	Na_2SO_4 end.
	66·4	"	$BaCl_2$ end.
In tube III.	21·5	"	Na_2SO_4 end.
	66·7	"	$BaCl_2$.

Current strength in each tube about ·01 ampère.

December 5.—Same experiment repeated with 22 cells, tube I. being the only one without paraffin. The distances were—

	I.	II.	III.
From Na_2SO_4 end	16·1	22·2	22·2
From $BaCl_2$ end	67·6	64·8	66·1

Current strength about ·015.

December 5.—The same experiment repeated, but with only 3 cells. By December 9 a ring had formed in II. and III., but not in I.

Distances of ring—

In tube II.	25·9	from Na_2SO_4 end.
	60·9	from $BaCl_2$ end.
In tube III.	27·1	from Na_2SO_4 end.
	60·9	from $BaCl_2$ end.

Current strength in each tube about ·002 ampère.

Experiments with tubes of different bore.

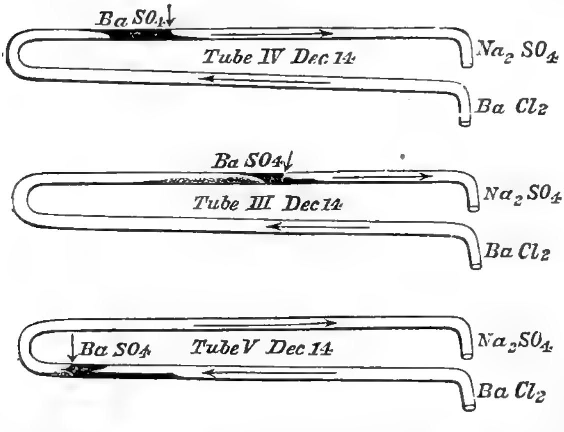
Two fresh tubes were prepared, Nos. IV. and V., of about the same length, but smaller in bore than the first three, No. IV. being about ·3 centim. diameter and No. V. about ·22.

(For more accurate gauging of all the tubes see below.)

December 9.—Two tubes, Nos. II. and V., arranged in series; two other tubes, Nos. III. and IV., also arranged in series, and the current from 16 secondary cells allowed to divide between the two pairs, starting at 4 P.M. on December 9.

Current strength in tubes III. and IV. decreasing from ·0075 to ·0035; in tubes II. and V. from ·005 to ·0012.

FIG. 5.

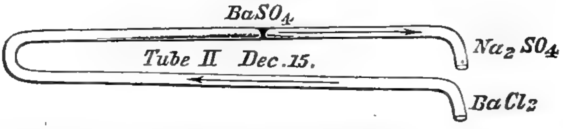


By December 11, 10 A.M., a ring was almost completely formed in tube IV., fairly so in V., an indication in III., and nothing in II. By December 12 a ring formed in tube III., and by December 14 it was beginning also in tube II.

On December 14 the state of the tubes was as sketched in fig. 5.

On the 15th the state of tube II. was this:—

FIG. 6.



A small arrow marks the place of first appearance of the ring in fig. 5.
The distances are as follows:—

	II.	III.	IV.	V.
Distance from Na_2SO_4 end	19·0	17·5	30·5	45·8
„ $BaCl_2$ end	66·7	69·5	54·7	40·7

December 15, 7 *p.m.*—Vessels same as in last experiment, but tubes arranged II. and IV. in series, one pair, and III. and V. in series, the other pair.

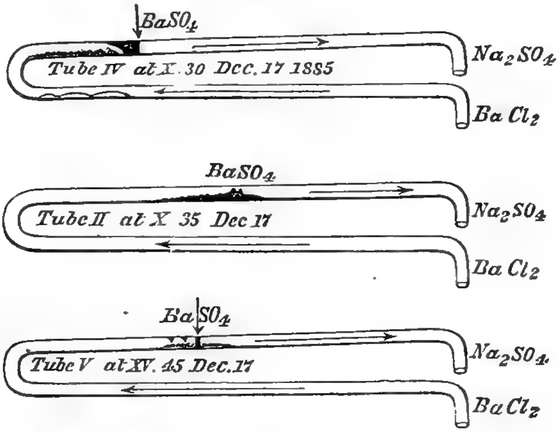
Current strength in II. and IV. from ·0095 to ·0044; and in III. and V. from ·0062 to ·0022.

By December 16, 4 P.M., deposit showed itself in tube IV.

December 17, 10 A.M., ring formed in tube IV., and almost complete in II. An indication in V. By 3 P.M. the ring in V. was complete, and a slight deposit in tube III.

On December 20 ring complete in III., and current stopped.

FIG. 7.



Distances of ring when first formed—

in tube	II.	III.	IV.	V.
from Na_2SO_4 end	21·5	17·1	28·6	24·3
„ $BaCl_2$ end	64·5	69·8	56·4	62·2

Gauging of the tubes.

January 6, 1886.—Determined bore of tube by filling them with mercury at 12° C.

	I.	II.	III.	IV.	V.
Length in centims. . . .	82·5	85·7	87·3	85·4	86·3
Weight of mercury filling tube, in grammes . .	157·0	161·5	157·92	113·4	56·65
Calculated volume . .	11·6	12·0	11·7	8·4	4·2
Sectional area . . .	·14	·14	·134	·0983	·0487
Diameter of bore . .	·423	·423	·404	·355	·25

January 7.—Experiment with all four tubes in multiple arc, two of them dipping into the same pair of vessels; the solutions of $BaCl_2$ and Na_2SO_4 weaker than before, viz., sp. gr. 1·050, because in the cold weather the sulphate of soda was apt to crystallise out of the old solutions. Current started at 5 P.M., 20 cells. By January 9, 9 A.M., rings were formed in tubes II., III., and IV. No ring in V., but some air-bubbles had collected in it, and apparently stopped its current. The rings in II. and IV. were beautifully sharp.

	II.	III.	IV.
Distance of ring from Na_2SO_4 end	17·0	6·5	16·9
	68·7	80·8	68·5

January 9.—Another similar experiment but with 15 cells. By the morning of January 11 rings were formed in 3 tubes, and one was forming in tube V.

	II.	III.	IV.	V.
Distance from Na_2SO_4 end	26·5	10·4	21·0	33·7
„ $BaCl_2$ end	59·2	76·9	64·4	52·6

January 22.—A precisely similar experiment, except that 20 cells were applied. By January 23 (evening) rings were forming in three of the tubes, but there was an air-bubble again in V.

	II.	III.	IV.
Distance of ring from Na_2SO_4 end	34·3	22·3	24·4
„ „ $BaCl_2$ end	51·4	65·0	61·0

February 1.—Similar experiment.

	II.	III.	IV.	V.
Distance from Na_2SO_4 end	38·2	30·6	26.2	23·1
„ „ $BaCl_2$ end	47·5	56·7	59·2	63·2

So far the data are not satisfactory. There is a decided consensus in favour of the more rapid travelling of Ba than of SO_4, but no estimate of the ratio of the velocities can be relied on. The average makes Ba travel 3·2 times as fast as SO_4 (see p. 394).

Experiments on jelly-filled tubes.

Four new tubes were made of dimensions and numbers here specified:—

Number	VI.	VII.	VIII.	IX.	
Length	86·6	88·3	84·8	103·8	centims.
Diameter	·327	·460	·476	·825	„

A gelatine solution was made by dissolving 20 grammes of gelatine in 150 cc. of dilute acetic acid of ordinary testing strength, viz., 1 centigramme molecule per 5 cc., the tubes filled and allowed to go solid. The tubes were arranged in multiple arc with a galvanometer able to be switched at pleasure into the circuit of each. The solutions in the vessels were $BaCl_2$ and Na_2SO_4, as before.

February 13.—The E.M.F. of 24 cells was applied to these four new tubes at noon, and readings of the current (which was very weak) taken at intervals.

It was found that something in travelling from the anode vessel (presumably the Ba) rendered the jelly turbid, and that the turbidity, being sharply defined, served as an indication of the distance to which this ion had reached. Marks were accordingly made on the tube to fix its position at different times, the distances of these marks from the end of the tube being afterwards measured. After a time the SO_4, travelling from the other end, met the Ba and precipitated a sharp ring of $BaSO_4$, whose position was noted. The current was not stopped, however; it was left on to see at what rate the precipitation advanced, and whether it advanced in both directions or in only one. In the free liquid HCl tubes it had seemed only to advance in the direction opposed to the current, viz., towards the $BaCl_2$ vessel. It was now observed in these jelly tubes to widen out both ways, but faster towards the $BaCl_2$ vessel than towards the Na_2SO_4.

It was specially noticeable that in these jelly tubes the disc of $BaSO_4$, indicating the meeting of the ions, formed near the middle of the tube, instead of much nearer the Na_2SO_4 end, as it had done in free liquid. Thus while Ba travelled 41·1 cm.

to the meeting-place, SO_4 travelled 45·5, in tube No. VI. In tube No. IX. Ba travels 47·8, while SO_4 travels 56·6, and so on; see following table.

SUMMARY OF EXPERIMENTS ON TRAVELLING OF BA THROUGH 4 JELLY TUBES.

Date		Tube VI.		Tube VII.		Tube VIII.		Tube IX.	
Day.	Hr. min.	Distance travelled by Ba	Current milliampères	Distance travelled by Ba	Current milliampères	Distance travelled by Ba	Current milliampères	Distance travelled by Ba	Current milliampères
Feb. 13	XII 0	started	·12	started	·18	started	·22	started	·54
„ 14	XIV 0	—	·12	—	·21	—	·25	—	·56
„ 15	XII 3	6·9	·12	6·5	·24	7·1	·28	5·9	·76
„ 15	XVI 15	7·88	·14	7·41	·32	8·1	·39	6·7	·83
„ 15	XX 15	8·75	·12	8·25	·21	8·95	·25	7·3	·61
„ 16	X 10	11·12	·12	10·12	·21	11·33	·25	8·92	·61
„ 16	XIX 10	12·75	·14	12·95	·24	12·95	·28	10·2	·64
„ 17	XI 10	15·45	·11	14·55	·21	15·65	·23	12·1	·46
„ 18	X 10	19·15	·16	18·02	·26	19·32	·30	14·8	·75
„ 18	XVIII 10	21·08	·17	19·9	·26	21·25	·33	16·12	·82
„ 19	X 10	23·98	·10	22·7	·17	24·2	·21	18·3	·49
„ 19	XXI 28	25·6	·09	24·25	·16	25·93	·17	19·5	—
„ 20	X 10	27·2	·09	25·85	·16	27·6	·20	20·8	—
„ 20	XX 15	—	·16	27·45	·20	29·32	·23	22·0	—
„ 21	IX 45	30·55	·11	29·2	·18	31·2	·20	23·43	—
„ 22	X 15	33·68	·12	32·55	·18	34·5	·24	25·8	—
„ 23	X 10	37·05	·10	35·72	·16	38·15	·18	28·45	—
„ 24	X 10	39·72	·09	38·5	·16	40·6	·18	30·5	—
„ 25	X 10	41·1	·11	40·85	·16	41·22	·18	32·6	—
		Ba SO_4 disc forming				Ba SO_4 disc formed			
				Ba SO_4 disc forming					
„ 25	XXI 15	—	·09	41·3	·14	—	·16	33·7	—
„ 26	X 10	41·4	·09	—	·15	41·5	·17	34·8	—
„ 27	XII 12	—	·08	—	·17	—	·18	37·5	—
				current stopped					
—	—	—	—	—	—	42·92 35·4	·13	40·9	—
March 4[1]	X 10	42·65 36·2	·07	—	—	—	·15	46·5	—
		current stopped							
„ 4	XXIII 57	—	—	—	—	43·16 34·6	·17	47·82	—
								BaSO$_4$ disc just forming.	
„ 5	X 10	—	—	—	—	—	·13	Disc 2 mms. wide	
							current stopped.		

Experiments on travel of both Ba *and* Cl *through jelly tubes.*

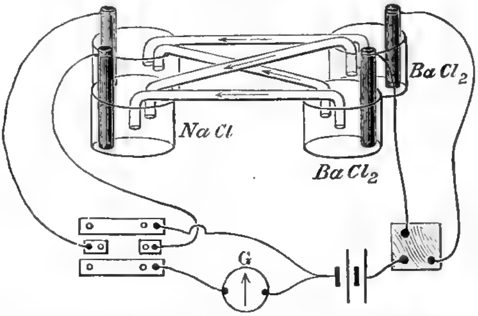
Four fresh tubes, numbered XII.–XV., each 40 centims. long, and more simply bent, were filled with the following jelly, containing sulphate of silver as a test for the presence both of Ba and of Cl. The jelly was made by taking 40 cc. of the previous acetic acid gelatine and adding to it 10 cc. of the following solution, viz., 20 cc. of nitrate of silver sol. ($AgNO_3$ in 50 cc.) + 2 cc. sulphuric acid (H_2SO_4 in

---

[1] The 3 pairs of bracketed numbers about this date relate to the two ends of the plug of precipitated $BaSO_4$, and show the rate at which this plug grew in thickness.

10 cc.) + 78 cc. of water. Tube XIV. was ·562 centims. in diameter; the others were not measured. The tubes were arranged thus:—

FIG. 8.



so that the current through any one of them could be measured, with short interruption to the others. The anode vessels contained $BaCl_2$, the cathode vessels NaCl.

The E.M.F. of the applied battery was measured by an Ayrton and Perry voltmeter as 29 volts.

TABLE OF RESULTS.

Date		Tube XII.			Tube XIII.			Tube XIV.			Tube XV.		
		Distance travelled by		Current milliamp.	Distance travelled by		Current milliamp.	Distance travelled by		Current milliamp.	Distance travelled by		Current milliamp.
Day	Hour	Ba	Cl		Ba	Cl		Ba	Cl		Ba	Cl	
Feb. 22	XVIII 30	started		·52	0	0	·36	0	0	·68	0	0	·50
„ 23	X 10	4·1	8·3	·41	3·9	7·8	·29	4·4	8·8	·54	3·93	8·0	·41
„ 23	XXII 10	6·85	13·9	·41	6·63	13·3	·29	6·5	14·5	·56	7·0	13·82	·41
„ 24	X 10	9·4	18·8	·41	9·0	18·0	·28	9·0	19·6	·53	9·6	18·9	·41
„ 24	XXI 45	12·1	24·1	·44	11·5	23·1	·32	11·6	25·0	·57	12·2	24·42	·44
„ 24	XXI 50	current stopped		0	—	—	0	—	—	0	—	—	0
Three faint extra precipitations were observed later, besides those caused by the recent current. They are here referred to as *a*, *b*, *c*.													
Feb. 27	XII	(*a*) 4·75	—	0	(*a*) 4·8	—	0	(*a*) 4·9	—	—	—	—	—
„ 27	„	(*b*) 12·85	(*c*) 26·5	0	(*b*) 12·26	(c) 25·68		*b* 4	—	—	—	—	—

Late on February 24 the current was stopped because the advancing ions had nearly met, and it was desired to observe whatever phenomenon might accompany their meeting. The tubes were left in position for a day or two, and by February 27 it was found that, while the precipitation boundaries due to the current still remained, three other fainter outlines had made their appearance, one, a fresh one, crawling along from the $BaCl_2$ end, the other two advancing beyond the current-formed precipitate. The three are labelled in the table *a*, *b*, *c* respectively, and their positions are indicated; but no meaning is yet attached to them.

The result of these experiments is to give a rough absolute determination of the rates of travel of Ba and of Cl through the jelly, and to show that the speed of Cl is pretty exactly twice that of Ba. Now can this be assumed to be probably due to the fact that barium is a dyad, while chlorine is a monad? or is it due to the fact that the atomic weight of Ba, 137, is almost twice that of Cl_2, viz., 71? The simplest mode of examining this question is to replace the chlorine by bromine or iodine, whose atomic weight is quite different, while its valency is the same.

Similar experiments with iodine instead of chlorine.

The cathode vessels were filled with a solution of potassic iodide instead of with sodic chloride solution. An E.M.F. of 29 volts was again applied to the same four tubes, filled with the same jelly as before, and the results are subjoined. The precipitation on the advancing iodine side was, however, double; one faint outline in advance, which it was suspected might be due to a trace of chlorine impurity in the KI, and the main precipitation, which was considered to be real AgI. Successive positions of the faint advance cloudiness are recorded in the following table in parentheses below the numbers giving the corresponding main advance:—

Volts applied	Date		Tube XII.			Tube XIII.			Tube XIV.			Tube XV.		
	Day	Hour	Distance travelled by		Current milliamp.	Distance travelled by		Current milliamp.	Distance travelled by		Current milliamp.	Distance travelled by		Current milliamp.
			Ba	I		Ba	I		Ba	I		Ba	I	
—	Mar. 5	XVI 22	0	0	·48	0	0	·36	0	0	·65	0	0	·48
—	,, 6	XXI 43	1·74	4·12	·40	1·78	3·00	·38	1·71	2·9	·56	1·6	2·82	·41
—	,, 6	X 10	4·6	8·08	·38	4·28	8·12	·29	4·3	8·4	·52	4·4	8·22	·34
				(8·5)			(8·72)			(8·95)			(8·8)	
—	,, 6	XIII 38	5·4	9·6	·49	5·12	9·75)	·37	5·03	9·93	·63	5·02	9·73	·48
				(10·3)			(10·4)			(10·6)			(10·5)	
—	,, 6	XX 56	7·15	13·16	·42	7·1	(13.31)	·33	6·9	13·75	·57	6·95	13·5	·42
				(14·02)			(14·2)			(14·65)			(14·4)	
—	,, 7	XII 15	10·62	19·29	·44	10·7	19·61	·34	10·48	20·22	·63	10·4	19·7	·45
				(20·5)			(21·08)			(23·6)			(21·08)	
—	,, 8	X 20	—	—	·59	—	—	·46	—	—	·91	—	—	·63
Current stopped and another experiment arranged.														
							Tube XIII. broken accidentally.							
28·6	Mar. 8	XV 45	0	0	·40	—	—	—	0	0	·56	—	—	·39
29·14	,, 8	XXI 51	1·58	2·7	·33	—	—	—	1·63	2·81	·45	1·5	3·0	·31
29·14	,, 9	IX 45	4·1	8·0	·30	—	—	—	4·15	7·7	·43	4·2	8·5	·30
				(8·59)						(8·3)			(9·18)	
29·14	,, 9	XVIII 55	6·89	12·8	·38	—	—	—	6·7	12·6	·52	6·8	13·5	·38
				(13·8)						(13·5)			(14·6)	
29·0	,, 10	X 15	10·8	19·73	·37	—	—	—	10·6	19·5	·53	10·6	20·61	·39
				(21·2)						(21·1)			(22·5)	
29·2	,, 10	XVII 56	13·5	23·84	·40	—	—	—	13·59	23·54	·60		24·7	·41
				(24·6)						(24·72)			(25·83)	

Similar experiments with bromine.

The cathode vessel was filled with a solution of potassic bromide containing 30 grammes of salt to 300 grammes of water. Tubes filled with same Ag_2SO_4 gelatine as before, each 40 centimetres long.

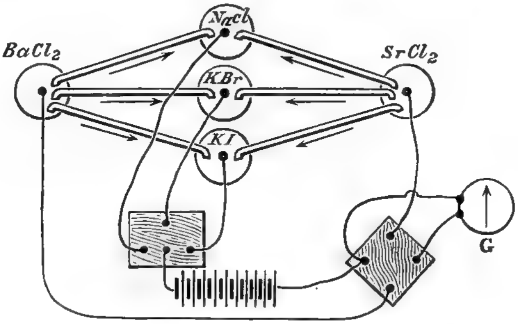
Date		E.M.F.	Tube XII.			Tube XIII.			Tube XIV.		
			Distance travelled by		Current milliamp.	Distance travelled by		Current milliamp.	Distance travelled by		Current milliamp.
Day	Hour	Volts	Ba	Br		Ba	Br		Ba	Br	
March 30	xv 50	26·8	0	0	·39	0	0	·57	0	0	·39
„ 31	ix 50	27·0	4·6	9·2 (9·7)	·35	4·4	9·6 (10·05)	·52	4·6	9·0 (9·4)	·34
„ 31	xvi 55	28·6	7·15	13·6 (14·37)	·44	6·6	14·21 (15·0)	·63	7·1	13·4) (14·1)	·42
April 1	x 17	27·0	12·1	23·0 (23·9)	·39	11·8	23·8 (24·72)	·56	11·9	22·6) (23·6)	·38

As in the iodine experiments there was an advance cloudiness, faint but well defined, in advance of the main precipitate. The readings of the position of this are specified in the above table in parentheses. The meaning of it was not certainly made out, but it was provisionally set down as due to impurity.

Combined experiments on several substances.

It thus appears that Cl, Br, and I all go at about the same rate and about twice as quick as Ba. It remained to see what strontium and calcium do. Calcium is not an easy substance to experiment on; its sulphate is too soluble. But strontium is sufficiently easy, though not so sharp and well-defined as barium. To make a better comparison six tubes were taken, each 40 centimetres long, filled with the same Ag_2SO_4 gelatine solution as before, and arranged in multiple arc with the same E.M.F. (about 40 volts) applied to all of them. This is the E.M.F. between the electrodes, and since gas is given off at the carbon electrodes something like three volts must be deducted for polarisation and for resistance of liquid in vessel. But it was not thought probable that absolute results could be of much use when the composition of jelly is so vaguely known. The diameter of tube XIX. was ·370 centim.

FIG. 9.



The six tubes were arranged as in figure 9; the two anode vessels being filled, one with $BaCl_2$, the other with $SrCl_2$, and the three anode vessels with NaCl, KBr, and KI, respectively; in each case 10 grammes of salt and 100 cc. of water.

COMPARATIVE EXPERIMENT ON BA, SR, CL, I, BR.

Date		E.M.F.	Tube XVI.			Tube XVII.			Tube XVIII.			Tube XIX.			Tube XX.			Tube XXI.		
			Distance travelled by			Distance travelled by			Distance travelled by			Distance travelled by			Distance travelled by			Distance travelled by		
Day	Hour	Volt	Ba	Cl	Current milliamp.	Ba	Br	Current milliamp.	Ba	I	Current milliamp.	Sr	Cl	Current milliamp.	Sr	Br	Current milliamp.	Sr	I	Current milliamp.
June 11	XII 40	38·2	0	0	·76	0	0	·72	0	0	·65	0	0	·61	0	0	·56	0	0	·72
„ 11	XIX 38	38·2	3·0	6·7	·75	3·3	6·1 (6·4)	·71	2·7	5 6	·64	2·6	6·6	·60	3·3	6·4 (6·6)	·57	2·9	6·0 (6·9	·71
„ 12	X 15	37·8	9·1	20·3	·81	9·3	18·6 (19·4)	·76	8·9	17·5 (20·7)	·66	11·1	20·1	·64	11·3	18·6 (19·3)	·62	10·9	18·2 (20·0)	·74
„ 12	XVIII 35	36	13·6	23·9	·96	13·6	24	·86	12·8	25·2	·76	*	—	·74	*	—	·72	*	—	6
June 16	XV 13	40·5	—	—	—	—	—	—	—	—	—	0	0	·57	0	0	·53	0	0	·51
„ 16	XXI 50	40·3	—	—	—	—	—	—	—	—	—	3·3	5·8	·56	3·1	5 7	·54	3·2	5·5	·52
„ 17	X 15	40·3	—	—	—	—	—	—	—	—	—	10·3	16·06	·39	10·0	16·0 (16·5)	·57	9·73	15·2 (15·8)	·53
„ 17	XVII 47	38·5	—	—	—	—	—	—	—	—	—	15·0	22·93	·90	14·5	22·6 (23·3)	·86	14·2	21·4 (22·35)	·82

* The Sr was not very clearly marked, so three tubes were refilled with stronger Ag_2SO_4 sol., viz., 15 cc. of the Ag_2SO_4 sol. (instead of only 10), to 40 cc. of the gelatine sol. and another experiment started.

[The numbers in parentheses again refer to the position of the faint advance precipitates.]

Determination of the resistance of a jelly-filled tube.

July 1.—One of the 40 centimetre tubes filled with plain gelatine gave 67,720 ohms resistance. The same tube had the jelly melted out, the tube cleared and filled with dilute acetic acid (centigramme molecule in 5 cc.), and its resistance was now 160,000.

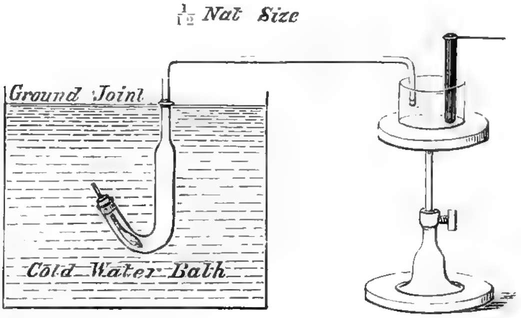
Another determination, by Mance's method, gave for the acetic acid filled tube 142,000 ohms, at 21° C.; for the jelly-filled tube at 19·5, 78,000 ohms; and for the same tube filled with dilute sulphuric acid (H_2SO_4 in 10 cc.) 730 ohms.

This jelly tube was then left to stand all night with its feet in dilute acetic acid. By the morning its resistance had increased, as the acid soaked up into it, to 84,000 ohms.

Improved experiments on the velocity of ions in free liquid.

Any siphon tube arrangement joining two open vessels cannot be free from difficulties caused by electric endosmose, whatever precautions be adopted. Hence a series of experiments were planned with one of the vessels closed and completely full, so that no more or less could be driven into or out of it, either by the action of the current or by changes of level, except such calculable changes as result from alteration of volume of electrode or solution near it, or from changes of temperature. To this end the cathode vessel was made of the shape shown in figure 10, and the experimental tube fitted to it by a ground joint. It was necessary to avoid evolution of gas, so the cathode vessel was filled with saturated sulphate of copper solution, and it was immersed in a constant-temperature water-bath. The tube was 40·7 centimetres long, and was filled with dilute HCl (1 centigramme molecule in 5 cc.). The anode vessel contained a solution of baric chloride (10 grammes salt to 100 of water) and a carbon electrode. The internal diameter of the tube was ·393 centim.

FIG. 10.



August 7.—The cathode vessel having been in the bath all night, and the temperature being 16·2°, the tube was put in at x. hrs. 20 min., and the current started at x. hrs. 48 min. with a difference of potential of 51·3 volts between the electrodes. A silver voltameter was included in the circuit.

By xxii. o'clock there was no ring formed in the tube, but in the bend near the cathode end of the tube there was a slight deposit. The temperature of the bath was still 16·2°. It was afterwards found that the silver plate of the voltameter had dissolved, and thereby broken contact.

August 9.—Another precisely similar experiment; except that a galvanometer was used instead of a voltameter. Current started at xii. hrs. 15 min. with E.M.F. 50·6 volts. The galvanometer readings fell gradually from 6·7° to 3·8°. At xvi. hrs. 40 min. a disc of precipitate was found in the tube, the volts being now 49·7. The thickness of the disc was ·17, and the positions of its two faces were 3·79 and 3·96 centims. from the cathode end of the tube. Result sketched here, fig. 11.

FIG. 11.

Summary of the experiment.

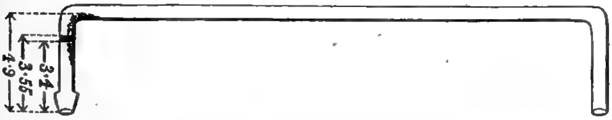
Time taken for ring to first form, estimated at 4 hours.
Distance travelled by Ba, 36·9 centims. $= b + x$.
" " SO_4, 3·96 centims. $= a - x$.

Average difference of potential *between electrodes*, 50·15 volts.
Length of tube, 40·7 cm. Diameter, 0·393 cm.
Current from 5 to 2·7 milliampères.

The *x* in the above relates to a possible contraction of the contents of cathode vessel, to be determined later.

August 10.—Another similar experiment with same tube. Result sketched in fig. 12.
Time taken for ring to form, 8 hours.
Distance travelled by Ba 37·3.

FIG. 12.



Distance travelled by SO_4 3·55.
Difference of potential, 48·4.
Current from 4 to 1·5 milliampères.

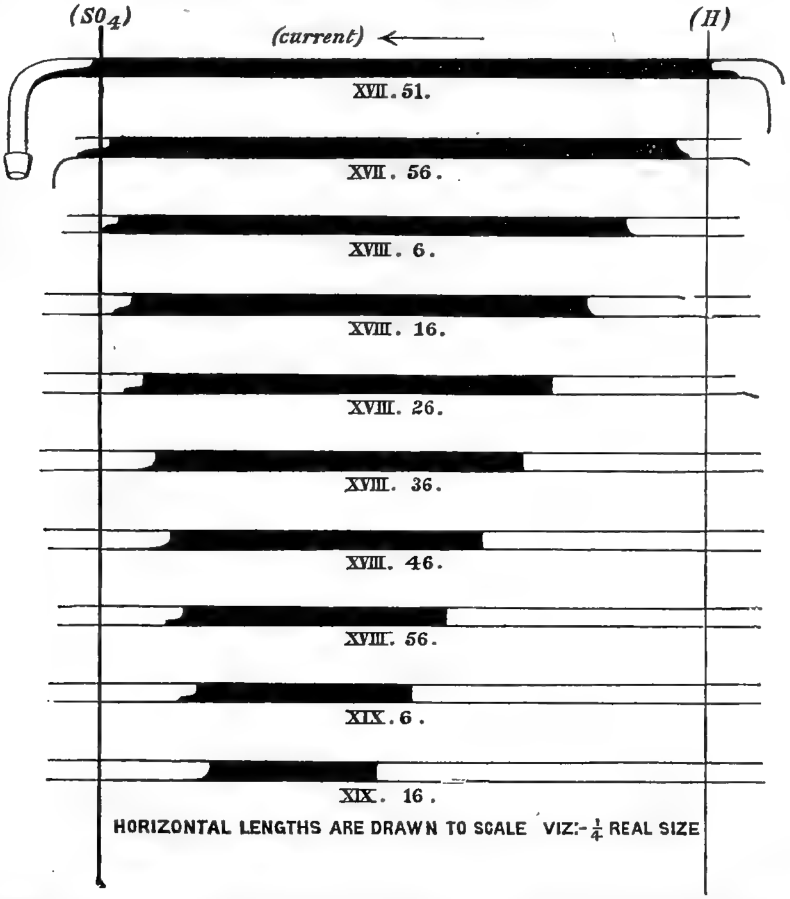
Blank experiment with no current on, to see the effect of diffusion.

August 12.—Tube connected at x. 30. No ring formed, but by August 17, xiv. 30, a slight precipitate was forming in the centre of the tube, *i.e.*, after 5 days 4 hours.

Experiment on the travelling of hydrogen.

August 17.—The same apparatus as in fig. 10 was again used, but the solutions arranged as follows:—In cathode vessel, sat. solution of $CuSO_4$ as before; in anode

IG. 13.

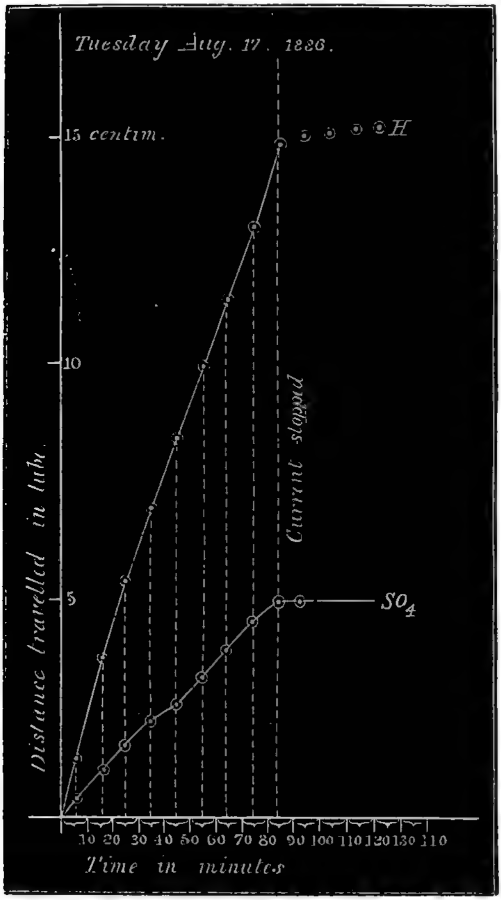


vessel, dilute sulphuric acid; in tube, the following: 49 cc. of sodic chloride sol.

(5 grammes salt in 100 of water) with 1 cc. of baric chloride sol. ($BaCl_2$, 2Ag centigrammes, or 2·44 of the crystallised salt, in 100 cc. water); add to this a little phenol-phthallein, and just enough NaHO to make it red. The destroying of the colour is the thing observed. No measurements made till the liquid is discoloured round the bends of the tube. At xvii. 43 the current was started, with an E.M.F. of 45 volts between terminals. The galvanometer deflection increased from 41·1° to 44·2° in the first half-hour, and then increased further to 46° in the next hour. By xvii. 51 the decolorisation had got round the bends, and the first or starting mark was made. The progress of the whole experiment was rapid, and is represented pictorially in figs. 13 and 14.

In the following summary the column headed, 'Progress of SO_4' gives the position of the marks made near cathode end of the tube. The column headed 'Progress of H' gives the position of the marks made near anode end. By these headings it is not intended to insist that the full theoretical meaning of the observations is the same as the obvious and apparent meaning. All distances are specified in centimetres.

Fig. 14.



Plotting of these numbers.

Time	Current in milliampères	Progress of SO_4	Progress of H
XVII 51	7·8	0	0
„ 56	—	0·5	1·45
XVIII 6	—	1·15	3·65
„ 16	—	1·65	5·33
„ 26	8·7	2·2	6·9
„ 36	8·8	2·6	8·5
„ 46	9·0	3·15	10·05
„ 56	9·1	3·8	11·6
XIX 6	9·2	4·4	13·21
„ 16	9·3	4·9	14·79
	Current stopped.		
„ 26	0	4·98	15·13
„ 36	0	4·98	15·35
„ 46	0	4·98	15·51
XX 56	0	4·98	15·59
„ 6	0	4·98	15·61

August 18.—Another similar experiment, but with a little more NaHO added to liquid in tube to make colour more distinct. No good observation could be obtained of the SO_4 progress this time, as it did not get up to the bend, but the H progress was read. The tube was graduated in millimetres for this experiment. 45 volts applied.

Time	Readings of decolorisation boundary, as it proceeds from anode end	Galvanometer readings
	Centimetres	
XV 0	—	40·5
„ 55	28·2	41·3
XVI 5	26·35	42·3
„ 15	24·93	42·8
„ 35	22·07	43·5
„ 55	17·21 [1]	44·0
XVII 15	16·32	44·7
„ 40	12·71	45·9
„ 50		Current stopped
XVIII 0	10·9 and 10·1	0
„ 10	10·8 „ 9·8	0
„ 20	10·6 „ 9·3	0
		Current started in reverse direction
„ 33	10·3 „ 8·8	—
„ 43	9·5 „ 7·8	—
„ 53	about 9·5 and 7·8 Boundary getting indistinct	—

The double number in the middle column represents the two ends of a slope into which the boundary threw itself as soon as the current was stopped: indicating convection. A galvanometer deflection of 45° means a current of ·009 ampère.

In the last experiment the tube was not perfectly horizontal, and this may have caused some disturbance. In future experiments the tube was carefully levelled to begin with.

Experiment on velocity of copper.

August 24.—Started an experiment with $CuSO_4$ in both vessels, and in tube some NaCl with a little K_4FeCy_6. But the indicator did not form a sharp boundary across the tube, and the experiment was not very satisfactory. 65 volts applied.

—	—	Current in milliampères
At XI 15	Current started	10·0
„ XIV 37	Reading on tube was 29·3	—
„ XVI 7	„ „ 21·8	—
„ XVII 37	„ „ 18·7	8·9
„ XVIII 37	„ „ 17·3	8·7

Experiment on the velocity of hydroxyl.

August 25.—Made an experiment on the rate of travel of the hydroxyl radicle of NaHO, by using the closed $CuSO_4$ vessel with copper electrode as *anode* vessel, and putting a solution of soda in the open (now) cathode vessel, fig. 10. The tube contained NaCl (5 grammes in 100 cc.) with a little phenol-phthallein not coloured as yet with alkali. The appearance of colour was the thing to be observed as the HO travelled against the current and attacked the NaCl. 65 volts applied to electrodes. Tube 40·7 cm. long. For diagram of results see fig. 16.

---

[1] It would seem probable that there was some unknown misreading here; probably 7 for 9.

Time	(Progress of HO). Reading on tube	Current in milliampères	Time	(Progress of HO). Reading on tube	Current in milliampères
X 50	Tube inserted.	0	XIII 39	12·4	11·2
XI 15	Current started	9·4	„ 59	9·58	11·4
„ 59	29·0	10·3	XIV 1	9·30	Current stopped
XII 9	27·0	—	„ 11	8·8	0
„ 19	25·18	10·4	„ 21	8·49	0
„ 39	21·7	10·6	„ 31	8·26	0
„ 59	18·3	10·8	„ 41	8·0	0
XIII 19	15·1	11·0	„ 53	7·72	0

Another experiment on the velocity of hydrogen.

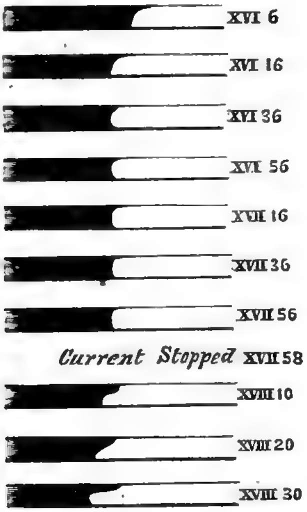
August 25.—Closed vessel (fig. 10), containing $CuSO_4$ used as cathode vessel again open vessel, containing dilute H_2SO_4.

Tube containing NaCl (5 to 100) with a little phenol-phthallein and a touch of NaHO as before.

Time	Reading on tube	Current in milliampères	Time	Reading on tube	Current in milliampères
XV 47	Current started	9·4	XVII 36	10·80	12·0
„ 56	29·19	—	„ 56	6·83	12·3
XVI 6	27·00	10·4	„ 58	6·43	Current stopped
„ 16	25·15	10·6	XVIII 10	6·00	0
„ 36	21·65	11·0	„ 20	5·85	0
„ 56	18·06	11·1	„ 30	5·65 to 5·3	0
XVII 16	14·50	11·4			

This experiment seemed to go well. The numbers are plotted in fig. 16. Successive appearances of the tube are shown in fig. 15.

FIG. 15.



Experiment on the velocity of ammonium.

August 26.—Made several attempts to get the speed of NH_4, using Nessler solution. The indicator is not very distinct: no precipitates seem to work well as indicators; they introduce disturbances. Fluid detectors answer better.

Ammonic sulphate was put in anode open vessel.

The tube contained NaCl + Nessler solution. 65 volts applied.

Time	Reading on tube	Current
XIII 29	—	Current started
„ 36	28·05	10·2
„ 46	26·10	—
„ 56	24·25	10·4
XIV 6	22·70	—
„ 16	21·30	10·5
„ 26	20·20	10·4
		Current stopped
„ 36	20·1	0

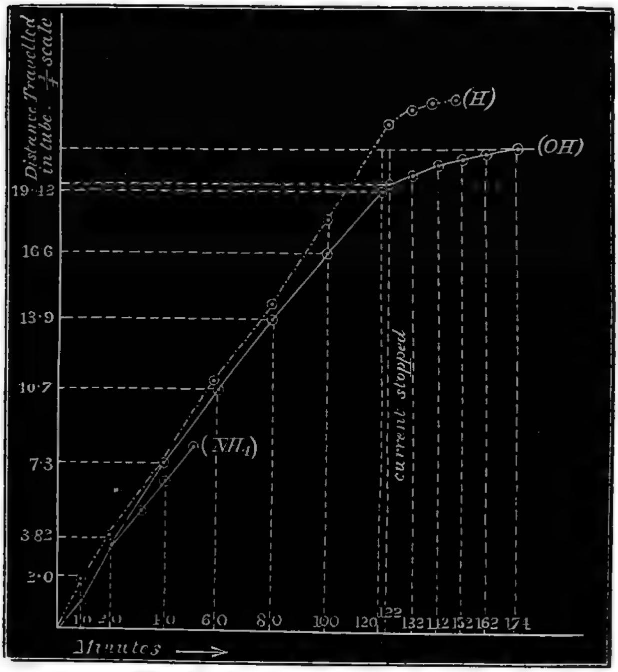
Current stopped because boundary was getting indistinct. This did not seem a very good experiment, but it is better than some here unrecorded which preceded it.

August 26.—A similar experiment with a drop of phenol-phthallein added to liquid in tube, because its indication is sharper. Boundary, however, still sloping, and therefore unsatisfactory to read.

PLOTTINGS IN FIG. 16.

Time	Reading on tube	Current
XIV 48	Current started	10·1
„ 54	27·55	—
XV 4	24·4	—
„ 14	22·3	10·6
„ 24	20·55	—
„ 34	19·1	10·6
	Current stopped	

FIG. 16.



Plotting of the last four tables.

Further experiments on the meeting of Ba *and* SO_4 *in jelly tubes.*

It may be remembered that, whereas in free liquid Ba appeared to travel about three times as fast as SO_4, the precipitated plug of $BaSO_4$ nearly always appearing much nearer the Na_2SO_4 or cathode end of the tube than near the $BaCl_2$ end, yet in jelly tubes they appeared to travel at about the same rate, the plug of precipitate forming near the middle of the tube. To make sure that there was no error of observation here, and to see if constitution of jelly affected the matter, a few experiments with jelly tubes were repeated, and different strengths of jelly were used.

August 24.—Two tubes, each 40 centimetres long, were filled with jelly made by dissolving 40 grammes of gelatine in 150 cc. of dilute acetic acid, of strength one centigramme molecule in 5 cc.

Another pair of similar tubes were filled with jelly made with 40 grammes of gelatine dissolved in 150 cc. of four times weaker acetic acid, viz., a centigramme molecule in 20 cc.

58 volts were applied to the carbon electrodes of all four tubes. The anode and cathode vessels contained $BaCl_2$ and $CuSO_4$ respectively.

In the tubes with weak acid, $BaSO_4$ began to form in 28½ hours after starting the current, and its position was 19·3 in one tube, and 19·2 in the other, from the $BaCl_2$ end, and therefore 19·7 and 19·8 from the Na_2SO_4 end.

In the tubes with stronger acid the precipitate took some hours longer to form, and its position was 19·2 in one tube, and 18·3 in the other, from the barium end. The relative speed of travel of Ba in the two pairs of tubes was taken by making simultaneous marks on each tube as the Ba proceeded; and the ratio of these rates was in the weak acid tube 1·21 times that in the stronger acid tube.

Thus, although the absolute speed is less in the stronger acetic acid jelly (as is quite right, because its conductivity is less; see above), the ratio of the speeds of Ba and SO_4 remains practically unity in both.

August 27.—To confirm, the four tubes were started again in just the same way, except that, while one pair contained jelly with $C_2H_3O_2$ centigramme molecules in 5 cc. as before, the other pair contained jelly with $C_2H_3O_2$ centigramme molecules in 40 cc. The distance travelled by Ba in the weak acid jelly tubes was 15·3 cm., and in the strong acid jelly tubes was 12·4 in the same time; giving a ratio 1·20 as before.

So far as it is wise to draw a moral from unfinished experiments it may be said, that while there are some divergencies, yet they are in the main confirmatory of the theory of Professor F. Kohlrausch, especially in the case of the velocity of hydrogen; and I think it may be regarded as a noteworthy instance of scientific prediction if numbers calculated theoretically from conductivity data be found to agree at all closely with the results of direct experiment.

In conclusion, I wish to record my best thanks to my assistant, Mr. Edward Robinson, for the care and assiduity he has bestowed upon these experiments. As I have had occasion to remark in the course of the paper, he has not only carried out my proposals with ingenuity and skill, but he has in several cases modified details and devised fresh combinations.

CONTENTS.

Sixth Report of the Committee, consisting of Mr. R. ETHERIDGE, Mr. THOMAS GRAY, *and* Professor JOHN MILNE (*Secretary*), *appointed for the purpose of investigating the Volcanic Phenomena of Japan.* (*Drawn up by the Secretary.*)

[PLATE VIII.]

I. *The Gray-Milne Seismograph.*

In 1883, partially at the expense of the British Association, Mr. James White, of Glasgow, constructed a seismograph to be used in Japan. I am pleased to say that for some time past this instrument has been in good working order, and examples of the records which it has furnished are given in the following table. The time records are expressed as Tokio mean time. The particular wave at which time was noted can only be seen by reference to the original diagrams. It is usually very near the commencement of a disturbance. The period which is expressed in seconds is the time taken to describe one of the principal vibrations (or *shocks*) in a disturbance. The longest period, it will be observed, is three seconds. The amplitude, which is expressed in millimeters, is half a semi-oscillation, the vibration which is measured being the one from which the period was recorded.

It will be observed that the larger the amplitude the longer is the period. I am writing more fully on the relationship of amplitude to period in a special paper. With period and amplitude before us, on the assumption of simple harmonic motion we may easily calculate the maximum velocity of motion which represents the projecting power of an earthquake, and the maximum acceleration which measures the overturning and shattering power of an earthquake. The direction which is given is that of the most prominent vibration in the disturbance. One disturbance, it will be noticed, had a duration of ten minutes. Without the aid of an instrument this disturbance might have been felt for a period of perhaps three minutes. It will be noticed that vertical motion has only been recorded twice. The records given in the following table are in the same form as the records published in the Japanese daily papers immediately after the occurrence of an earthquake. The original publications followed Palmiere's method, where a set of arbitrary degrees took the place of the present absolute measures.

Catalogue of Earthquakes felt at the Meteorological Department in Tokio, between May 1885 *and May* 1886, *as recorded by the Gray-Milne Seismograph.*

No.	Months	Day	Time	Period sec.	Amplitude m.m.	Principal Direction	Duration
			H. M. S.				M. S.
607	V.	1	2 47 27 A.M.	—	—	—	—
608	,,	7	8 58 8 A.M.	—	—	—	2 49
609	,,	19	about 2ʰ 50ᵐ A.M.	—	—	—	—
610	VI.	7	11 34 18 P.M.	—	—	—	—
611	,,	11	9 19 40 A.M.	2·2	1·6	W. 11° N.	6 38
612	,,	15	1 41 41 A.M.	2·3	5·9	E. 9° S.	6 0
613	,,	,,	8 40 0 P.M.	—	—	—	—
614	,,	18	1 36 45 P.M.	1·8	0·8	W. 10° N.	2 30
615	,,	28	2 24 18 A.M.	—	—	—	—
616	VIII.	26	5 2 30 A.M.	—	—	—	—
617	,,	28	9 37 28 A.M.	—	—	E. or W.	32
618	,,	31	5 23 55 A.M.	—	—	N. or S.	10
619	IX.	2	8 31 42 A.M.	0·4	0·4	N. 19° E.	25
620	,,	10	8 19 6 P.M.	—	—	—	—
621	,,	11	1 24 30 A.M.	—	—	—	10
622	IX.	20	1 13 50 A.M.	0·4	0·4	W.S.W. or E.N.E.	24
623	,,	22	2 29 43 A.M.	1·6	0·8	E. 27° S.	1 20
624	,,	26	0 2 45 P.M.	3·0	13·7	N. 7° E.	9 0
625	,,	28	5 27 43 A.M.	2·2	11·1	E. 17° S.	4 0
626	,,	29	8 39 9 A.M.	–	—	N. or S.	—
627	X.	1	1 8 57 P.M.	0·5	0·8	S. 42° E.	1 14
628	,,	7	7 34 45 A.M.	—	—	E. or W.	41
629	,,	9	7 53 5 P.M.	—	—	E. or W.	1 12
630	,,	11	about 5ʰ 30ᵐ A.M.	—	—	N. or S.	1 30
631	,,	15	9 2 29 A.M.	—	—	N. or S.	1 7
632	,,	,,	8 43 18 P.M.	1·1	0·3	E. 29° S.	1 10
633	,,	21	1 19 35 A.M.	0·9	0·2	E. 29° S.	1 20
634	,,	24	5 12 58 A.M.	0·9	0·2	E. 28° N.	1 39
635	,,	26	10 41 11 P.M.	2·9	1·9	N. 45° W.	4 48
636	,,	30	8 31 16 P.M.	1·5	0·2	E. 17° 30′ S.	2 5
637	XI.	11	8 51 24 P.M.	—	—	E. or W.	—
638	,,	16	1 50 36 P.M.	0·7	0·2	E. 27° S.	30
639	,,	20	7 41 35 P.M.	—	—	S.E. or N.W.	—
640	XII.	3	6 1 42 A.M.	0·5	0·2	S.W. or N.E.	50
641	,,	6	8 13 0 P.M.	—	—	E. or W.	—
642	,,	7	1 2 23 P.M.	3·0	4·0	E. 12° S.	5 0
643	,,	,,	7 56 57 P.M.	—	—	E. or W.	—
644	,,	18	3 0 38 A.M.	—	—	—	—
645	,,	19	6 26 40 P.M.	1·0	1·8	W. 29° N.	2 43
646	,,	28	10 6 30 P.M.	1·8	3·3	N.	3 40
647	I.	5	4 23 42 P.M.	0·8	0·4	N. 26° E.	23
648	,,	22	10 58 0 A.M.	very	slight	S.–N.	15
649	,,	31	7 22 46 A.M.	very	slight	S.–N.	—
650	II.	19	2 54 11 A.M.	very	slight	E.–W.	—
651	,,	24	7 34 0 A.M.	0·6	0·5	N. 40° E.	1 24
652	,,	,,	3 36 25 P.M.	—	0·2	E.–W.	1 20
653	III.	2	5 13 49 A.M.	1·4	0·4	N. 25° 30′ W.	1 55
654	,,	13	6 25 0 P.M.	1·4	0·3	W. 33° N.	33
655	,,	26	6 6 0 A.M.	very	slight	S.–N.	10
656	IV.	13	5 45 0 A.M.	1·4	0·7	S. 33° E.	3 10
657	,,	23	4 22 22 A.M.	1·8	0·3	S.–N.	33
658	V.	3	noon	—	0·2	E.–W.	1 30
659	,,	8	10 14 0 P.M.	0·4	2·8	W. 39° 30′ N.	1 40
			vertical	0·3	0·5		

No.	Months	Day	Time	Period sec.	Amplitude m.m.	Principal Direction	Duration
			H. M. S.				M. S.
660	V.	9	about 3^h 10^m P.M.	2·2	0·3	W. 37° 50′ N.	1 40
661	,,	11	2 31 58 P.M.	very	slight	S.E.–N.W.	30
662	,,	12	11 43 49 A.M.	—	0·04	N.E.–S.W.	30
663	,,	16	9 3 0 A.M.	0·7	1·7	E. 27° S.	3 0
			vertical	0·4	0·9		
664	,,	18	8 12 51 P.M.	1·7	0·4	E. 16° S.	2 25
665	,,	30	8 38 18 P.M.	very	slight	—	abt. 10

The successful working of the seismograph giving the above records has led the Meteorological Department of this country to have a number of somewhat similar, but less expensive, instruments constructed. These are gradually being distributed throughout the empire. One feature peculiar to the new instruments is that the drum on which the records are written instead of being in continuous motion is only set in motion at the time of an earthquake. When a drum or record-receiving surface is in continuous motion beneath the pointers of a seismograph, these latter, even with the best of instruments, will in time often describe a line the breadth of which may be greater than the range of the preliminary tremors of a disturbance. These tremors are therefore not visible on the record. We find by experience that a record-receiving surface which is only started at the time of a disturbance may be set in motion to receive the preliminary movements, and is therefore, in the opinion of observers in this country, better than an instrument where the record-receiving surface is in continuous motion.

In conclusion to this portion of the subject, I may remark that observations made with instruments at a distance of about half a mile from where the Gray-Milne seismograph is situated give for the same earthquakes amplitudes which are about twenty-five per cent. greater than those given in the preceding table. These instruments are on low flat ground, while the Gray-Milne seismograph is on ground which is relatively high and hard. Another point worthy of record is that very small earthquakes are sometimes felt upon the low ground which are altogether unnoticed by the instruments upon the high ground.

II. *Frequency and General Character of recent Earthquakes.*

From the preceding list of earthquakes it will be seen that between the end of May 1885 and May 1886 fifty-six earthquakes were recorded at the Meteorological Observatory in Tokio. Many of these were very slight. During the previous year (May 1884–May 1885) seventy-three shocks were recorded.

As I did not return from the Australian colonies until last November, I was unable to make observations on earthquakes which occurred during the previous autumn and summer. In consequence of this, I regret to state that the most important shocks of the season (Nos. 624 and 625) were not recorded by the instruments which are employed for special investigations. The special investigations now going on are observations in a pit and on a piece of ground which I have the intention of endeavouring to partially isolate from earthquake movement by trenching. If these experiments are ever completed they will remain to be described in a future report. In the report written last year some reference was made to the experiments in a pit. For a strong earthquake I showed that the motion at the bottom of the pit (which is ten feet in depth) was very much smaller than the motion on the surface. For very small earthquakes this distinction is not so marked; the only difference between the movement below and that above is that the former has a longer period.

Among the earthquakes which have occurred during the last few months several have been felt as short sharp bumps. On these occasions I have repeatedly noticed that a lamp hanging in the centre of my room acquires a rapid vibratory vertical movement, and there has been no perceptible swing. My impression with regard to these shocks, which are usually very short, is that they have an origin immediately beneath Tokio. The vertical motion of the disturbances we feel in Tokio is relatively to the horizontal motion extremely small, seldom exceeding the fraction of a millimeter. So far as I am aware, it has never exceeded two or three millimeters, and the general rule is that vertical movement is but rarely recorded.

In addition to the short sudden vertical movements, we have had others which have been characterised by their length and the slowness of their period. Such a disturbance occurred a few days before I left Tokio. At the time I was sitting at a table upstairs, when I fancied that I felt a movement. On looking up I saw that my lamp was swinging back and forth through a considerable arc. A disturbance of this kind would hardly be recognised as an earthquake by a person who had not been in the habit of recording such phenomena.

III. *The Earthquakes of* 1885–1886.

In my fourth report to the British Association I gave, in an epitomised form, the results obtained by the observation of 387 earthquakes which had occurred between October 1881 and October 1883 in North Japan. A complete account of this work has now been published by the Seismological Society as Vol. VII. Part II. of their Transactions. Similar work, but extended to embrace the whole of the empire, has been undertaken by the Meteorological Department of this country, and results of a valuable nature have already been obtained. As this work is a continuation of that which has already been brought to the notice of the British Association, and as I have from time to time been consulted as to how it should be carried out, a brief account of the more important results which have been obtained may not be out of place. Professor K. Sekiya, who now holds the chair of seismology in the Imperial University of Japan, and who has had the immediate superintendence of these observations, will give a translation and fuller account of this work to the Transactions of the Seismological Society.

The observations were made with the assistance of bundles of post-cards distributed with observers at 600 stations situated in various parts of the empire. During the year 1885 records were received at the Meteorological Department which formed the foundation for a series of maps showing the areas shaken by 482 distinct disturbances.

On the average there were, therefore, 40 earthquakes per month, or 1·3 per day.

The distribution of these disturbances according to months and seasons is shown in the following tables:—

January	32	Spring 113.	July	32	Autumn 106.
February	44		August	29	
March	37		September	45	
April	37	Summer 131.	October	41	Winter 132
May	51		November	51	
June	43		December	40	

Cold Months	245
Warm Months	237
Total	482

The total area of ground disturbed each month is shown in the following table, which may therefore be regarded as an approximate measure of the intensity of seismic action each month:

	Square miles			Square miles	
January	60,000	Spring 205,000.	July	55,000	Autumn 178,000.
February	101,000		August	36,000	
March	44,000		September	87,000	
April	28,000	Summer 184,000.	October	13,000	Winter 107,000.
May	62,000		November	25,000	
June	94,000		December	69,000	

Cold Months	312,000
Warm Months	362,000
Total	674,000

Disturbances shaking more than	30,000	square miles	2
" " " "	18,000	" "	6
" " " "	12,000	" "	13
" " " "	5,955	" "	9
" " " "	4,500	" "	12
" " " "	3,000	" "	17
" " " "	1,800	" "	24
" " " "	1,200	" "	27
" " " "	600	" "	63
" " less than	100	" "	319
		Total	492

The largest shock disturbed a *land* area of 34,700 square miles.

Out of the 492 shocks 279 originated beneath the sea or near the seashore. The district most shaken is the alluvial plain near Yedo (Tokio). The eastern and southern part of Japan, or that portion of the country facing the Pacific Ocean, is shaken very much more than the western side facing the Japan Sea. The northern half of the empire, that is to say the country north of Tokio, is shaken very much more than the southern half.

In Kiushiu, where volcanoes are numerous, earthquakes have not been so frequent as near the province of Kii, where there are no volcanoes. In two instances volcanoes and earthquakes appear to be related. Thus the earthquakes at the southern end of Satsuma occur at or near the volcanoes of that district, while the shocks at the north-east extremity of Honshiu occur at or near Osori-san. In the former district there were 9, and in the latter 24 local shocks recorded.

In the centre of Honshiu, near to Tokio, volcanoes are very numerous, and it is in this part of the empire that there is the greatest seismic activity, and it may also be added, abundant evidence of recent elevation.

The earthquakes, however, do not originate at the volcanoes. They originate near the coast, where evidences of elevation are to be seen.

On the opposite side of the island, where earthquakes are scarce, there are said to be evidences of depression.

The Volcanoes of Japan.

During the last year I have spent considerable time in arranging for publication the various notes which I have from time to time collected during the last ten years, relating to the volcanoes of Japan.

Many of these I have personally visited and ascended. In the account which I am giving of these mountains, I am intercalating notes obtained from friends, together with the more important portions of some thirty or forty Japanese works specially describing volcanoes in this country.

The chief results obtainable from this work are given in the following notes:

1. *Map of Volcanoes.*

Among the more important results which have been arrived at has been the compilation of the accompanying map. For assistance other than that mentioned in the preceding pages I have to thank Mr. Tsunashiro Wada, Director of the Geological Survey, who has already drawn up a map of the volcanoes in Japan; Mr. N. Fukushi, Director of the Survey Department in Yezo; and my own private assistant, Mr. Matoba Naka. The following tables form a key to the map:

KURILE ISLANDS.

NOTE.—There are therefore at least 23 well-formed volcanic mountains, and 16 mountains yet steaming in the Kurile Islands. Kurile is derived from the Russian *kooreet*, to smoke. The Aino name for the Kuriles also means The Smokers.

Name	Remarks
1. Shumshu . . .	Somewhat flat island.
2. Alaid . . .	A well-formed cone. Erupted in 1770 and 1793. Height about 7,000 feet.
3. Paramushir . .	Contains two well-formed cones and three or four less prominent peaks. Erupted 1737, 1742, and 1793. One cone steaming.
4. Shirinki . . .	A dilapidated cone and ridge.
5. Makanrushi . .	Contains five or six rugged peaks rising from the mass.
6. Onekotan . . .	Contains two well-formed cones.
7. Kharimkotan . .	Contains one well-formed cone. Erupted 1883.
8. Shaiskotan . .	Contains five or six peaks. Erupted 1855. Two cones steaming.
9. Ekarma . . .	Contains one fairly good cone and a ridge.
10. Chirimkotan . .	Contains one fairly good cone. It steams, and lava occasionally flows.
11. Musisir . . .	—
12. Raikoke . . .	Dilapidated cone. Erupted 1778 and 1780.
13. Matau . . .	A very well formed cone. Erupted 1878. Lava flows occasionally. Steaming.
14. Rashau . . .	Several rugged peaks. One peak steaming.
15. Ushishir . . .	One peak steaming.
16. Ketoy . . .	Several irregular peaks. Two are steaming.

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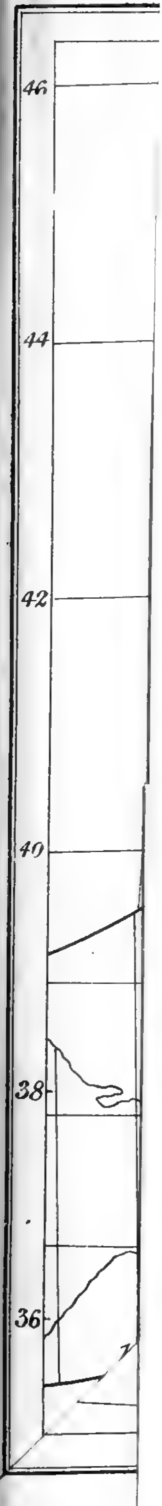

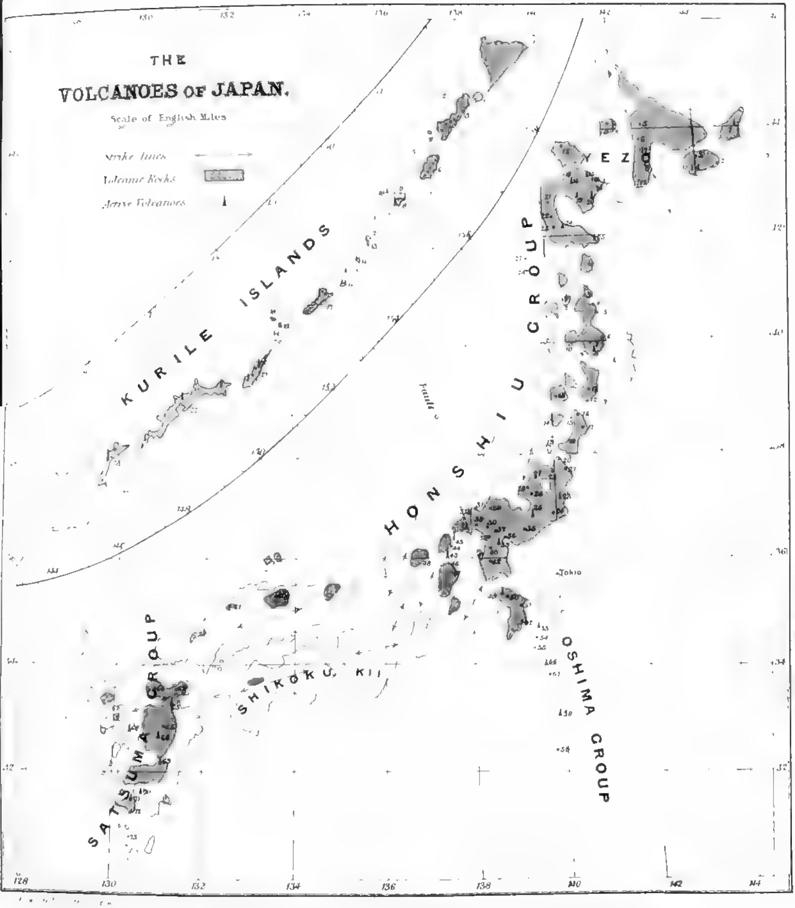

Illustrating the 6th Report of the Committee appointed to investigate the Volcanic Earthquake Phenomena of Japan.

Name	Remarks
17. Simshir	Three well-formed cones, Prevost peak being very noticeable. Violent eruption at the south end in September 1881. One peak steaming.
18. Makanruru	—
19. North Brother	Two good cones. One dilapidated. Violent eruption May and June 1879. Two peaks steaming.
20. South Brother	One dilapidated peak. (The active peaks shown on the map refer to the North Brother, No. 19.)
21. Urup	Three good cones, with very many more or less conical peaks rising from the interior. Two peaks steaming.
22. Iturup	Five good cones, with many imperfectly formed cones. Violent eruption in 1883. Two peaks steaming.
23. Kunashir	One good peak.

VOLCANOES OF YEZO.

Name	Height in feet	Remarks
1. Iwo-san	—	Active. There is here a cauldron of boiling mud and sulphur. The mountain is irregular in outline.
2. Kusuri	—	—
3. Oakan	—	Regular form.
4. Meakan	—	Active. Regular.
5. Nisuikawoshipe	7,000	Between Nisuikawoshipe and Tourawoshi there is a range of unnamed volcanic peaks.
6. Obutatishike	7,500	—
7. Kushambitz	—	Active.
8. Tourawoshi	—	—
9. Ofui	3,450	—
10. Shokambitz	7,200	—
11. Yubari	—	Here there is a group of volcanic peaks.
12. Shakotan	—	—
13. Raiden	3,250	—
14. Iwo-san	3,600	Active.
15. Shiribitz	—	Active. Regular.
16. Iniwa	—	Active.
17. Tarumai	—	Active. Volcanic cone eruption in the spring 1874, October 7, 1883, January 4, 1885, April 28, 1886.
18. Shiraoi	—	—
19. Usu	—	Active. Well-formed crater.
20. Noboribitz	—	Active.
21. Obira	—	—
22. Yurap	4,100	—
23. Nigorikawa	2,700	—
24. Komaga-take	3,380	Active. Volcanic cone regular on north side; well-formed crater; eruption on June 27, 1710, September 26, 1856.
25. Esan	1,920	Active. Irregular. Sulphur deposits.
26. Rishiri	—	—
27. Oshima	—	—
28. Koshima	—	—

NOTE.—There are therefore in Yezo at least 28 volcanoes. Of these three or four are regularly formed and eleven are still steaming.

VOLCANOES OF HONSHIU AND KIUSHIU.

Name	Height in feet	Nature of rocks	Remarks
1. Osori-san . .	3,200	Augite andesite with a little hornblende and quartz	On Osore-san there is a solfatara. Yake-yama has a well-defined form; a third crater is broken. There is a crater lake here.
2. Iwaki-san . .	5,260	—	Last eruption 1848. Regular form. Crater somewhat worn.
3. Hakko-san .	—	—	Three craters.
4. Herai-dake .	—	—	One crater.
5. Nakui-dake .	—	—	Volcanic nucleus.
6. A mountain between Nanashizure and Anhidake	—	—	Volcanic nucleus.
7. A mountain west of Biobudake	—	—	Volcanic nucleus.
8. Ganju-san . .	7,000	—	Last eruption 1824. Regular cone, with crater slightly steaming
9. Komaga-take .	—	—	Regular cone.
10. Moriyosh-zan .	5,800	Basalt and augite trachyte	Well formed, with crater.
11. Mikoma-dake .	—	—	Well formed, with crater.
12. Sukawa-dake .	—	—	Well formed, with crater.
13. Chokai-zan .	7,100	Basalt, augite andesite with a little hornblende	Regular cone, with three craters.
14. Gas-san . .	—	—	Volcanic nucleus.
15. Arakami-yama .	—	—	Two peaks (Arakami and Funagamine), and two craters.
16. A mountain to the N.W. of Arakami-yama	—	—	Volcanic nucleus.
17. Neshiroishi-yama	—	—	Crater and cone.
18. Zōō-san . .	—	—	Crater and cone.
19. Kokuzo-san .	—	—	Volcanic nucleus.
20. Adzuma-san .	—	—	Four craters.
21. Adachitaro .	—	—	One crater.
22. Bandai-san . .	5,800	Augite andesite with a little quartz	Last eruption 807. Irregular mountain with old lava streams and broken crater. Covered with vegetation.
23. Nasu-dake .	6,300	—	A solfatara and boiling stream. In eruption about 1880.
24. Shiowara-dake (Takahara)	—	—	Crater and cone.
25. Nekko-san. .	8,500	Augite andesite and basalt	Five craters. Nantai-san, Shirane-san (8,500), in eruption in June, 1872. Irregular crater. Komanako, Nyobo, Yu-dake, a solfatara.
26. Hiuchi-dake .	—	—	Cone and crater.
27. Sumon-dake .	—	—	Cone and crater.

VOLCANOES OF HONSHIU AND KIUSHIU—*continued.*

Name	Height in feet	Nature of rocks	Remarks
28. Komaga-take	—	—	Cone and crater.
29. Nayebaga-take	—	—	Cone and crater.
30. A mountainN.W. of Kusatsu	—	—	Cone and crater.
31. Mioko-san	—	—	Two craters, one a solfatara.
32. Yake-yama	7,800	Andesite	Cone and crater; near the top a solfatara. No lava, well formed.
33. Kurohime-yama	6,900	—	Cone and crater.
34. Renge-san	9,800	—	Two craters; Renge and Nosi-kusa.
35. Akagisan	6,045	Augite andesite	Two craters, one broken. A crater lake.
36. Haruna-san	3,438	Quartz, hornblende, andesite (dacite) hornblende, andesite	A crater lake. Altogether five craters. A solfatara.
37. Kusatsu-yama	6,500	Augite andesite, with a little olvine	Three craters with walls to form lakes. Sulphur deposits.
38. Adzuma-san	—	—	Cone and crater.
39. Asama-yama	8,800	Augite andesite	Well formed. Three craters; one, which is very deep, is steaming violently. Last eruption about 1870.
40. Miogi-san	—	—	Volcanic nucleus (?).
41. Yatsuga-dake	9,114	Basalt with augite andesite with a little hornblende	Two cones and craters (Yatsugadake and Tate-shima).
42. Raya-dake	—	—	Volcanic nucleus.
43. Tate-yama	9,400	Granite near base. Augite andesite, with hornblende, also with quartz	Two craters broken. Solfatara, irregular form. Last eruption 704.
44. Iyakushi-dake	—	—	A complete crater.
45. Yake-dake	7,953	Andesite	Three cones and craters (Yake-dake, Kasa-dake, Iwo-dake). Near top a solfatara, well shaped, no lava.
46. Norikurayama	10,447	Augite andesite, with hornblende	Three craters with lakes on top. Black scoria and lava flows.
47. Mitake	10,000	Obsidian, perlite, augite andesite, with hornblende	Five craters. Weathered and rugged on the top.
48. Haku-san	8,947	Half-way up sandstone. Augite andesite with quartz	Two craters and solfatara. Craters with water, sulphur deposits.
49. Fuji-san	12,400	Anorthite, basalt	Last eruption 1707. Regular form, with a crater 600 feet deep. A little steam escapes.
50. Ashidaka-yama	—	—	Two craters.
51. Hakone-yama	4,474	Basalt and augite andesite	Three craters (Kamuriga-dake, Komaga-dake, Futago-yama) crater lakes.
52. Amagi-san	4,700	Obsidian, augite andesite, basalt	—

VOLCANOES OF HONSHIU AND KIUSHIU—*continued.*

Name	Height in feet	Nature of rocks	Remarks
53. O-shima	2,500	Augite andesite	Last eruption 1876. Crater gives off steam.
54. Nii-shima	1,400	—	—
55. To-shima	1,730	—	—
56. Miake-shima	—	—	Last eruption 1876. Black flattish cone.
57. Mikura-shima	—	—	—
58. Hachijō	2,840	—	Last eruption 1789–1801.
59. Aoga-shima	1,500	—	Distinct crater. Vegetation on the cone and in the crater.
60. Daisen	—	Augite andesite	Cone and crater.
61. Mikame-yama	—	—	Cone and crater.
62. Futago-yama	—	—	Cone and crater.
63. Tsumuri-san	—	—	Last eruption 867. Five craters and peaks, one solfatara.
64. Hiko-san	—	—	Volcanic nucleus.
65. Kiucho-san	—	—	Four cones and craters (Kurodake, Kiuchosan, Waiita-yama, a solfatara).
66. Aso-san	5,000	Augite andesite, basalt	Large crater 10 miles diameter. Central cone steaming.
67. Tar-dake	—	—	Broken crater.
68. Onsen-dake	—	Hornblende andesite with a little quartz	Broken crater and solfatara. Last eruption 1791. Irregular form.
69. Kirishima-yama	4,816	Augite andesite	Last eruption 1772. Well formed. Eleven complete craters.
70. Sakura-jima	3,060	Augite andesite glass	Three craters.
71. Ikeda-yama	3,069	Augite andesite	Four craters (Kaimon-dake, two solfataras).
72. Hirakiki-yama	—	—	Last eruption 1615.
73. Iwoga-shima	2,331	—	These islands are yet active. There are other islands in the chain stretching towards Formosa, of volcanic origin.
Yerabu-shima	2,297		
Naka-shima	3,400		
Kaminone	972		
Yoko-shima	1,700		
Iwo-shima	541		

In Honshiu, Kiushiu, and the southern islands there are at least seventy-eight volcanoes. Out of these about twelve have well-formed cones and twenty-four are still steaming.

2. *Number of Volcanoes.*

Because Japan has not yet been completely explored, and because there is considerable difficulty in defining the kind of mountain to be considered as a volcano, it is impossible to give an absolute statement as to the number of volcanoes in this country. If under the term volcano we include all mountains which have erupted within the historical period, those which have a true volcanic form, together with those which still exhibit materials on their flanks, which have been ejected from a crater, traces of which can still be seen, we may conclude that there are *at least*

100 such mountains in the Japanese empire. These mountains are distributed as follows:

Northern Region	Kuriles	23
	Yezo	28
Central Region	Northern Honshiu Central Honshiu Oshima Group	35
Southern Region	Southern Honshiu	1
	Kiushiu Southern Islands	13
	Total	100

If we add to our list the ruins and basal wrecks of volcanic cones, this number is considerably increased.

The number of mountains which are easily recognisable as being of volcanic origin as given in the map is 129.

Of this number about 51 are still active, that is to say, are now giving off steam. These active volcanoes are distributed as follows:

Northern Region	Kuriles	16	27
	Yezo	11	
Central and Southern Region			24
	Total		51

Out of the 129 volcanoes, 39 are symmetrically formed cones.

The greatest proportion of regularly formed mountains and of mountains yet giving off steam are in the Kuriles. From this it may be argued that the mountains in the north are younger than those in the middle and south.

3. *Number of Eruptions.*

Altogether in the preceding pages about 233 eruptions have been recorded. The distribution of these in the different districts, and with regard to time, is shown in the accompanying table. The greater number of records in the southern districts, as compared with the northern districts, may be accounted for by the fact that Japanese civilisation advanced from the south. In consequence of this, records were made of various phenomena in the south, while the northern districts were unknown and unexplored regions. The greater number of eruptions have taken place in the months of February and April. Comparing the frequency of eruptions in the different seasons, the volcanoes of Japan appear to have followed the same law as the earthquakes; a greater number of eruptions having taken place during the cold months. This winter frequency may possibly be accounted for in the same manner that Dr. Knott accounted for the winter frequency of earthquakes. During the winter months the average barometric gradient across Japan is steeper than in summer. This, coupled with the piling up of snow in the northern regions, gives rise to *long-continued* stresses, in consequence of which certain lines of weakness of the earth's crust are more prepared to give way during the winter months than they are in summer.

Eruptions in Relation to Months and Seasons.

SOUTHERN DISTRICT.

—	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Unknown	Total
Aso-san	2	12	2	5	3	2	4	8	4	2	6	9	8	67
Sakurajima	—	1	1	4	1	—	2	2	5	2	2	1	6	27
Kirishima	—	1	2	—	1	—	—	1	—	—	1	2	17	25
Tsumuri-zan	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Onsen-dake	—	—	—	—	—	—	—	—	—	—	1	—	—	1
Islands near Satsuma	2	—	—	—	1	1	1	—	1	1	—	1	3	11
Hirakiki-yama	—	—	—	1	1	—	—	1	—	—	2	—	1	6
Kiushiu District	4	14	5	10	7	3	7	12	10	5	12	13	36	138

CENTRAL DISTRICT.

—	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Unknown	Total
Vries Island Group	1	1	2	—	1	—	2	1	—	—	1	2	7	18
Fuji-san	—	—	—	2	—	1	—	1	—	—	—	1	6	11
Asama-yama	3	2	—	4	1	1	2	1	—	1	2	1	4	22
Tate-yama	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Natsu-yama	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Ganju-san	—	1	—	—	—	—	—	—	—	—	1	—	—	2
Iwaki-zan	1	1	2	4	—	—	—	—	—	—	—	—	—	8
Central District	5	5	4	10	2	2	4	3	—	1	4	4	19	63

NORTHERN DISTRICT.

—	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Unknown	Total
YEZO :—														
Komaga-take	—	—	—	—	—	1	—	—	1	—	—	—	—	2
Tarumai	1	1	1	—	—	—	—	—	—	1	—	—	—	4
KURILE ISLANDS :—														
Alaid	—	1	—	—	—	—	—	—	—	—	—	—	1	2
Paramushir	—	—	—	—	—	—	—	—	—	—	—	—	4	4
Makanrushi	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Shaiskotan	—	—	—	—	—	—	—	—	—	—	—	—	2	2
Ikarma	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Chirimkotan	—	—	—	—	—	—	—	—	—	—	—	—	2	2
Matau	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Raikoke	—	—	—	—	—	—	—	—	—	—	—	—	2	2
Rashau	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Ushishir	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Ketoy	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Simushir	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Brat Chirnoi	—	—	—	—	—	—	—	—	—	—	—	—	2	2
Urup	—	—	—	—	—	—	—	—	—	—	—	—	2	2
Iturup	—	—	—	—	—	—	—	—	—	—	—	—	2	2
Kunashiri	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Northern District	1	2	—	1	—	1	—	—	1	1	—	—	25	32
Total	10	21	9	21	9	6	11	15	11	7	16		80	233
		40			36			37			40			

Winter Months, 80; Summer Months, 73; Unknown, 80: Total, 233.

4. *Position and Relative Age of Japanese Volcanoes.*

The youngest of the Japanese volcanoes appear to be those which exist as or on small islands. On the islands in the Kuriles, in the Oshima Group, and in the Satsuma Sea, many of the volcanoes are yet young and vigorous. Further, many of these islands have been formed during the historical period. The island-forming period in the Satsuma Sea occurred about the year 1780.

Looked at generally, the volcanoes of Japan form a long chain running from the N.E. towards the S.W. A closer examination of the distribution of the volcanic vents shows that there are probably four lines.

1. The N.E. S.W. line running from Kamtschatka through the Kuriles and Northern Yezo.

2. The curved line following the backbone of Honshiu and terminating on the western side of the Yezo anticlinal.

3. The N.N.W. S.S.E. line of the Oshima Group. This line, coming from the Ladrones, passes through Oshima and Fujisan parallel to and near to the line of a supposed fault. Here it intersects the main line running through Honshiu. Volcanic vents are here very numerous. As the Honshiu line is intersected, while the Oshima line is the intersector, it may be argued that the Oshima-Fujisan line of volcanoes are younger than many of those on the Honshiu line.

4. The Satsuma line, coming from the Philippines through Sakurajima and culminating in the famous Mount Aso, which is the nucleus of Kiushiu.

5. *Lithological and Chemical Character of Lavas.*

Although I have made an extensive collection of the volcanic rocks of this country, opportunity has not hitherto presented itself for their examination. I can therefore only speak of them in general terms. They are now, I believe, being carefully studied by the officers of the geological survey of Japan. The rocks in my possession are chiefly andesites. Those containing augite, like the rocks of Fujisan, as pointed out by Mr. Wada, the director of the geological survey, closely approximate to basalts. True basalt is, however, rare. Another common rock is hornblende andesite, some of which contains free quartz. Quartz trachytes occur in the north of Japan. The following table, which is chiefly drawn up from material kindly placed at my disposal by Mr. Wada, shows the percentages of silica, ferrous and ferric oxide contained in the rocks of ten volcanoes:

PERCENTAGE OF SIO.$_2$ FEO AND FE.$_2$ O$_3$ IN THE VOLCANIC ROCKS OF JAPAN.

Locality	Sio.$_2$	FeO	Fe.$_2$ O$_3$
1. Norikura	61.72	1.35	3.50
2. Mitake	59.97	3.27	3.86
3. Kusatsu (near Zi goedo Amiguchi)	61.49	3.30	4.35
4. Amagi (Hakone)	65.34	2.45	3.09
5. Komagadake	56.27	2.19	6.69
6. Moriyoshisan	56.17	2.65	4.15
7. Chokai	60.64	3.81	3.14
	54.55	5.19	4.42
8. Hakone (Tonosawa)	48.97	4.02	4.81
9. Fujisan	49.00	5.1	6.06
10. Oshima	52·00	13.70 (?)	—

One feature exhibited by the table is, that the rocks of Oshima, Fujisan, and Tonosawa are basic, while those like Chokaisan and Moriyoshiyama, belonging to the Honshiu line of volcanoes, are relatively acidic. More extended observations of this description may show that different lines of volcanoes have erupted different lavas, or that the lavas of different constitution are of different ages.

6. *Magnetic Character of Rocks.*

Mr. E. Kinch, when speaking of the soils in the neighbourhood of Tôkyô, makes special reference to the magnetite they contain. A great portion of this comes from the disintegration of volcanic rocks. Many of the Japanese lavas have a distinct effect upon a compass needle. The black lavas from the crater of Fujisan will deflect the needle of an ordinary compass through 180 degrees. Many of the pieces of lava are not only magnetic, but they are polar. Dr. E Naumann found a block of augite-trachyte on the top of Moriyoshisan which would deflect the needle of a compass through 155°.

The most curious observation made by this investigator was that the magnetic declination near to Ganju-san has during the last 80 years (when it was about 14.30 E.) decreased 19°, it now being about 5° W. As we recede from this mountain the amount of change has been less. Assuming this result to be correct, it would seem justifiable to look towards Ganju-san as connected with these local changes. Some of the volcanoes in the Kuriles are said to exert a marked influence upon the compasses of ships. When a vessel is lying near certain mountains, as for instance in Bear Bay, at the north end of Iturup, a distant mountain has a very different bearing to that which is indicated by the same compass when the vessel is a short distance outside Bear Bay.

In both cases the ship may be lying in the same direction, and the direction of observation is practically along the same line.

This leads me to repeat a suggestion that I have several times made during the last few years, namely, that a magnetic observatory be established on or near one of the more active volcanoes of this country. Many of these volcanoes, like that of Oshima (Vries Island), lie in the track of so many vessels that to determine whether local and rapid changes in magnetic declination are taking place in these localities appears to be a legitimate investigation. Changes in volcanic activity are probably accompanied by local changes in the magnetic effects produced by subterranean volcanic magmas. These changes may be due to alterations in position, alterations in chemical constitution, and changes due to the acquisition or loss of heat. If such is the case, the records of a magnetic observatory would lead us to a knowledge of changes taking place beneath the ground. When we remember that volcanoes like Oshima (Vries Island) lie in the track of so many vessels where it seems probable that there may be local and rapid changes in magnetic variation taking place, it seems that the suggested investigations have a practical as well as scientific aspect. An investigation of earth-currents at and near volcanoes might be added to the magnetic investigations.

7. *Intensity of Eruptions.*

Judging from the accounts of eruptions which have been given in the preceding pages, it would appear that the intensity of volcanic action in

Japan has been as great as in any other portions of the world. One period of unusual activity was between the years 1780 and 1800, a time when there was great activity exhibited in other portions of the world. It was during this period that a portion of Mount Unsen was destroyed and from 27,000 to 53,000 persons perished; that many islands were formed in the Satsuma Sea; that Sakurajima threw out so much pumiceous material that it was possible to walk a distance of 23 miles upon the floating *débris* in the sea, and that Asama ejected so many blocks of stone, some of which are said to have been from 40 to over 100 feet in diameter, and a lava stream 68 kilometers in length.

8. *The Form of Volcanoes.*

The form I particularly refer to is the regular so-called conical form, which is very noticeable in many of the Japanese mountains, especially perhaps in those of recent origin. Outlines of these volcanoes, as exhibited either by sketches or photographs, show curvatures which are similar to each other. In the Kurile Islands I have had opportunities of comparing two volcanoes by so altering my position until one of the mountains partially eclipsed another standing at no great distance in the background. One of these mountains was Otosoyama (Mount Fuss). The other mountain, like many of the peaks in the Kurile Islands, is without a name.

From a collection of photographs, I traced the profiles of a number of important mountains in this country. These profiles are repeated in this paper. From an examination of these figures I found that the curvature of a typical volcano was logarithmic, or in other words the form of such a mountain was such as might be produced by the revolution of a logarithmic curve round its asymptote. In my original paper on this subject I said that the form agreed with that which would be produced by the piling up of loose material. As pointed out by Mr. George F. Becker, in a paper on the form of volcanic cones, &c. ('American Journal of Science,' October 1885), I ought to have said it was the form due to a self-supporting mass of coherent material. Mr. Becker continues my observations by an analytical investigation of the conditions of such equilibrium. If the height of a column is a, its radius y, the distance of any horizontal plane from the base x, the specific gravity of the material r, and the coefficient of resistance to crushing at the elastic limit k, then the equation of the curve which, by its revolution about the x axis, will generate the finite unloaded column of 'least variable resistance' is

$$\frac{y}{c} = \frac{e^{\frac{-x}{c}} - e^{\frac{x}{c}}}{2}$$

Where $c = \frac{2k}{r}$

This latter quantity is of course different for different materials. It can be expressed in terms of x and y

$$\frac{2k}{r} = \frac{y}{(\tan^2 d - 1)^{\frac{1}{2}}}$$

d being the angle which the tangent at any point makes with the x axis.

The value c can be obtained from photographs or drawings of a mountain, while r may be obtained from pendulum experiments or from specimens of volcanic material. With these data we can determine the modulus of resistance for the elastic limit of the materials which compose a mountain on a large scale, for many constituents of the earth's crust.

Mr. Becker concludes his observations by remarking that a study of the form and dimensions of lunar volcanoes would lead to values of $\frac{k}{r}$, whence we might approximately determine whether the lunar lava is similar to that of terrestrial origin.

In the following table I have followed out Mr. Becker's suggestion and calculated 'the modulus of resistance to crushing at the elastic limit in lbs. per square foot for a number of Japanese mountains.'[1] The different values for $\frac{2k}{r}$ for the same mountain are in great measure due to my not being able to obtain an accurate scale for the various photographs which had to be investigated. Another difficulty was obtaining a value for r or the density of the mountain. Professor T. C. Mendenhall, who made a number of experiments with pendulums on the summit of Fujiyama, says the rocks of that mountain have a density of 1.75. This is when they have air in their pores. As powder, the density becomes 2.5. Wada gives the specific gravity of the rock on Fujisan as 2.6. Assuming the density of the earth at 5.67 (Bailey) then the density of Fujisan, as determined by Professor Mendenhall's experiments, is 2.08. In my calculations for the following table I have assumed a density of 2.5 for the materials of all the mountains mentioned.

—	Height in feet	$\frac{2k}{r}$	$\frac{k}{r}$	Load in lbs. per square foot	Kind of profile examined
Fujisan	12,441	4,200	—	—	Photograph.
	—	5,000	—	—	Photograph.
	—	4,240	—	—	Photograph.
	—	3,500	—	—	Photograph.
	— —	5,420 5,450	—	—	Photograph.
	—	5,440	—	—	Photograph.
	— —	3,945 4,133	—	—	Photograph.
	—	4,430	—	—	Surveyed section.
	—	3,640	—	—	Surveyed section.
Average for Fujisan	—	4,490	2,245	350,220	—
Iwaki-san	5,260	2,360	1,180	174,080	Photograph.
Nantai-san. . . .	3,800[2]	2,000	1,000	156,000	Photograph.
Alaid	7,773 —	2,195 2,120	1,078	163,168	Photograph.
Krakatoa (Java). .	2,745 —	1,310 1,310	655	102,180	Surveyed section.

Comparing the results given in the above table with the numbers in the following table, which are based on experiments referred to in Ran-

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[1] It will be noticed that there is difficulty in defining the quantity $\frac{2k}{r}$, as calculated from the shape of a mountain. It is assumed that the materials are not crushed.

[2] This is the height above Lake Chuzenji.

kine's 'Civil Engineering,' we may say that the average strength of Fujisan lies between that of rubble work and sandstone. Iwaki-san, Nantai-san, and Alaid are like good rubble masonry, while the strength of the ill-fated Krakatoa is not much above that of ordinary brickwork. In making the above calculations I have used:

1. The profiles of volcanoes traced from photographs which I used in my original communication on the forms of volcanoes published in the 'Geological Magazine.'

2. A series of tracings from photographs of Fujisan and other mountains not hitherto published. For most of these a scale can be obtained. The best scale for Fujisan is probably the difference in height of Hoyei-san and the summit. Hoyei-san is a parasitic crater on the southern side of Fuji and in the profiles is marked H. This difference in height is about 4,137 feet.

A scale may also be obtained from the line of sea-level or from the diameter of the crater, which is about 750 metres.

Two profiles of Fujisan from the surveys of Mr. O. Schütt are also given.

Causes modifying the natural curvature of a mountain and therefore interfering with the above calculations are:

1. The tendency, during the building up of the mountain, of the larger particles to roll farther down the mountain than the smaller particles.
2. The effects of atmospheric denudation which carries materials from the top of the mountain down towards the base.
3. The position of the crater and the direction in which materials are ejected.
4. The existence of parasitic craters on the flanks of a mountain.
5. The direction of the wind during an eruption.
6. The sinking of a mountain in consequence of evisceration beneath its base.
7. The expansions and contractions at the base of a mountain due to the acquisition or loss of heat before and after eruptions.

9. *Theoretical Mountains.*

As it might be interesting to compare actual mountains with theoretical mountains constructed from the equation $y=\frac{c}{2}\left(e^{-\frac{n}{c}}-e^{\frac{n}{c}}\right)$ such mountains have been drawn.

The values of c are given in the following table:

Material	Instantaneous breaking strength in lbs. per sq. foot	Crumbling strength or k in lbs.	Weight. Cubic foot lbs.	$c=\frac{2k}{r}$
Granite	1,584,000	1,580,000	170	18,500
Sandstone	790,000	590,000	144	8,200
Rubble masonry . . .	316,000	150,000	120	2,500
Brickwork	144,000	72,000	112	1,300

In drawing up the table, I have taken the instantaneous breaking strength of granite and its crumbling strength, which is the largest possible value for k, as being equal. For sandstone I have assumed the crumbling strength as being three-quarters of the breaking strength, while for rubble work and brickwork it has been taken as one-half. (*See* Rankine's 'Civil Engineering,' p. 361, &c.)

The diameter of the base of each of these mountains is 48,000 feet, and the height to which mountains of the following different materials could be built upon such a base without crushing would approximately be:

Brickwork	4,600 feet.
Rubble masonry	7,300 "
Sandstone	14,500 "
Granite	20,000 "

10. *Effect of Volcanic Eruptions on the People.*

From the translations of Japanese works relating to volcanoes which I have given, it is seen that the eruptions of these mountains have from time to time exerted a very marked influence upon the minds of the Japanese people. Divine interference has been sought to prevent eruptions, priests have been ordered to pray, taxes have been repealed, charities have been instituted, special prayers against volcanic disturbances have been formulated and have remained in use for the period of one hundred years, while special days for the annual offering up of these prayers have been appointed. At the present day there is a form of worship to mountain deities not uncommon, which may have had its origin through the fear created by volcanic outbursts. Displays of volcanic activity have certainly intensified this form of worship.

Conclusion.

In conclusion to this report, it gives me pleasure and satisfaction to testify to the great work which has been accomplished, and the great interest which is still being displayed in connection with seismological investigation in this country. Professor Forrel, of Switzerland, speaking at the Institution of Civil Engineers, testified to the great merit of the work which has been accomplished in Japan, and remarked that the observers of seismographs in that country had in two years accomplished more than twenty centuries of European science had been able to show ('Minutes of Proceedings of the Institution of Civil Engineers,' vol. lxxxvi., session 1885–6, part 1, p. 40). Inasmuch as the grants of the British Association have in no little measure assisted towards whatever may have been done in Japan, it cannot fail to be of interest to the members of that Association to know the extent to which they have rendered assistance in advancing seismological science in Japan.

With the assistance of the British Association, an extensive series of experiments lasting over several years were made upon artificially produced disturbances, which led to an insight into the nature and method of propagation of earth-vibrations. It was with the assistance of the British Association that a general seismic survey was made of North Japan. One result of this work has been that the Imperial Government of Japan has extended similar observations over the whole empire, and now there are about 600 stations at which earthquakes are recorded. The first complete seismograph made under the auspices of the British Association has been reproduced in this country, and is now being gradually distributed throughout the empire.

The Imperial University has endowed a chair of seismology, which is held by Mr. K. Sekiya, an indefatigable worker at earthquake phenomena, and has established a well-equipped earthquake observatory. The Imperial Meteorological Department has also established an observatory, at which, in addition to the ordinary work of observing, they make and test instruments to be used in the country.

In these and other ways is Japan working at a study which for many years has made but little progress.

One valuable work towards which the Government of this country is at present directing its attention is, how and where to construct buildings which either partially or wholly may escape the effects of earthquake movement.

With these few general remarks on what is being accomplished in Japan, the members of the British Association will recognise that their endeavour to give an impetus to scientific investigation in the far East has not been unsuccessful.

The Modern Development of Thomas Young's Theory of Colour-vision. By Dr. ARTHUR KÖNIG.

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

§ 1. IN the third book of his 'Optics' Isaac Newton puts the question, whether the sensation of colour is brought about by some sort of vibrations which the light produces in the constituents of the retina.

In a paper read before the Royal Society of London in 1801 Thomas Young makes an observation bearing upon this statement of Newton, in which he points out that the number of those vibrations depends on the nature of the above-mentioned constituents.

The infinite number of perceptible colours requires an infinite number of various constituents in each surface element of the retina. This is an impossible supposition. But we can explain all phenomena of colour-perception by supposing that each surface element of the retina consists of three constituents, each of which, when affected, causes a different colour-sensation. On this supposition all the various shades of colour are resultants of three fundamental sensations originating in those constituents. Later on Thomas Young proposes red, green, and violet as these fundamental sensations. It is true that he does not explicitly say that the sensation of white is the resultant of the simultaneous action of all the three constituents, but this is a self-evident conclusion if his supposition is to explain the famous experiment of Newton.

The principle which he intuitively laid down for the more limited field of the theory of colour-vision was, a quarter of a century later, brought out again by Johannes Müller under the name 'the law of specific energy of the organs of sensation' ('Gesetz der specifischen Energie der Sinnesorgane'), and proved to hold good for the whole field of physiology.

It is little known that the insight of Thomas Young had even a greater depth. He had already explained that the confusion of colours, which his contemporary Dalton made, was a consequence of the absence or paralysis of those fibres of the retina—as he calls them—which are calculated to perceive red. Thus the theory of colour-vision, accepted up to the present date, was already established in principle.

The knowledge of facts was too meagre as yet to prove the ideas of Thomas Young, and, therefore, they were gradually more and more disregarded. It was not until thirty years ago that Maxwell and Helmholtz saved them from utter oblivion. The former even attempted an experimental quantitative demonstration of the truth of these ideas.

The methods and the results of Maxwell's investigations are too well known to be specially dwelt upon here. But we must specially dwell upon this point, that at the same time Helmholtz most emphatically declared that colour-blindness (which in the meantime was better studied) was the result of the absence of one fundamental sensation, although he did not know Thomas Young's ideas on this point.

The results of Maxwell's investigation must be greatly valued, because they contained the first measurements with spectral light; but for the very same reason, that they were the first, they could not be such that final conclusions could be drawn from them.

During the last ten years—that is, twenty years after Maxwell's investigations—the well-known scientists Kries, Frey, Donders, and Lord Rayleigh, supplied with greatly improved instruments, carried out more exact measurements, which, however, extend only over certain parts of the spectrum. These facts, and the circumstance that great facilities were offered at the physical laboratory of the University in Berlin for investigations of this kind, induced me to take up these measurements and to extend them over the whole spectrum, and they were finally carried out by me and my colleague Dr. Dieterici.

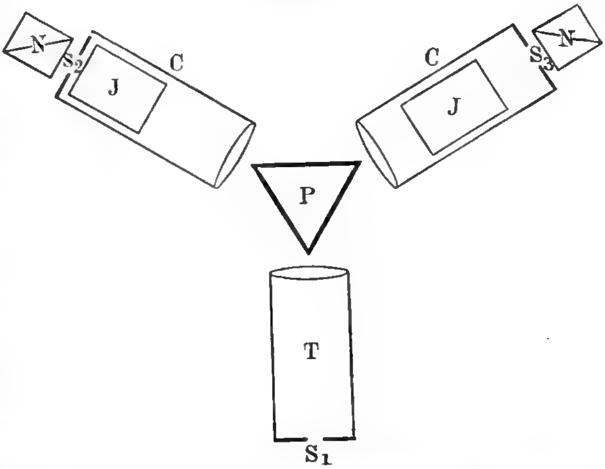
§ 2. The investigation must begin with the reduction of the infinitely large number of colour-sensations to the smallest possible number of *elementary sensations*, which by their intensity and mutual relation produce every possible kind of colour-sensation. This is a purely experimental problem, whose solution can and will be made independent of every theoretical hypothesis. This is the reason why we choose the expression 'elementary sensation' and not 'fundamental sensation,' because the latter expression usually refers to a simple process going on at the terminal of the optical nerve. This distinction is necessary, as will appear later on.

The first important simplification of our problem is afforded by the fact that in the case of every individual we can produce every sensation of colour by spectral light and their mixture. It seems expedient here to lay down the following definition: given that the distribution of light in our spectrum is such as we have it in a diffraction-spectrum, then we shall call 'curves of elementary sensation' those curves which determine the intensity of elementary sensation for any given wave-length.

Having premised this definition we can at once proceed to a brief description of the apparatus.

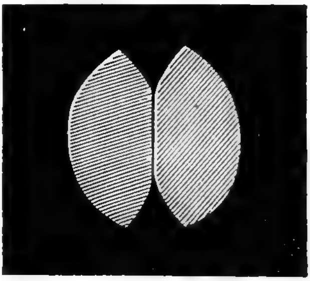
It is an apparatus constructed by Prof. Helmholtz for mixture of colours, and on this occasion improved by us in many details. It is a spectroscope with an equilateral prism P (fig. 1), and two collimators C C; the telescope T having instead of the eye-piece a slit S_1 at the focus of its object-glass. Each collimator contains an achromatical iceland-spar J, and in front of the slit a Nicol N; but for the present we shall disregard these additions to the collimators. The slits S_2 and S_3 being illuminated we shall evidently have two spectra at the slit S_1 superposed one over the other. An eye placed close before the slit S_1 sees a picture like fig. 2. A little consideration will make it plain to us that the coloured parts in the figure are the two faces of the prism shining with that light, which coming from them passes through the slit S_1 to our eye.

FIG. 1.



Let us consider the effect of placing the iceland-spar between the slit and the object-glass of the collimator. This effect will be that in general we shall have two pairs of spectra at S_1, one pair due to slit S_2, the other due to S_3, and that the lights of one pair belonging to the same slit will be polarised perpendicularly to each other. It is evident that an eye placed close before the slit S_1 will see the same picture as before, but now we do not see in each half monochromatic light, but a light which is the resultant of two component lights, and now the object of interposing the Nicol between the slit and the source of light is simply to vary the ratio of these two components to each other. When the iceland-spar is quite close to the slit we have monochromatic light in the corresponding half of the picture.

FIG. 2.



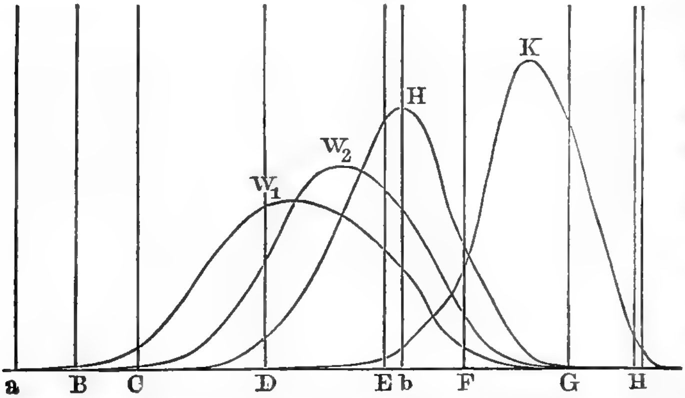
(The two parts of this figure, which are differently hatched, are supposed to be differently coloured.)

In this manner we can compare monochromatic light with monochromatic, a mixture of two components with monochromatic and two such mixtures. This comparison consists in producing the same shade of colour and the same intensity in each half of our picture, which gives us a colour-equation. A great number of such colour-equations was made by those persons whom we examined.

The coefficients and variables of the equation are given by the position of the collimators, the distances between the iceland-spars and the slits, the positions of the Nicols, and the micrometrically measured width of the two bilateral slits. The source of light was a specially constructed gas-lamp, so that our direct results had, of course, reference to the prismatic spectrum of a certain kind of gaslight. But in order that they should have a general character we calculated what they would have been if we had employed a diffraction spectrum of sunlight. Of course I cannot think of entering upon the description of a great many and very interesting details of our proceeding. I shall therefore pass over directly to the results of our investigation.

§ 3. (*a*) There are persons who can distinguish no different shades of colour, and therefore the world, as far as colour is concerned, appears to them like an engraving or a photograph to us. Such persons, whose number is very small, have one elementary sensation only. I have met one such a person, and the curve of elementary sensation which we obtained from him is the curve H in fig. 3. Professor Donders has made the same curve for another similar individual and has obtained almost identical results. So that we may regard this as a typical form for monochromatic colour-systems.

FIG. 3.



(*b*) There is another very numerous class of persons, generally called colour-blind, in whose case we can divide the whole spectrum into three parts. The parts near the ends we shall call 'boundary regions' and the parts between them the 'interval.' For these persons each boundary region has its own light, varying in intensity only but not in colour, and the colour of any part of the interval they can produce by the mixture of the light of two parts, one from each boundary region. Here we must assume two elementary sensations, and the simplest way to analyse the colour-system of such persons is to take the sensations of the boundary regions as elementary sensations. On these assumptions we have determined the curves of elementary sensations for this class of persons.

We have obtained three different curves. The curve K in fig. 3 was obtained from every person but the other curve was different with different persons. Some had the curve W_1, others had the curve W_2. So that as far as our own observations go we must distinguish all the colour-blind into two classes, and two classes only. A third very different class of the colour-blind was found by Professors Holmgren and Donders. But their analysis was a qualitative one only. For the purpose of simplifying calculations, which I shall mention later on, the curves were drawn in such a manner that the area bounded by them and the axis of abscissæ should be the same for each curve.

So far we have two large classes of persons, and we have seen that the small number of persons belonging to the first class possess one elementary sensation only, whereas the large number of persons belonging to the second class possess two elementary sensations, and we have also seen that this class must be subdivided into two divisions or types.

(*c*) Now we pass over to the third very large class, which includes all persons not belonging to any of the two preceding classes. We shall presently see that if in the case of these persons we assume three elementary sensations, we shall be able to explain all colour-equations made by them.

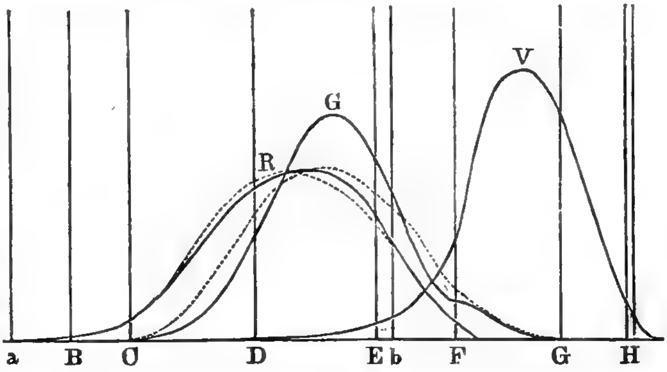
It has been found by Lord Rayleigh and Professor Donders that the persons of this class differ from each other considerably, and that this class, too, must be divided into two subdivisions at least; the persons belonging to the first subdivision forming the great majority of this third class, whereas the persons of the second subdivision are not more numerously represented than the persons of the preceding class.

A person of this third class on examining the spectrum finds two boundary regions situated similarly as in the preceding class, and we assume, as we did before, that the colour-sensations of these regions are elementary sensations. The parts from the boundary regions to a certain distance towards the middle of the spectrum we shall call the 'boundary intervals,' and the remaining part between them we shall call the 'central interval.' The colour-equations have shown that in each boundary interval we must assume two elementary sensations, one which is the same for both, whereas the other is the elementary sensation of the adjoining boundary region, and similar equations have also shown that any colour of the central interval is the result of the three elementary sensations already found, that is, the sensations R, G, and V. I would like to mention here that only such colour-equations could be used, in the case of which the colours as to their hue and saturation could be easily matched, and in whose combination the errors of observation had no great influence upon the results of calculation.

To obtain the first object whitish colours had to be avoided, and only neighbouring parts of the spectrum had to be mixed; whereas to obtain the second object the component parts of the spectrum had to be at a considerable distance from each other. This, of course, places the experimenter in a sort of dilemma, and many thousands of colour-equations had to be produced before the proper ones were obtained.

The continuous curves R, G, and V (fig. 4) belong to the first subdivision of this third class, and the two dotted curves together with the curve V belong to the second subdivision. I shall henceforth denote the colour-sensations of the first subdivision as the normal, and those of the second as the abnormal.

FIG. 4.



§ 4. Having accomplished the analysis of colour-sensations without the assistance of any hypothesis let us consider whether we can draw any inferences as to the physiological process which produces the sensations of colours. Following the above-mentioned usual definition, we shall call that sensation, which is caused by a simple process at the terminal of the optical nerve, a 'fundamental sensation.' It is evident that for every person the number of fundamental sensations is equal to the number of elementary sensations, and that we can speak of 'curves of fundamental sensation' just the same as we did before of curves of elementary sensation. We shall employ the following symbols for fundamental sensations:—

For the first class			$\mathfrak{H}$
" " second "	first	type	$\mathfrak{W}_1$, $\mathfrak{K}_1$
	second	"	$\mathfrak{W}_2$, $\mathfrak{K}_2$
" " third "	normal		$\mathfrak{R}$, $\mathfrak{G}$, $\mathfrak{V}$
	abnormal		$\mathfrak{R}'$, $\mathfrak{G}'$, $\mathfrak{V}'$

All colour equations are known to be linear and homogeneous, and since both the elementary and the fundamental sensations are the solutions of these equations it follows that the fundamental sensations of every person must be homogeneous linear functions of his elementary sensations, and *vice versâ*. We know the elementary sensations, and hence we can write the following relations:—

I. $\mathfrak{H} = \mathrm{H}$
II. (1) $\mathfrak{W}_1 = \alpha_1' \mathrm{W}_1 + \beta_1' \mathrm{K}_1$ where $\alpha_1' + \beta_1' = 1$
$\mathfrak{K}_1 = \alpha_1'' \mathrm{W}_1 + \beta_1'' \mathrm{K}_1$ „ $\alpha_1'' + \beta_1'' = 1$
(2) $\mathfrak{W}_2 = \alpha_2' \mathrm{W}_2 + \beta_2' \mathrm{K}_2$ „ $\alpha_2' + \beta_2' = 1$
$\mathfrak{K}_2 = \alpha_2'' \mathrm{W}_2 + \beta_2'' \mathrm{K}_2$ „ $\alpha_2'' + \beta_2'' = 1$
III. (1) $\mathfrak{R} = a_n'.\,\mathrm{R} + b_n'.\,\mathrm{G} + c_n'.\,\mathrm{V}$ where $a_n' + b_n' + c_n' = 1$
$\mathfrak{G} = a_n''\,\mathrm{R} + b_n''.\,\mathrm{G} + c_n''\,\mathrm{V}$ „ $a_n'' + b_n'' + c_n'' = 1$
$\mathfrak{B} = a_n'''\mathrm{R} + b_n'''\mathrm{G} + c_n'''\mathrm{V}$ „ $a_n''' + b_n''' + c_n''' = 1$
(2) $\mathfrak{B}' = a_a'\,\mathrm{R}' + b_a'\,\mathrm{G}' + c_a'\,\mathrm{V}'$ „ $a_a' + b_a' + c_a' = 1$
$\mathfrak{G}' = a_a''\,\mathrm{R}' + b_a''\,\mathrm{G}' + c_a''\,\mathrm{V}'$ „ $a_a'' + b_a'' + c_a'' = 1$
$\mathfrak{R}' = a_a'''\mathrm{R}' + b_a'''\mathrm{G}' + c_a'''\mathrm{V}'$ „ $a_a''' + b_a''' + c_a''' = 1$

By means of these equations we can construct curves having the same relation to fundamental sensations as the others had to elementary sensations.

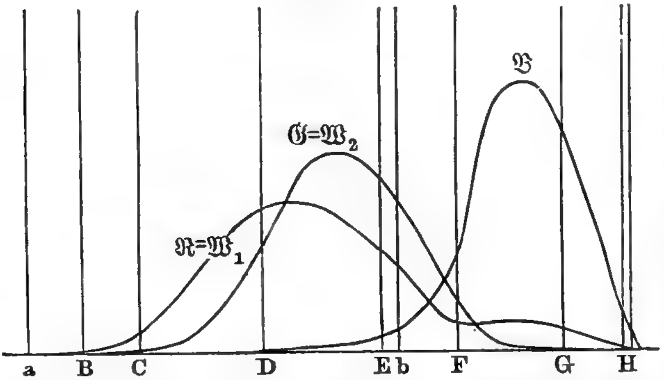
The object of this superposition is to examine whether among the infinite number of possible curves of fundamental sensations we can find three such curves that a person of the first class will have some one of them, a person of the second class will have some two of them, and a person of the third class will have all three of them. This of course would be the simplest relation between the three classes.

Such a relation was found to exist, but only after we disregarded the first class and the second (abnormal) division of the third class. But it is a remarkable circumstance that all persons of the first class so far known were found to have pathologically defective eyes.

The case of the first (normal) subdivision of the third class we shall presently discuss.

The result of those superpositions were the curve $\mathfrak{R}$, $\mathfrak{G}$, and $\mathfrak{B}$ in fig. 5. They all belong to the normal (the numerous) division of the third class. The curves $\mathfrak{R}$ and $\mathfrak{B}$ are identical with the curves $\mathfrak{W}_1$ and $\mathfrak{K}_1$ of the first, and the curves $\mathfrak{G}$ and $\mathfrak{B}$ with the curves $\mathfrak{W}_2$ and $\mathfrak{K}_2$ of the second type of the second class.

Fig. 5.



A much deeper insight into the nature of colour-sensations is obtained by examining more closely the case of the abnormal division of the third class. By the above-mentioned process of superposition we can get the two curves $\mathfrak{R}$ and $\mathfrak{B}$, but instead of the middle curve $\mathfrak{G}$ we get a transition form between $\mathfrak{R}$ and $\mathfrak{G}$.

Could we suppose that the first type of the second class is only a special case of the third class, namely, a case in which the curve $\mathfrak{G}$ has so far altered its form as to coincide with $\mathfrak{R}$, then the abnormal division would be a transition form. Are there any facts in our experience that could lead us on to make such an assumption? Before answering this question I must call your kind attention to the following circumstance:—

If we construct Newton's colour-diagram (fig. 6), we find that the colours of the three fundamental sensations are:—

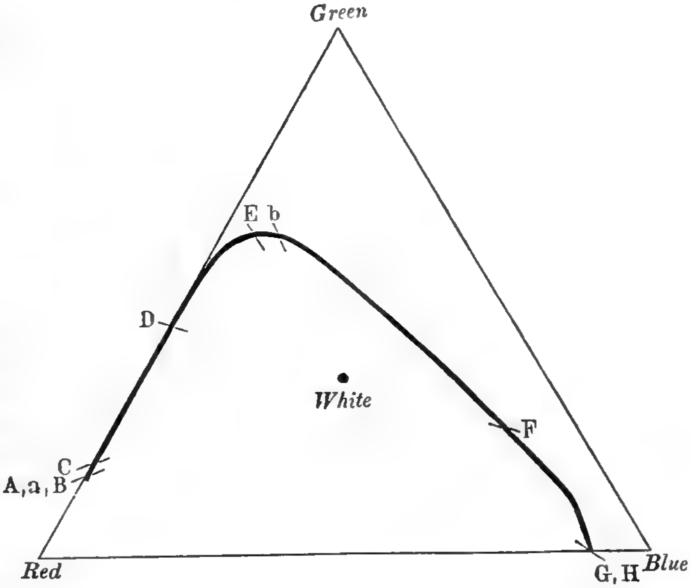
For $\mathfrak{R}$, red (somewhat more purple than the colour of the long-waved end of the spectrum).

For $\mathfrak{G}$, green (about the wave-length 505 $\mu\mu$).

For $\mathfrak{B}$, blue (about the wave-length 470 $\mu\mu$).

Assuming now that the colour of the fundamental sensation of $\mathfrak{G}$ remains the same, whereas the form of the curve is altered in such a manner as to coincide with $\mathfrak{R}$, it is evident that the sensation belonging to this curve would be a resultant of the sensations belonging to $\mathfrak{R}$ and $\mathfrak{G}_1$, that is, a yellow of about the wave-length 575 $\mu\mu$.

FIG. 6.



I need hardly mention that colour-sensations are entirely subjective, and that in general the colour-sensations of two classes cannot be compared to each other. Fortunately Professors von Hippel and Holmgren have met with a young man who with respect to his right eye belonged to the first type of the second class, and with respect to his left eye belonged to the normal division of the third class.

And this is the only person who can assist us in answering our question. His fundamental sensations for the first-mentioned eye were yellow and blue as compared to the sensations of the other, that is, the normal eye.

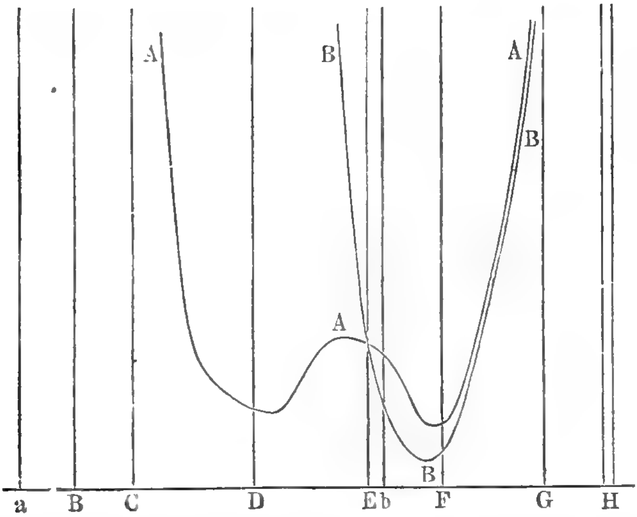
This circumstance, therefore, justifies us in assuming that the first type of the second class is a special case of the third class. But whether the second type is also a special case of the third class future experience only will show.

§ 5. The following experiments will serve as an additional evidence that our results are correct. These experiments were made at my instigation by Mr. Brodhun, a student in our laboratory.

Before entering upon the details of these experiments I must premise a few observations. According to our theory the colour at any part of the spectrum is determined by the ratio between the fundamental sensations, whose resultant produces that colour. The change of this ratio determines the rate at which the colour changes. A slight inspection of our fundamental curves shows that in the normal division of the third class there are two places in the spectrum at which the ratio of the fundamental sensations changes most rapidly, the one near the line D, the other near the line F.

Now what is the simplest experimental method for determining the places in the spectrum at which the change of colour is the most rapid? If we take a light of known wave-length, and match it to a part of another spectrum, simply by subjectively judging the colour, the difference in wave-length will give us the error of our judgment. Repeating this process with the same light at the same place a great number of times we shall obtain a mean error, which our judgment is apt to make in regard to this colour. It is evident that the smaller the change of colour at a given place of the spectrum the larger will be that mean error. This is the way in which Mr. Brodhun has determined experimentally the places in the spectrum at which the colour changes most rapidly. The curve A A A is the result of this sort of experimental investigation on a person of the third class. We see that the places of most rapid change of colour are about the lines D and F, and this agrees perfectly with what we have predicted from the inspection of our curves of fundamental sensation.

Fig. 7.



The curve B B B, which was obtained in the same way from a person belonging to the second type of the second class, shows that there is one place of most rapid variation of colour, and this agrees perfectly with the inferences which we can draw from the inspection of the two curves of fundamental sensation for this type.

These are the principal features of our investigation on this subject. Its result seems to prove that the views of Thomas Young, slightly modified by modern experimental research, are perfectly correct.

Thomas Young's theory of colour-vision, one of the most beautiful twigs in his laurel crown, after lying as it were buried in the darkness of oblivion for more than half of a century, was brought to light again by Maxwell and Helmholtz, and, as we have seen, modern science seems to have breathed into it a life of such vigour that it will flourish for ever.

On the Explicit Form of the Complete Cubic Differential Resolvent.

By the Rev. ROBERT HARLEY, *F.R.S.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

THIS paper is intended as supplementary to others relating to the theory of differential resolvents which I have had the honour to submit to the Section at former meetings of the Association (see 'Reports,' Transactions of Sections, 1862, pp. 4, 5; 1865, p. 6; 1866, pp. 2, 3; 1873, pp. 17–21; 1878, pp. 466–8).

About four years ago Mr. Robert Rawson and myself calculated by independent methods the complete cubic differential resolvent; in other words, we determined the explicit form of the linear differential equation of the second order which is satisfied by any root of the general algebraical equation (with unmodified coefficients) of the third degree. The result at which, after much labour, we both arrived has not hitherto been published; and I desire now to place it on record, indicating at the same time some of the details of my own calculation. The process employed by Mr. Rawson may be elsewhere explained.

Write the cubic equation in the form

$$ay^3+3by^2+3cy+d=0,$$

and consider the coefficients a, b, c, d as functions of a single parameter, say x. Differentiate with respect to x, and denote the differentiations by accents; then a slight reduction gives

$$y'=\frac{(a'b-ab')\,y^2+(a'c-ac')\,y+\frac{1}{3}(a'd-ad')}{a(ay^2+2by+c)}.$$

Integralise the function of y by any of the known methods, the result takes the form

$$\begin{aligned}\mathrm{A}y'=\{&(a'b-ab')y^2+(a'c-ac')y\\&+\tfrac{1}{3}(a'd-ad')\}\,(\mathrm{B}y^2+\mathrm{C}y+\mathrm{D}),\end{aligned}$$

where

$$\begin{aligned}\mathrm{A}&=a(a^2d^2-6abcd+4ac^3+4b^3d-3b^2c^2);\\ \mathrm{B}&=2a(ac-b^2);\\ \mathrm{C}&=-a^2d+7abc-6b^3;\\ \mathrm{D}&=-abd+4ac^2-3b^2c.\end{aligned}$$

Develop the right-hand member and eliminate all powers of y higher than the second by means of the original cubic.

We thus find

$$\square\, y'=\mathrm{E}y^2+\mathrm{F}y+\mathrm{G}\,. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

in which

$$\square=a^2d^2-6abcd+4ac^3+4b^3d-3b^2c^2,$$

the cubic discriminant;

$$\mathrm{E}=\begin{array}{r|r|r|r|l} -acd & \tfrac{1}{3}a'-2abd & b'+a^2d & c'-2a^2c & \tfrac{1}{3}d'\,; \\ +4b^2d & +2ac^2 & -abc & +2ab^2 & \\ -3bc^2 & & & & \end{array}$$

$$\mathrm{F}=\begin{array}{r|r|r|r|l} -ad^2 & \tfrac{1}{3}a'-acd & b'+abd & c'+a^2d & \tfrac{1}{3}d'\,; \\ +7bcd & -2b^2d & +2ac^2 & -7abc & \\ -6c^3 & +3bc^2 & -3b^2c & +6b^3 & \end{array}$$

$$\mathrm{G}=\begin{array}{r|r|r|r|l} 2bd^2 & \tfrac{1}{3}a'-ad^2 & b'+2acd & c'+abd & \tfrac{1}{3}d'. \\ -2c^2d & +bcd & -2b^2d & -4ac^2 & \\ & & & +3b^2c & \end{array}$$

Differentiate (1) and reduce. Then

$$\square^2y''=\mathrm{H}y^2+\mathrm{I}y+\mathrm{J} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

in which

$$\mathrm{H}=\square\mathrm{E}'-\square'\mathrm{E}-\frac{6b}{a}\mathrm{E}^2+3\mathrm{EF}\,;$$

$$\mathrm{I}=\square\mathrm{F}'-\square'\mathrm{F}-\frac{6c}{a}\mathrm{E}^2+2\mathrm{EG}+\mathrm{F}^2\,;$$

$$\mathrm{J}=\square\mathrm{G}'-\square'\mathrm{G}-\frac{2d}{a}\mathrm{E}^2+\mathrm{FG}.$$

The elimination of y^2 between (1) and (2) gives

$$\square^2\mathrm{E}y''-\square\mathrm{H}y'=(\mathrm{EI}-\mathrm{FH})y+\mathrm{EJ}-\mathrm{GH} \quad . \quad . \quad (3)$$

a result which admits of reduction, since both members contain the discriminant as a factor. For,

$$\mathrm{EI}-\mathrm{FH}=\square(\mathrm{EF}'-\mathrm{E}'\mathrm{F}) -\frac{2\mathrm{E}}{a}\{\mathrm{E}(3c\mathrm{E}-3b\mathrm{F}-a\mathrm{G})+a\mathrm{F}^2\}\,;$$

$$\mathrm{EJ}-\mathrm{GH}=\square(\mathrm{EG}'-\mathrm{E}'\mathrm{G}) -\frac{2\mathrm{E}}{a}\{\mathrm{E}(d\mathrm{E}-3b\mathrm{G})+a\mathrm{FG}\}.$$

Now

$$\mathrm{E}(3c\mathrm{E}-3b\mathrm{F}-a\mathrm{G})+a\mathrm{F}^2=\square\times$$

$$\begin{array}{r|r|l} ad^2 & \tfrac{1}{9}a'^2-2abd & b'^2+a^2cc'^2+a^3\tfrac{1}{9}d'^2 \\ -9bcd & +3ac^2 & \\ +9c^3 & & \end{array}$$

$$\begin{array}{r|r|r|r|l} +acd & \tfrac{1}{3}a'b'-abd & \tfrac{1}{3}a'c'-2a^2d & \tfrac{1}{9}a'd'+a^2d & b'c' \\ +6b^2d & -6ac^2 & +18abc & -3abc & \\ -9bc^2 & +9b^2c & -18b^3 & & \end{array}$$

$$\begin{array}{r|l} -4a^2c & \tfrac{1}{3}b'd'-2a^2b(\tfrac{1}{3}c'd'). \\ +6ab^2 & \end{array}$$

And

$$\mathrm{E}(d\mathrm{E}-3b\mathrm{G})+a\mathrm{FG}=\square\times$$

$$\begin{array}{r|l|l|l|l} -2bd^2 & \tfrac{1}{9}a'^2+acd & b'^2+a^2d & c'^2+a^2b & \tfrac{1}{9}d'^2 \\ +3c^2d & & & & \end{array}$$

$$\begin{array}{r|r|r|l|l} +ad^2 & \tfrac{1}{3}a'b'-4acd & a'c'+abd & \tfrac{1}{9}a'd'-2abd & b'c' \\ -3bcd & +6b^2d & +6ac^2 & & \\ & & -9b^2c & & \end{array}$$

$$\begin{array}{r|l|l} -a^2d & \tfrac{1}{3}b'd'-2a^2c & \tfrac{1}{3}c'd'. \\ +3abc & & \end{array}$$

We have, therefore, the differential equation

$$\begin{aligned}a\,\square\,\mathrm{E}y''-a\mathrm{H}y'+[a\mathrm{E}'\mathrm{F}+\mathrm{E}\{&(a^2d^2-7abcd+6ac^3)\tfrac{1}{3}a''\\&+(a^2cd+2ab^2d-3abc^2)b''-(a^2bd+2a^2c^2-3ab^2c)c''\\&-(a^3d-7a^2bc+6ab^3)\tfrac{1}{3}d''+(5ad^2-18bcd+18c^3)\tfrac{1}{9}a'^2\\&+3ac^2b'^2-(2a^2c-3ab^2)c'^2-a^3(\tfrac{1}{9}d'^2)\\&-(2acd-12b^2d+18bc^2)\tfrac{1}{3}a'b'-(4abd-6b^2c)a'c'\\&-(4a^2d-36abc+36b^3)\tfrac{1}{9}a'd'+(2a^2d-6abc)b'c'\\&+2a^2c(\tfrac{1}{3}b'd')\}]y+a\mathrm{E}'\mathrm{G}+\mathrm{E}\{-(2abd^2+2ac^2d)\tfrac{1}{3}a''\\&-(a^2d^2-abcd)b''+(2a^2cd-2ab^2d)c''\\&+(a^2bd-4a^2c^2+3ab^2c)\tfrac{1}{3}d''-(4bd^2-6c^2d)\tfrac{1}{9}a'^2\\&+acdb'^2-a^2b(\tfrac{1}{9}d'^2)+(ad^2-2bcd)a'b'\\&-(10acd-12b^2d)\tfrac{1}{3}a'c'-(13abd-30ac^2+18b^2c)\tfrac{1}{9}a'd'\\&-abdb'c'+(a^2d-abc)b'd'-(2a^2c-3ab^2)\tfrac{1}{3}c'd'\}=0,\end{aligned}$$

the full development of which is an equation containing no fewer than 423 terms; namely,

$\frac{1}{3}a' \times$	$b' \times$	$c' \times$	$\frac{1}{3}d'$
$-a^4cd^3$ $+4a^3b^2d^3$ $+3a^3bc^2d^2$ $-4a^3c^4d$ $-28a^2b^3cd^2$ $+37a^2b^2c^3d$ $-12a^2bc^5$ $+16ab^5d^2$ $-24ab^4c^2d$ $+9ab^3c^4$	$-2a^4bd^3$ $+2a^4c^2d^2$ $+12a^3b^2cd^2$ $-20a^3bc^3d$ $+8a^3c^5$ $-8a^2b^4d^2$ $+14a^2b^3c^2d$ $-6a^2b^2c^4$	$+a^5d^3$ $-7a^4bcd^2$ $+4a^4c^3d$ $+4a^3b^3d^2$ $+3a^3b^2c^2d$ $-4a^3bc^4$ $-4a^2b^4cd$ $+3a^2b^3c^3$	$-2a^5cd^2$ $+2a^4b^2d^2$ $+12a^4bc^2d$ $-8a^4c^4$ $-20a^3b^3cd$ $+14a^3b^2c^3$ $+8a^2b^5d$ $-6a^2b^4c^2$

$y''+$

$\frac{1}{3}a'' \times$	$b'' \times$	$c'' \times$	$\frac{1}{3}d'' \times$	$\frac{1}{3}a'^2$	$b'^2 \times$	$c'^2 \times$
$+a^4cd^3$ $-4a^3b^2d^3$ $-3a^3bc^2d^2$ $+4a^3c^4d$ $+28a^2b^3cd^2$ $-37a^2b^2c^3d$ $+12a^2bc^5$ $-16ab^5d^2$ $+24ab^4c^2d$ $-9ab^3c^4$	$+2a^4bd^3$ $-2a^4c^2d^2$ $-12a^3b^2cd^2$ $+20a^3bc^3d$ $-8a^3c^5$ $+8a^2b^4d^2$ $-14a^2b^3c^2d$ $+6a^2b^2c^4$	$-a^5d^3$ $+7a^4bcd^2$ $-4a^4c^3d$ $-4a^3b^3d^2$ $-3a^3b^2c^2d$ $+4a^3bc^4$ $+4a^2b^4cd$ $-3a^2b^3c^3$	$+2a^5cd^2$ $-2a^4b^2d^2$ $-12a^4bc^2d$ $+8a^4c^4$ $+20a^3b^3cd$ $-14a^3b^2c^3$ $-8a^2b^5d$ $+6a^2b^4c^2$	$-2a^3cd^3$ $+12a^2b^2d^3$ $-6a^2c^4d$ $-64ab^3cd^2$ $+88ab^2c^3d$ $-30abc^5$ $+32b^5d^2$ $-48b^4c^2d$ $+18b^3c^4$	$+2a^4d^3$ $-6a^3bcd^2$ $+2a^3c^3d$ $-4a^2b^3d^2$ $+12a^2b^2c^2d$ $-6a^2bc^4$	$-2a^4bd^2$ $+6a^4c^2d$ $-6a^3b^2cd$ $-2a^3bc^3$ $+4a^2b^4d$
$\frac{1}{3}d'^2 \times$	$\frac{1}{3}a'b' \times$	$\frac{1}{3}a'c' \times$	$\frac{1}{3}a'd' \times$	$b'c' \times$	$\frac{1}{3}b'd' \times$	$\frac{1}{3}c'd' \times$
$-2a^5cd$ $+2a^4b^2d$ $+6a^4bc^2$ $-10a^3b^3c$ $+4a^2b^5$	$-20a^3bd^3$ $+18a^3c^2d^2$ $+84a^2b^2cd^2$ $-128a^2bc^3d$ $+48a^2c^5$ $-32ab^4d^2$ $+48ab^3c^2d$ $-18ab^2c^4$	$+4a^4d^3$ $-12a^3bcd^2$ $+4a^3c^3d$ $-8a^2b^3d^2$ $+24a^2b^2c^2d$ $-12a^2bc^4$	$-2a^4cd^2$ $+4a^3b^2d^2$ $-4a^2b^3cd$ $+2a^2b^2c^3$	$-6a^4cd^2$ $+12a^3b^2d^2$ $-12a^2b^3cd$ $+6a^2b^2c^3$	$-4a^4bd^2$ $+12a^4c^2d$ $-12a^3b^2cd$ $-4a^3bc^3$ $+8a^2b^4d$	$+2a^5d^2$ $-16a^4c^3$ $-4a^3b^3d$ $+30a^3b^2c^2$ $-12a^2b^4c$

$y'+$

$\frac{1}{3}a''b'\times$	$\frac{1}{3}a''c'\times$	$\frac{1}{3}a''d'\times$	$\frac{1}{3}b''a'\times$	$b''c'\times$	$\frac{1}{3}b''d'$	$\frac{1}{3}c''a'\times$
$-2a^3bd^3$ $+3a^3c^2d^2$ $+12a^2b^2cd^2$ $-26a^2bc^3d$ $+12a^2c^5$ $-8ab^4d^2$ $+18ab^3c^2d$ $-9ab^2c^4$	$+a^4d^3$ $-9a^3bcd^2$ $+4a^3c^3d$ $+4a^2b^3d^2$ $+15a^2b^2c^2d$ $-12a^2bc^4$ $-12ab^4cd$ $+9ab^3c^3$	$-1a^4cd^2$ $+2a^3b^2d^2$ $+6a^3bc^2d$ $-4a^3c^4$ $-16a^2b^3cd$ $+11a^2b^2c^3$ $+8ab^5d$ $-6ab^4c^2$	$+2a^3bd^3$ $-3a^3c^2d^2$ $-12a^2b^2cd^2$ $+26a^2bc^3d$ $-12a^2c^5$ $+8ab^4d^2$ $-18ab^3c^2d$ $+9ab^2c^4$	$+a^4cd^2$ $-6a^3bc^2d$ $+4a^3c^4$ $+4a^2b^3cd$ $-3a^2b^2c^3$	$-2a^4bd^2$ $+12a^3b^2cd$ $-8a^3bc^3$ $-8a^2b^4d$ $+6a^2b^3c^2$	$-a^4d^3$ $+9a^3bcd^2$ $-4a^3c^3d$ $-4a^2b^3d^2$ $-15a^2b^2c^2d$ $+12a^2bc^4$ $+12ab^4cd$ $-9ab^3c^3$
$c''b'$	$\frac{1}{3}c''d'\times$	$\frac{1}{3}d''a'\times$	$\frac{1}{3}d''b'\times$	$\frac{1}{3}d''c'\times$	$\frac{1}{27}a'^3\times$	$b'^3\times$
$-a^4cd^2$ $+6a^3bc^2d$ $-4a^3c^4$ $-4a^2b^3cd$ $+3a^2b^2c^3$	$+a^5d^2$ $-6a^4bcd$ $+4a^4c^3$ $+4a^3b^3d$ $-3a^3b^2c^2$	$+a^4cd^2$ $-2a^3b^2d^2$ $-6a^3bc^2d$ $+4a^3c^4$ $+16a^2b^3cd$ $-11a^2b^2c^3$ $-8ab^5d$ $+6ab^4c^2$	$+2a^4bd^2$ $-12a^3b^2cd$ $+8a^3bc^3$ $+8a^2b^4d$ $-6a^2b^3c^2$	$-a^5d^2$ $+6a^4bcd$ $-4a^4c^3$ $-4a^3b^3d$ $+3a^3b^2c^2$	$-2a^2cd^3$ $+20ab^2d^3$ $-18abc^2d^2$ $-72b^3cd^2$ $+126b^2c^3d$ $-54bc^5$	$+2a^3cd^2$ $+4a^2b^2d^2$ $-12a^2bc^2d$ $+6a^2c^4$
$c'^3\times$	$\frac{1}{27}d'^3\times$	$\frac{1}{3}a'^2b'\times$	$\frac{1}{3}a'^2c'\times$	$\frac{1}{9}a'^2d'\times$	$\frac{1}{3}b'^2a'\times$	$b'^2c'\times$
$-2a^4cd$ $+2a^3b^2d$	$+2a^5c$ $-2a^4b^2$	$-4a^2bd^3$ $+4a^2c^2d^2$ $+12ab^2cd^2$ $-16abc^3d$ $+6ac^5$ $+16b^4d^2$ $-36b^3c^2d$ $+18b^2c^4$	$+10a^2bcd^2$ $-6a^2c^3d$ $-16ab^3d^2$ $-6ab^2c^2d$ $+12abc^4$ $+24b^4cd$ $-18b^3c^3$	$+2a^3cd^2$ $-8a^2b^2d^2$ $-24a^2bc^2d$ $+18a^2c^4$ $+84ab^3cd$ $-60ab^2c^3$ $-48b^5d$ $+36b^4c^2$	$+2a^3d^3$ $-12a^2bcd^2$ $+2a^2c^3d$ $-28ab^3d^2$ $+72ab^2c^2d$ $-36abc^4$	$-6a^3bd^2$ $+12a^2b^2cd$ $-6a^2bc^3$
${}'^2d'\times$	$c'^2a'\times$	$c'^2b'\times$	$c'^2d'\times$	$\frac{1}{9}d'^2a'\times$	$\frac{1}{3}d'^2b'\times$	$\frac{1}{3}d'^2c'\times$
$-2a^4d^2$ $+12a^3bcd$ $-2a^3c^3$ $-8a^2b^3d$	$-2a^3bd^2$ $+4a^3c^2d$ $-4a^2b^2cd$ $-2a^2bc^3$ $+4ab^4d$	$+2a^4d^2$ $+2a^3c^3$ $-4a^2b^3d$	$+2a^4c^2$ $-2a^3b^2c$	$-2a^4cd$ $+2a^3b^2d$ $+12a^3bc^2$ $-24a^2b^3c$ $+12ab^5$	$-2a^4c^2$ $+6a^3b^2c$ $-4a^2b^4$	$-2a^4bc$ $+2a^3b^3$
$a'b'c'\times$	$\frac{1}{3}a'b'd'\times$	$\frac{1}{3}a'c'd'\times$	$b'c'd'\times$			
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$y+$

$\frac{1}{3}a''b'\times$	$\frac{1}{3}a''c'\times$	$\frac{1}{3}a''d'\times$	$\frac{1}{3}b''a'\times$	$b''c'\times$	$\frac{1}{3}b''d'\times$	$\frac{1}{3}c''a'\times$
$+a^3cd^3$ $-6a^2bc^2d^2$ $+4a^2c^4d$ $+4ab^3cd^2$ $-3ab^2c^3d$	$-2a^3bd^3$ $+12a^2b^2cd^2$ $-8a^2bc^3d$ $-8ab^4d^2$ $+6ab^3c^2d$	$+a^3bcd^2$ $-6a^2b^2c^2d$ $+4a^2bc^4$ $+4ab^4cd$ $-3ab^3c^3$	$-a^3cd^3$ $+6a^2bc^2d^2$ $-4a^2c^4d$ $-4ab^3cd^2$ $+3ab^2c^3d$	$+a^4d^3$ $-6a^3bcd^2$ $+4a^3c^3d$ $+4a^2b^3d^2$ $-3a^2b^2c^2d$	$-2a^4cd^2$ $+12a^3bc^2d$ $-8a^3c^4$ $-8a^2b^3cd$ $+6a^2b^2c^3$	$+2a^3bd^3$ $-12a^2b^2cd^2$ $+8a^2bc^3d$ $+8ab^4d^2$ $-6ab^3c^2d$
$c''b'\times$	$\frac{1}{3}c''d'\times$	$\frac{1}{3}d''a'\times$	$\frac{1}{3}d''b'\times$	$\frac{1}{3}d''c'\times$	$\frac{1}{27}a'^3\times$	$b'^3\times$
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$c'^3\times$	$\frac{1}{27}d'^3\times$	$\frac{1}{3}a'^2b'$	$\frac{1}{3}a'^2c'\times$	$\frac{1}{9}a'^2d'\times$	$b'^2a'\times$	$b'^2c'\times$
$-2a^3bcd$ $+2a^2b^3d$	$+2a^4bc$ $-2a^3b^3$	$+8ab^2d^3$ $-8abc^2d^2$ $+2ac^4d$ $-8b^3cd^2$ $+6b^2c^3d$	$+2a^2bd^3$ $-20ab^2cd^2$ $+14abc^3d$ $+16b^4d^2$ $-12b^3c^2d$	$-4a^2bcd^2$ $-8ab^3d^2$ $+48ab^2c^2d$ $-30abc^4$ $-24b^4cd$ $+18b^3c^3$	$-4a^2bd^3$ $+2a^2c^2d^2$ $+6ab^2cd^2$ $-4abc^3d$	$-6a^3cd^2$ $+6a^2b^2d^2$
$b'^2d'\times$	$c'^2a'\times$	$c'^2b'\times$	$c'^2d'\times$	$\frac{1}{9}d'^2a'\times$	$\frac{1}{3}d'^2b'\times$	$\frac{1}{3}d'^2c'\times$
$-2a^3bd^2$ $+4a^3c^2d$ $-2a^2bc^3$	$-2a^2bc^2d$ $+2ab^3cd$	$+6a^3c^2d$ $-6a^2b^2cd$	$+2a^3bc^2$ $-2a^2b^3c$	$+4a^3bcd$ $-4a^2b^3d$ $-6a^2b^2c^2$ $+6ab^4c$	$-2a^4cd$ $+2a^3b^2d$ $+4a^3bc^2$ $-4a^2b^3c$	$-2a^3b^2c$ $+2a^2b^4$
$\frac{1}{3}a'b'c'\times$	$\frac{1}{3}a'b'd'\times$	$\frac{1}{3}a'c'd'\times$	$\frac{1}{3}b'c'd'\times$			
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On the Phenomena and Theories of Solution.
By Professor W. A. TILDEN, *F.R.S.*

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IN what follows I propose to review the principal phenomena observed in the act of solution of solids, and especially of metallic salts and other comparatively simple compounds in liquids, with the object of arriving, if possible, at some conclusion as to the physical explanation of the facts. For want of time and space an exhaustive statement of all that is known cannot be attempted. The most important parts of the subject omitted are the following:—Electrolysis, formulæ relating to expansion and density of solutions, their absorption-spectra, and other optical properties, and magnetic rotatory power.

One question which must arise in the course of the discussion is whether the phenomena are to be accounted as chemical or physical, and this necessarily involves another question, namely, what is chemical combination, and by what criterion can it be distinguished from adhesion or cohesion, or other manifestation of molecular or molar attraction? Postponing this enquiry for the present, we may assume that chemical combination has generally been supposed to be distinguished by definite proportions in weight and volume of the acting masses, by definite thermal changes, and by marked differences between the properties of the compound and those of its components.

The various theories which have been proposed to explain the nature of solution are roughly divisible into two classes, namely, those which represent solution as a kind of chemical combination, and those which explain the phenomena by reference to the mechanical intermixture of molecules, or by the influence of the rival attractions of cohesion in the solid and liquid, and of adhesion of the solid to the liquid.

The older writers seem universally to have regarded the act of solution as a manifestation of chemical attraction. Thus Henry (‘Elements of Chemistry,’ 11th ed., 1829, vol. i. Chap. II.) refers to the solution of common salt in water as ‘one of the simplest cases that can be adduced of the efficiency of chemical affinity, for solution is always the result of an affinity between the fluid and the solid which is acted upon, often feeble it is true, yet sufficient in force to overcome the cohesion of the solid. This affinity continues to act until at length a certain point is attained where the affinity of the solid and fluid for each other is balanced by the cohesion of the solid, and the solution cannot be carried further. This point is called *saturation*, and the fluid obtained is termed a *saturated solution.*’

Turner, in his ‘Elements of Chemistry’ (1842), also attributes solution to ‘the exercise of chemical attraction.’

Gay-Lussac (‘Ann. Chim. Phys.’ xi. 297) states that ‘the solubility of a body in water depends on two causes, affinity and heat; or more exactly the affinity of salt for water varies with the temperature.’

Berthollet, in his ‘Statique Chimique,’ gives an elaborate statement of his view, which is too long to quote in full, but the substance of which is to set forth the influence of affinity in bringing about solution and the resistance offered by gases in virtue of their elasticity and by solids in virtue of their cohesion.

But Berthollet seems to have regarded chemical affinity as very closely connected with the cause of cohesion, if not identical with it. In the English translation by B. Lambert, 1804, to which alone I have had access, the following passages occur in the introduction, pp. xviii et seq.: 'The first effect of affinity to which I call attention is that produced by the cohesion of the particles which enter into the composition of a body; it is the effect of the reciprocal affinity of these particles which I distinguish by the name of the force of cohesion, and which becomes a force opposed to all those tending to cause them to enter into another combination, while it, on the contrary, tends to reunite them.

'Every affinity which tends by its action to diminish the effect of cohesion ought to be regarded as a force opposed to it, and of which the result is solution. When, therefore, a liquid acts on a solid, the force of solution can produce the liquefaction of the solid if it is superior to that of cohesion; but this effect sometimes takes place immediately and sometimes it requires that the cohesion should be first weakened by a commencement of combination; there are circumstances in which the liquid can only act on the surface of the solid and wet it; finally the solid cannot even be wetted when its affinity with the liquid does not produce an effect greater than that of the mutual affinity of the parts of this latter.

'These two forces, therefore, according to their relations produce different results, which must be distinguished, but which are not to be attributed, in conformity with the opinion of some philosophers, to two affinities, one of which they have considered as chemical and the other as derived from the laws of physics,' &c.

The same views with illustrative examples are expressed in Berthollet's work on the 'Laws of Chemical Affinity.' On page 63 of the English translation, by M. Farrell, 1804, we find this passage: 'Solvents act on bodies which they dissolve by their affinity and quantity like all substances which tend to combine; and whatever has been said of combination in general is applicable to them.'

It seems pretty clear, therefore, that Berthollet regarded solution as an act of chemical combination. He seems to have got some of his ideas from Guyton de Morveau, who some years before had published experiments on the adhesion of solids to liquids with the object of proving that 'the adhesion of solids to liquids is in proportion to their affinity of solution.'[1]

L. Gmelin ('Handbook,' vol. i. p. 112) summarises very clearly the views prevailing up to his time: 'Cohesion appears to exert a much more decided influence (than gravitation) on the decomposition of chemical compounds—at least of the less intimate kind. The hitherto received theory on this matter is as follows:—When a solid body dissolves in a liquid, the cohesion of the solid acts in opposition to the dissolving power of the fluid; the two forces tend to equilibrate each other; and in proportion as the fluid takes up more and more of the solid, its tendency to dissolve a further quantity—or in other words, its affinity for the solid—diminishes, and ultimately becomes no greater than the cohesion of the

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[1] Footnote in Berthollet's *Chemical Affinity*, English ed. p. 43; and *Ann. Chim.* vii. p. 32.

solid and the tendency of its particles to remain united amongst themselves, and then the process of solution stops. But the cohesion of a solid body is generally diminished by elevation of temperature; consequently when the fluid is heated up to a certain point a further solution usually takes place, till by this new addition of the solid body the affinity of the fluid for it is so far diminished that equilibrium between that force, and the cohesion of the solid is again established. If now a solution thus saturated while warm be cooled down to its former temperature the solid body regains its original cohesive power, and a portion of it separates from the fluid in order to unite in larger and usually crystalline masses, the quantity remaining in solution being only just so much as the fluid would directly have taken up at this lower temperature.'

Among modern chemists we find Professor Josiah P. Cooke stating in his 'Chemical Philosophy' (ed. 1882, p. 151) 'that the facts seem to justify the opinion that solution is in every case a chemical combination of the substances dissolved with the solvent, and that it differs from other examples of chemical change only in the weakness of the combining force.'

But the most consistent and powerful supporter of the hypothesis that in solutions the dissolved substance and the solvent are chemically combined together is M. Berthelot, whose views are expressed very clearly in his 'Mécanique Chimique,' from which the following is extracted (vol. ii. p. 160 et seq.):—

'Les phénomènes de la dissolution normale sont en quelque sorte intermédiaires entre le simple mélange et la combinaison véritable. En effet, d'une part l'aptitude à s'unir pour former un système homogène indique une affinité réelle entre le solide et le dissolvant; mais, d'autre part, cette union cesse sous l'influence d'une simple évaporation, et elle se produit, en apparence du moins, suivant des proportions qui varient d'une manière continue avec la température.

'Cependant il me paraît probable que le point de départ de la dissolution proprement dite réside dans la formation de certaines combinaisons définies entre le dissolvant et le corps dissous. Tels seraient les hydrates définis formés au sein de la liqueur même, entre les sels et l'eau existant dans cette liqueur; hydrates analogues ou identiques aux hydrates définis des mêmes composants, connus sous l'état cristallisé. . . .

'On est donc conduit tout naturellement à se demander si ces hydrates ne subsisteraient pas jusque dans les dissolutions, et s'il ne s'en formerait pas d'analogues, dans les cas mêmes où l'on ne saurait pas les isoler par cristallisation.

'Je pense en effet qu'il en est ainsi, et que chaque dissolution est réellement formée par le mélange d'une partie du dissolvant libre avec une partie du corps dissous, combinée au dissolvant suivant la loi des proportions définies. Tantôt cette combinaison se formerait intégralement et d'une façon exclusive, ce qui me paraît être sensiblement le cas pour les premières limites d'équilibre entre l'eau et les acides forts. Tantôt, au contraire, cette combinaison ne se formerait qu'en partie, le tout constituant un système dissocié dans lequel le corps anhydre coexiste avec l'eau et son hydrate, ce qui me paraît être le cas pour les dissolutions formées par l'acétate de soude, le sulfate de soude et la plupart des sels alcalins. Plusieurs hydrates définis d'un même corps dissous, les uns stables, les autres dissociés, peuvent exister à la fois au sein d'une dissolution. Ils constituent alors un système en équilibre, dans lequel les proportions relatives de chaque hydrate varient avec la quantité d'eau, la température, ainsi qu'avec la présence des autres corps, acides, bases ou sels, capables de s'unir pour leur propre compte, soit à l'eau, soit au corps primitivement dissous. Ce serait le degré inégal de cette dissociation des hydrates, variable avec la température, qui ferait varier le coefficient de solubilité du corps dissous lui-même.'

We may now turn to those writers who, whilst referring the phenomena of solution to a molecular attraction of some kind, do not attribute solubility to the formation of chemical compounds of definite composition.

Graham is one writer who distinctly ranges himself on this side. He says :—'The attraction between salt and water which occasions the solution of the former, differs in several circumstances from the affinity which leads to the production of definite chemical compounds. In solution combination takes place in indefinite proportions, a certain quantity of common salt dissolving in or combining with any quantity of water, however large. . . . But the maximum proportion of salt dissolved or the saturating quantity has no relation to the atomic weight of the salt, and indeed varies exceedingly with the temperature of the solvent. The limit to the solubility of a salt seems to be immediately occasioned by its cohesion.' And again: "The force which produces solution differs essentially from chemical affinity in being exerted between analogous particles, in preference to particles which are very unlike and resembles more in this respect the attraction of cohesion.'

Brande, also, appears to have taken a similar view, for, although he makes no formal statement of his opinion, the following passage occurs in his 'Manual' (5th edition, 1841), p. 110 :—'When common salt is dissolved in water its particles may be regarded as disposed at regular distances throughout the fluid ; and if the quantity of water be considerable, the particles will be too far asunder to exert reciprocal attraction ; in other words, they will be more powerfully attracted by the water than by each other.'

Daniell, in his 'Chemical Philosophy' (1842), ascribes the phenomena of solution to the conflict between the 'heterogeneous adhesion' of liquid to solid and the 'homogeneous attraction' of cohesion.

In Miller's 'Chemistry,' vol. i. (2nd edit. 1860), p. 67, we find the following passages, which show more in detail the application of the same idea :—'Adhesion is frequently manifested between solids and liquids with sufficient force to overcome the power of cohesion, and the substance is then said to become dissolved, or to undergo solution. . . . Anything that weakens the force of cohesion in the solid favours solution. Thus if the substance be powdered it becomes dissolved more quickly, both from the large extent of surface which it exposes and from the partial destruction of cohesion. In the same way heat, by increasing the distance between the particles of the solid, lessens its cohesion, and probably thus contributes so powerfully to assist in producing solution. If a solid body be introduced in successive portions into a quantity of a liquid capable of dissolving it, the first portions disappear rapidly, and as each succeeding quantity is added it is dissolved more slowly, until at length a point is reached at which it is no longer dissolved. When this occurs the force of cohesion balances that of adhesion, and the liquid is said to be *saturated*. . . . Although in the majority of instances the solubility of a substance is increased by heat, it is not uniformly so. (Exceptions quoted : lime, sulphate and sucrate of lime, sulphate and seleniate of soda, &c.). These anomalous results may be partly explained by the consideration that heat diminishes the force of adhesion as well as that of cohesion ; generally speaking cohesion is the more rapidly diminished of the two, although not uniformly so, and in the cases of which we are now speaking it would appear that the adhesive force decreases in a greater ratio than the cohesion of the saline particles.'

The same idea forms the basis of the theory which has been supported so actively by the writings and experimental researches of Dr. W. W. J. Nicol ('Phil. Mag.' Feb. 1883, &c.).

Dr. Nicol's view is stated in the following passage :—'The solution of a salt in water is a consequence of the attraction of the molecules of water for a molecule of salt exceeding the attraction of the molecules of salt for one another. It follows, then, that as the number of dissolved salt molecules increases, the attraction of the dissimilar molecules is more and more balanced by the attraction of the similar molecules ; when these two forces are in equilibrium saturation takes place' (Feb. 1883).

L. Dossios has made use of the kinetic theory of Clausius relating to the constitution of bodies and the process of evaporation as the basis of a theory of solution. If we assume the kinetic energy of two neighbouring molecules to be less than their attraction, such molecules remain at a determinate distance from each other. This is the solid state. The gaseous condition is assumed when the kinetic energy of a molecule overcomes the combined attractions of the other molecules present. In a liquid the energy of two neighbouring molecules is sufficient to enable them to overcome each other's attraction, but is not equal to the united attractions of the surrounding molecules. Relations of the same kind may be supposed to exist in an aggregation of dissimilar molecules such as compose a solution.

Two liquids are miscible in all proportions when the attraction of dissimilar molecules is capable of overcoming the attraction of similar molecules, &c.

The solution of solid bodies in liquids may be reduced to the same principles. As, however, the attraction of the molecules of solids to one another is large, and the kinetic energy destroyed, a solution of a solid cannot be formed in all proportions, but a point of saturation is attained, whilst the solubility of solid bodies increases generally with the temperature, since the action of heat is always opposed to molecular attraction ('Jahresbericht,' 1867, p. 92).

A physical theory, which differs from those referred to above in not requiring the assumption of an attraction of either chemical or mechanical nature between the molecules of the solvent and those of the solvend, was briefly enunciated in a paper communicated to the Royal Society by Tilden and Shenstone in 1883. In discussing the connection between fusibility and solubility of salts, the authors point out that the facts tend to 'support a kinetic theory of solution based on the mechanical theory of heat. The solution of a solid in a liquid would accordingly be analogous to the sublimation of such a solid into a gas, and proceeds from the intermixture of molecules detached from the solid with those of the surrounding liquid. Such a process is promoted by rise of temperature, partly because the molecules of the still solid substance make longer excursions from their normal centre, partly because they are subjected to more violent encounter with the moving molecules of liquid' ('Phil. Trans.' i. 1884, p. 30). Such a theory, however, serves to account only for the initial stage in the process of solution, and does not explain the selective power of solvents nor the limitation of solvent power of a given liquid, &c.

THERMAL PHENOMENA.

How far is it true that evolution of heat indicates chemical combination? Does the evolution of heat in dissolving a solid in water or in adding more water to its solution indicate the formation of hydrates, that is, of chemical compounds of the dissolved substance with water in definite proportions? Thomsen answers this question in the negative ('Thermochem. Untersuchungen,' iii. p. 20).

Take the case of sulphuric anhydride, SO_3.

SO_3,H_2O = + 21320 (Solid SO_3 into liquid H_2SO_4)
$(SO_3H_2O),H_2O$ = 6379 (No change of state)
$(SO_32H_2O)\,H_2O$ = 3039
$(SO_33H_2O)\,H_2O$ = 1719
For next $2H_2O$ average = 985·5 per H_2O
For next $4H_2O$ average = 461 ,, ,,
For next $10H_2O$ average = 130·4 ,, ,,
Up to 1599 H_2O total = 17857

The total heat of solution of SO_3 in 1600 H_2O is therefore 21320 + 17857 = 39177.

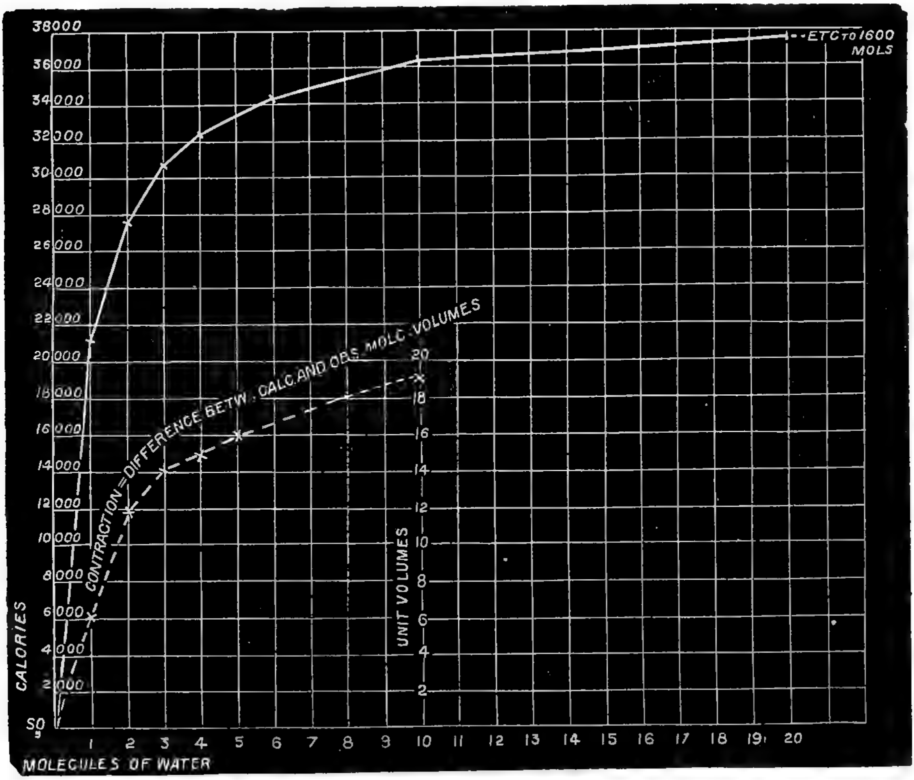
The following diagram (1) shows graphically the successive thermal changes consequent upon adding this quantity of water gradually to sulphuric anhydride. Although more than half the total heat evolution occurs on addition of the first molecule of water, the succeeding molecules give a quite appreciable amount; the second gives, in fact, $\frac{6379}{39177}$, or nearly $\frac{1}{6}$ of the whole.

At what point in such a curve should we be justified in setting up a distinction between the effect due to chemical combination and that due to other causes?

In the act of solution of solids, and especially of *anhydrous* salts in water, the volume of solution is always less than the sum of the volumes of the solid and its solvent, with the exception of some ammonium salts, in which expansion occurs. Similarly the addition of water to a solution is followed by contraction. This contraction may be due to mere mechanical fitting of the molecules of the one liquid into the interspaces between the molecules of the other, just as when one pint of small shot is mixed with one pint of large shot the volume of the mixture is less than two pints. This, I apprehend, would not by itself be attended by loss of energy (See Mendelejeff, 'J. Russ. Chem. Soc.' xvi. 643, 644. Abs. in 'J. Chem. Soc.' Feb. 1885, p. 114). Or it may arise from the adjustment of the motion of the molecules of the constituents to the conditions requisite for the formation of a uniform liquid (Thomsen, iii. p. 18).

If we know the coefficient of expansion of the liquid and its specific heat we can calculate the amount of heat that would be evolved for a given contraction.[1] The contraction which ensues when H_2SO_4 is diluted with H_2O amounts to 5·814 unit volumes upon 53·203+18, or 71·203, which is the sum of the molecular volumes of these liquids. And taking the coefficient of expansion of $H_2SO_4H_2O$ to be ·00056 for 1° C., and its specific heat ·442, we find that this would correspond to an evolution of heat amounting to 4588·9 calories. The evolution of heat actually observed being 6379 according to Thomsen, there is a difference of 1790 heat units, which is unaccounted for on the hypothesis that the change of volume is due to just such a change in the mean distances and motions of the molecules of the liquid as would be brought about by a change of temperature, and this may really indicate some kind or some amount of chemical combination.

FIG. 1.



The majority of solids, and nearly all salts, expand on being melted. And as, whatever theory we adopt as to the constitution of solutions, we must admit that the dissolved substance is in the liquid state, it is obvious that in all cases where a solid is dissolved by a liquid the change of volume which is observed must be the resultant of the two distinct changes of volume consequent upon the (1) liquefaction of the solid, and (2) the intermixture of the resulting liquid with the solvent.

The diagram (fig. 1) already given exhibits the amount of contraction observed in the case of sulphuric acid and water, and the following table shows the observed and calculated molecular volumes by which the amount of contraction is indicated.

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[1] Favre & Valson, *Compt. Rend.* lxxvii.; *Jahresb.* 1872.

n	Molecular Volumes of SO_3+nH_2O		Contraction = Difference between Calc. and observed Mol. Vol.
	Density	$\text{Mol. Vol.}=\frac{\text{Mol. Wt.}}{\text{Density}}$	
0	1·940 (Solid. Weber)	41·23	
1	1·842	53·20	6·03
2	1·774	65·39	11·84
3	1·652	81·11	14·12
4	1·547	98·25	14·98
5	1·475	115·25	15·98
10	1·286	202·18	19·05

The contraction consequent on the first addition is greater than the second, and for each succeeding molecule is a diminishing quantity, becoming rather less than 1 after addition of $3H_2O$.

A similar result ensues if we calculate the contraction following upon the dilution of liquid H_2SO_4 with successive quantities of water.

Take now another case, that of common salt (see diagram 2).

The heat of solution of NaCl in $100H_2O$ is -1180, a negative quantity. On adding more water to a solution of sodium chloride a further absorption of heat is observed. Thomsen gives the following values :—

$$\begin{aligned}(NaCl\,10H_2O) &+ 40H_2O = -528;\\ (NaCl\,50H_2O) &+ 50H_2O = -127;\\ (NaCl\,100H_2O) &+ 100H_2O = -\ \ 50.\end{aligned}$$

So that heat of solution of NaCl in

$$\begin{aligned}10H_2O &= -(1180-655) = -\ \ 525;\\ 50H_2O &= -(1180-127) = -1053;\\ 200H_2O &= -(1180+\ \ 50) = -1230.\end{aligned}$$

Tracing now the changes of volume which attend the processes of solution and dilution we get the following results :—

Taking 2·15 as the density of the solid salt we have its molecular volume = 27·1. Then the following are the molecular volumes of its solutions :—

nH_2O	Molecular Volume		Contraction
	Calculated	Observed[1]	
n = 10	207·1	200·9	5·2
n = 50	927·1	918·1	9·0
n = 100	1827·1	1817·5	9·6

Another way of stating these results would be to set down the thermal and volume changes resulting from the addition of successive molecular proportions of salt to the same amount of water.

From the foregoing results we find—

	Difference per Molecule
$NaCl+100H_2O = -1180$ C.	—
$2NaCl+100H_2O = -2106$ C.	926;
$10NaCl+100H_2O = -5250$ C.	$\frac{3144}{8}=393.$

So that whilst the addition either of salt or of water to a solution of salt occasions an absorption of heat, the solution of a molecule of solid sodium chloride in a relatively large quantity of water is attended by the absorp-

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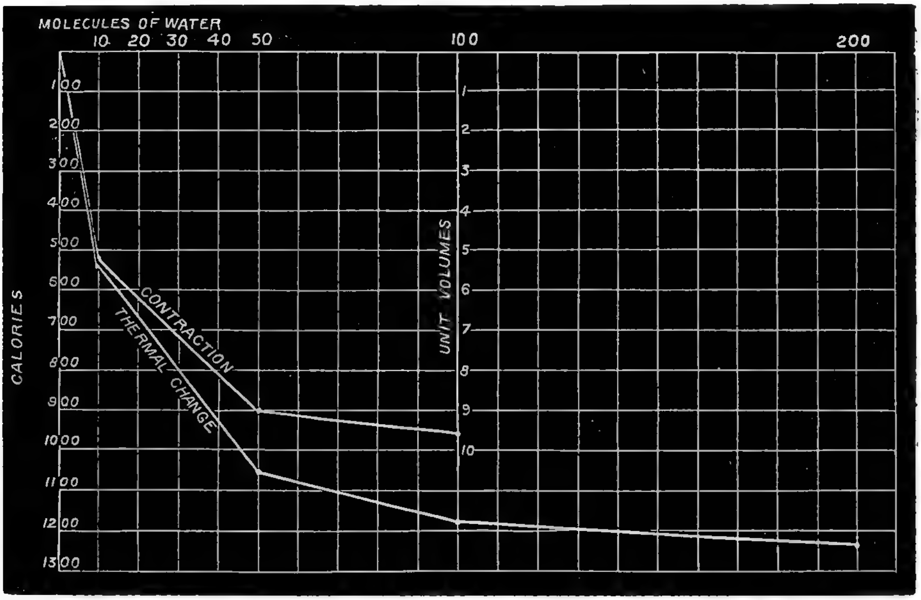
[1] Nicol, *Phil. Mag.* June 1884.

tion of a much greater amount of heat than the solution of the same quantity of the solid in a relatively small mass of water.

In like manner it is observed that the addition of water or of salt to a solution already formed occasions contraction, but the amount of this contraction constantly diminishes with each successive dose of water or of solid salt. This has just been shown for the water. The following table, taken from Nicol's paper ('Phil. Mag.,' June 1884),[1] shows the effect of adding salt in successive molecules. The column headed Δ shows that the molecular volume of each successive molecule is greater than the preceding, the increase being from 17·08 up to 22·87 for the last molecule.

FIG. 2.



nNaCl+100H$_2$O			
t°	n	M.V.	Δ
20°	·5	1808·54	17·08
”	1·0	1817·60	17·60
”	2·0	1836·42	18·82
”	3·0	1856·13	19·71
”	4·0	1876·74	20·61
”	5·0	1897·79	21·05
”	6·0	1919·44	21·65
”	7·0	1941·54	22·10
”	8·0	1963·93	22·39
”	9·0	1986·72	22·79
”	10·0	2009·65	22·93
”	11·0	2032·52	22·87

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[1] The figures given in the table are the result of recent more accurate determinations, kindly communicated by the author.

In this case, common salt, we find in accordance with the general rule (Thomsen, iii. p. 28 et seq.) that the heat of dissolution being negative the heat of dilution is also negative. Supposing we explain the heat-absorption which attends the act of solution by referring to the change of the solid salt to liquid it still remains to be considered to what cause we can ascribe the heat-absorption attending dilution when liquid is mixed with liquid and no change of state is involved. There is contraction upon adding water to a solution of common salt, but this, if it is connected with any thermal change at all, would probably lead to an evolution of heat. It has just been shown that the thermal change attending solution of salt in water cannot be due solely to the change of state from solid to liquid. If it were, the same amount of heat-absorption would be observed in dissolving salt in any proportion of water, and no change would be produced by adding more water. There is therefore apparently some agency which gives a positive thermal change on solution of the solid, and another which occasions a negative change on the dilution with more water, the observed amounts of heat absorbed being the difference between these two.

The positive thermal change probably corresponds to some kind of union between the salt molecules and the water. The negative thermal change is chiefly connected in the act of solution with the physical change from solid to liquid. The negative change consequent on dilution is not so easily accounted for. But it may be due to double decomposition with the water. The reaction

$$\mathrm{NaHO + HCl = NaCl + H_2O}$$

is attended with heat-evolution, and its reversal

$$\mathrm{NaCl + H_2O = NaHO + HCl}$$

must lead to heat-absorption.

From Thomsen's results

$$\mathrm{NaHO + HCl + 200H_2O} = +13745,$$

and

$$\mathrm{NaCl + 10H_2O} = -525,$$

and

$$\begin{aligned}&\mathrm{(NaCl10H_2O) + 190H_2O} = \\ &\qquad -(1230 - 525) = -705.\end{aligned}$$

So that for complete decomposition we should require -13745 cal., whilst in diluting a solution almost saturated down to a very weak condition, the hypothesis does not require more than $\frac{705}{13745 + 705}$, or a little more than five per cent. of the whole.

My own experiments on heat of dissolution of salts at different temperatures ('Proc. R. S.' 1885) led me to the conclusion that decomposition of this kind did occur, and that it increases with rise of temperature. Thomsen, on the other hand (iii. p. 20), considers that his results do not point to a decomposition in such cases as common salt; but he admits it in the case of bisulphates of sodium and potassium.

As a rule, a salt which on being dissolved in water gives out heat gives a further amount when its solution is diluted. On the other hand, a salt which in dissolving absorbs heat absorbs a further amount when its solution is diluted. Of thirty-five salts examined by Thomsen, twenty-nine conform to this rule. The exceptions most difficult to explain are sodium sulphate and carbonate, both of which exhibit anomalies in their solubility.

However we may ultimately explain the peculiarities of these two salts, the fact remains that heat evolved or absorbed during the admixture of any substance with water is in every case a continuous function of the quantity of water added, and a thermal change gradually diminishing in amount is observed on the addition of successive quantities of water, till an indefinitely large volume has been added, and the change becomes too small to be traced by the thermometer.

Similarly the contraction which ensues on diluting an aqueous solution proceeds continuously, and, as already shown, the molecular volume of a salt in solutions of different strengths is continuously greater the larger the amount of salt present, so that in none of these thermal or volumetric phenomena is any discontinuity observed nor any indications of the formation of compounds of definite composition distinguishable by characteristic properties.

If, however, we admit that no definite chemical compounds are formed in such a case as the admixture of sulphuric acid H_2SO_4 with water, what are we to say to the parallel case of the neutralisation of some polybasic acids with alkali?

Take orthophosphoric acid.

		Difference per Molecule of NaHO.
$H_3PO_4Aq+\frac{1}{2}NaHOAq$	$= + \ 7329$ C.	
$+1NaHOAq$	$= + 14829$	
$+2NaHOAq$	$= + 27078$	12249
$+3NaHOAq$	$= + 34029$	6951
$+6NaHOAq$	$= + 35280$	$\frac{1251}{3}=417$.

The addition of

The first mol. H_2O to H_2SO_4 gives	+ 6379
The second mol. H_2O to the preceding mixture	+ 3039
The third mol. H_2O to the preceding mixture	+ 1719

So the addition of

The first mol. of NaHO to H_3PO_4 gives	+ 14829
The second mol. of NaHO to the preceding mixture	+ 12249
The third mol. of NaHO to the preceding mixture	+ 6951

Arsenic acid gives similar results, the several values being in each case a little higher than those obtained with phosphoric acid (Thomsen, i. 204).

The case of periodic acid (Thomsen, i. 244) is still more noteworthy.

$$H_5IO_6Aq+\ KHOAq=+5150 \text{ C.}$$
$$+2KHOAq=\ 26590$$
$$+3KHOAq=\ 29740$$
$$+5KHOAq=\ 32040$$

Here we have great inequality in the amount of heat evolved on addition of successive molecules of alkali and no sign of approaching a maximum. These values are indicated on the accompanying diagram (fig. 3):—

In the case of sulphuric acid, neutralisation by soda shows a more nearly equal amount of heat evolved per molecule of NaHO added. Thomsen gives (i. p. 297)—

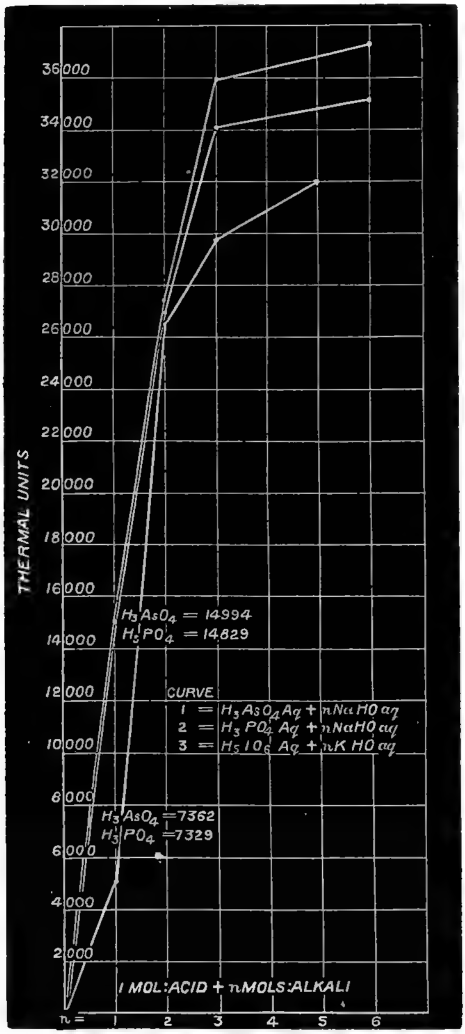
$$\left.\begin{array}{l}\text{NaHOAq} + H_2SO_4\text{Aq} = +\ 14754\\ 2\text{NaHOAq} + H_2SO_4\text{Aq} = +\ 31378\end{array}\right\}\text{Difference } 16624$$
$$4\text{NaHOAq} + H_2SO_4\text{Aq} = +\ 31368$$

The second molecule of NaHO therefore seems to give more heat than the first.

In the case of acids and alkalies we do not hesitate to accept such results as indicating the formation of definite chemical compounds, and that they do correspond with the known basicity of the majority of the acids there can be no doubt. But there are very few cases in which the thermal value of the action of the second or third molecule of alkali is exactly equal to that of the first.

There can be little doubt that in every one of these cases of dilution and of neutralisation the observed thermal effect is due partly to chemical combinations, partly to changes which are commonly distinguished as physical.[1]

FIG. 3.



SPECIFIC HEATS AND VAPOUR PRESSURES.

The question we are now considering as to whether in a solution the solvent and the substance dissolved in it or any portion thereof exist independently of each other is in some degree answered by the facts known as to the specific heats and vapour pressures. In the case of salts dissolved in water the value of the molecular heat (that is, the product of the specific heat into molecular weight) in moderately dilute solutions differs very little from that of the water alone contained in the solution. In strong solutions of salts (5 to 20 mols. of water to 1 mol. salt) it is sometimes greater, sometimes less than that of the water alone. In weaker solutions (50 to 200 molecules water) it is generally less than the water alone. For example :—

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[1] Vide *Correlation of Physical Properties of Solution with Concentration.*—Mendelejeff, *Ber.* xix. 370 and 400, discusses the relations of contraction and thermal change.

n	$NaCl+nH_2O$			
	Spec. Heat	Mol. Weight	Molec. Heat	Difference from water alone
10	·791	58·5+180	188·5	+8·5
20	·863	58·5+360	361·0	+1·0
30	·895	58·5+540	536·0	−4·0
50	·931	58·5+900	892·0	−8·0
100	·962	58·5+1800	1788·0	−12·0
200	·978	58·5+3600	3578·0	−22·0

(Thomsen, i. 48.)

The specific heat of substances in the liquid state is always greater than that of the same in the solid, but the difference is in no case of those recorded so great as the difference between water and ice [except such things as chloral hydrate, in which water may be supposed to be formed during fusion, and the solitary case of iodine, solid ·05412 (Regnault) and liquid ·10822 (Favre and Silbermann)]. The specific heat of solid sodium nitrate is ·278 (Regnault, 'Ann. Chim. Phys.' 1841, i. 179), and in the liquid state it is ·413 (Person, 'Ann. Chim. Phys.' 1847, xxi. 332).

Hence the molecular heats are—

Solid	23·63
Liquid	35·10

If we assume the latter for the solution we have

$$\begin{array}{lr} NaNO_3 & 35{\cdot}10 \\ 25H_2O & \underline{450{\cdot}00} \\ & 485{\cdot}10 \end{array}$$

The observed molecular heat of the solution $NaNO_3+25H_2O$ is 465·5 (Marignac), or 461·7 (Thomsen). Now suppose $25H_2O$ more water to be added, the molecular heat is not 465·5+450=915·5, but 908 (Marignac), or 904 (Thomsen). And again when 50 more molecules of water are added the molecular heat is not 908+900=1808, but 1802·25 (Marignac), or 1791 (Thomsen), and so on.

So that all the water added seems to be influenced, at least until a very large quantity is present. In this case one molecule of sodium nitrate can affect the movements of 100 molecules of water, and probably more.

This effect is doubtless connected with the changes of volume which the solution undergoes on dilution.

Marignac has given the results of the determination of the specific heats of a number of salt solutions at different temperatures, but though it may be stated, as generally true, that the specific heat of a solution increases with rise of temperature, the differences observed are too small to afford much ground for speculation. They are generally much less than the increase in the specific heat of water for the same range of temperature, namely, from about 18° to 20° and from 20° to 50°, taking even the lowest value which has been assigned by different authorities to the increase in the specific heat of water at this higher temperature. (For numerical values see Naumann, 'Thermochemie,' pp. 269—271.)

It is also well known that the vapour pressure of water holding in solution almost any dissolved solid is less than the vapour pressure of pure water, and that the boiling point of a liquid is raised by the addition to it of any soluble non-volatile substance.

The well-known researches of Wüllner (Pogg. 'Ann.' ciii. p. 529, and cx. p. 564) led him to the conclusion that the reduction in the tension of the vapour of water consequent upon the addition of soluble substances is proportional to the amount of dissolved substance (see, however, Nicol, 'Phil. Mag.' Oct. 1885).

The law connecting the amount of dissolved substance with the diminution of pressure, or the amount of diminution with the temperature, is, however, a matter of small importance in connection with the present inquiry. The fact that there is reduction of pressure is the important point, and this can only be explained upon the hypothesis that there is no free water present at all; that is, that there is no water present which is not more or less under the influence of the dissolved substance. If any water were present in an uncombined state the rate of evaporation from the surface would doubtless be slower than the rate of evaporation of pure water at the same temperature, but the pressure of the evolved vapour must in time attain to the same maximum..

WATER OF CRYSTALLISATION.

What becomes of water of crystallisation forms a part of the same question as to the relation of solvent to solvend. We know that when white copper sulphate is dissolved in water evolution of heat results, and a blue solution is formed of the same colour as the crystals of the hydrated salt and the solution formed by dissolving them in water. Similarly blue anhydrous cobalt chloride dissolves in water, forming a red solution of the same tint as the red crystals which contain the salt and water united together. We are, therefore, disposed to conclude that these salts, and by analogy those which are colourless, retain their hold upon the water of crystallisation when they are dissolved in water.

Thomsen has also shown [1] that of the thirty-five salts examined by him twenty-nine exhibit the peculiarity that when the anhydrous salt dissolves in water with evolution of heat, the addition of more water also causes evolution of heat, and that when, on the contrary, the heat of solution is negative, the heat of dilution is also negative. The former without exception unite with water to form crystallisable definite hydrates; the latter do not.

Thomsen states his opinion on the point thus (iii. p. 31):—'There is no doubt that the salts which dissolve in water with evolution of much heat, and form crystallised hydrates, are present also in the solution as hydrated compounds; but a determination of the number of water molecules contained in such compounds would be very difficult,' &c. Thomsen considers the hypothesis very probable that a salt dissolved in water cannot retain chemically combined a larger number of water molecules than are

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[1] THOMSEN'S TWO GROUPS.—I. Chlorides, Ca, Mg, Zn, Ni, Cu; nitrates, Mg, Mn, Zn, Cu; acetates, K, Na, Am, Zn; sulphates, Mg, Mn, Zn, Cu, and $NaHSO_4$. II. Chlorides, Na, Am; bromide, K; cyanide, K; sulphate, Am; nitrates, Na, Am, Sr, Pb; tartrate, Am; and bicarbonate, Am. Exceptions: $KHSO_4$, $AmHSO_4$, NaI, K_2CO_3, Na_2CO_3, Na_2SO_4.

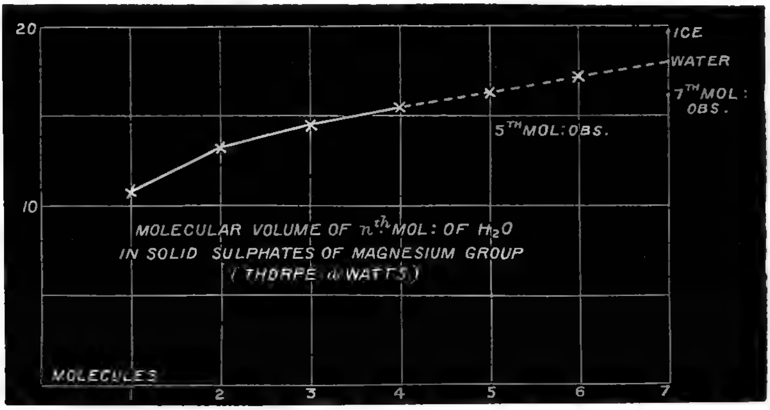
already combined in the acid and base from which the salt may be produced. Thomsen also considers that the chemical constitution of the hydrates present in a solution is not altered by dilution of the liquid with more water.

But against these facts above stated we find that salts which are very soluble, and which crystallise with a large amount of water, such as calcium chloride, do not, as a rule, reduce the pressure of vapour of water in which they are dissolved to a greater extent than salts which, like sodium chloride and potassium nitrate, crystallise habitually without water. There can be no doubt that every one of these and similar thermal effects are, like the corresponding volume changes, merely differential results, which represent the resultant of several simultaneous or immediately consecutive operations.

A very important observation has been made by Dr. Nicol, which bears directly on this question. In his study of the molecular volumes of salt solutions ('Phil. Mag.' Sept. 1884) he finds that when a salt containing water of crystallisation is dissolved this water is indistinguishable by its volume from the rest of the water of the solution. In the Report[1] presented to the British Association last year the following passage occurs:—'These results point to the presence in solution of what may be termed the anhydrous salt, in contradistinction to the view that a hydrate, definite or indefinite, results from solution; or in other words, no part of the water in solution is in a position, relatively to the salt, different from the remainder.' These two statements are not strictly consequent upon each other.

I feel inclined to take the view that, save perhaps in excessively dilute solutions, the dissolved substance is attached in some mysterious way (it matters not whether it is supposed to be chemical or physical) to the *whole of the water*. We cannot otherwise get over the difficulties presented by the hydrated salts which give coloured solutions, by the control of the vapour pressure by the dissolved salt, and by the altered specific heat.

FIG. 4.



With regard to water of crystallisation, E. Wiedemann ('Wiedem. Ann.' xvii. 1882, p. 561) has shown that hydrated salts in general expand

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[1] Report of Committee on Vapour Pressures, &c., of Salt Solutions, Dr. W. W. J. Nicol, secretary. Presented at Aberdeen Meeting.

enormously at the melting point, and sometimes at lower temperatures, and the observations of Thorpe and Watts ('Chem. Soc. Journ.' 1880, p. 102) on the specific volume of water of crystallisation in the sulphates of the so-called magnesium group show that, whilst the constitutional water, or water of halhydration, as it was called by Graham, occupies less space than the remaining molecules, each successive additional molecule occupies a gradually increasing volume.

The following are mean specific volumes of

MSO_4nH_2O, where M is Cu, Mg, Zn, Ni, Co, Mn, or Fe.

Value of *n*	Mean Specific Volume	Molecular Volume of *n*th mol. of H_2O
0	44·8	
1	55·5	10·7
2	68·8	13·3
3	83·3	14·5
4	98·7	15·4
5	112·9	14·2
6	130·0	17·1
7	146.1	16·1

These last figures approach the specific volume of ice, which is $\frac{18}{\cdot 92}$ $=19{\cdot}6$, that of water being 18.

So that, when a salt with its water of crystallisation passes into the liquid state, either by melting or solution in water, it requires a very slight relaxation of the bonds which hold the water to the salt for it to acquire the full volume of liquid water, whilst the water of constitution is not so easily released. And this conclusion accords with Nicol's observations on the molecular volumes of the salts when in solution.

CHEMICAL CONSTITUTION.—FUSIBILITY.—MOLECULAR VOLUME IN RELATION TO SOLUBILITY.

And now comes the question as to what determines the solubility of a substance. Why, for example, is magnesium sulphate very soluble in water whilst barium sulphate is almost totally insoluble?

With regard to salts the following propositions seem to be true:—

1. Nearly all salts which contain water of crystallisation are soluble in water, and for the most part they are easily soluble, calcium sulphate being one of the least soluble, magnesium phosphates and arsenates and some natural silicates (zeolites) being also exceptions.

2. Insoluble salts are almost always destitute of water of crystallisation, and rarely contain the elements of water.

3. In a series of salts containing nearly allied metals the solubility and capacity for uniting with water of crystallisation generally diminish as the atomic weight increases, as in the following examples:—

$$\begin{cases} Na_2SO_4 10H_2O \\ K_2SO_4 \end{cases}$$

$$\begin{cases} Na_2CrO_4 10H_2O \\ K_2CrO_4 \end{cases}$$

$$\left\{\begin{array}{l}MgSO_4 7H_2O\\CaSO_4 2H_2O\\SrSO_4\\BaSO_4\end{array}\right.$$

$$\left\{\begin{array}{l}CaCl_2 6H_2O\\SrCl_2 6H_2O\\BaCl_2 2H_2O\\PbCl_2\end{array}\right. \qquad \left\{\begin{array}{l}Mg(NO_3)_2 6H_2O\\Ca(NO_3)_2 6H_2O\\Sr(NO_3)_2 4H_2O\\\text{or anhydrous from hot solution.}\\Ba(NO_3)_2\\Pb(NO_3)_2\end{array}\right.$$

In the preceding examples disposition to combine with water seems to depend more on the nature of the basic radicle than on the acid radicle of the salt. On the other hand we have

$$\begin{array}{lll}NaCl & & \\ NaNO_3; & \text{but} & Na_2CO_3 10H_2O\\ & & Na_2SO_4 10H_2O\\ & & Na_2HPO_4 12H_2O, \text{ \&c.}\end{array}$$

The fusibility of a substance has much to do with its solubility. This has been pointed out by Carnelley ('Phil. Mag.' March 1882) in reference to carbon compounds, and by myself and Mr. Shenstone ('Phil. Trans.,' 1884, and 'Jour. Chem. Soc.' July 1884) in reference to salts.

Neither fusibility alone nor chemical constitution alone seems to be sufficient to determine whether a solid shall be soluble or not; but it may be taken as a rule to which there are no exceptions that when there is close connection in chemical constitution between a liquid and solid, and the solid is at the same time easily fusible, it will also be easily soluble in that liquid.[1]

I take it that a salt containing water of crystallisation may be considered as closely resembling water itself. For example—

$$MgSO_4 7H_2O$$

may be considered as a congeries of eight molecules of water, $H_2O 7H_2O$, in which one molecule of water is replaced by the elements of the salt. We know that exchange of a similar kind is possible in the case of water of halhydration, as long ago pointed out by Graham.

$$MgSO_4 H_2O 6H_2O \quad \text{giving} \quad MgSO_4 K_2SO_4 6H_2O, \text{ \&c.}$$

So that $MgSO_4 7H_2O$ being like solid water in constitution, and also easily fusible by heat (it melts at 70°), it is easily soluble in water, and the solubility increases rapidly with rise of temperature.

The effect of fusibility on increase of solubility with rise of temperature is well shown by comparison of two such salts as

Potassium chlorate . . . m.p. 359°
Potassium chloride . . . m.p. 734°

both of which are destitute of water, and are therefore comparable (see fig. 5, p. 46).

There are many substances which contain much water—or the elements of water—which, nevertheless, do not dissolve in water, or dissolve with

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[1] This, of course, does not explain how it is that, although silver chloride is insoluble in water, the less fusible sodium chloride is easily soluble.

difficulty. Such are the hydrated oxides or hydroxides of the metals; but these are generally infusible :—

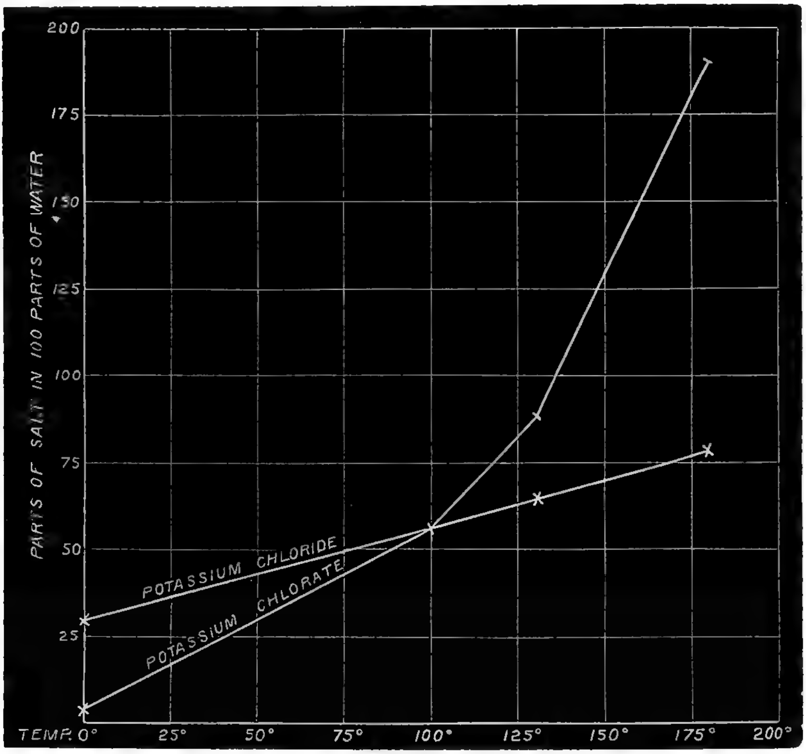
$$\left.\begin{array}{l} Al_2O_3.3H_2O \\ Fe_2O_3.3H_2O \\ Cr_2O_3.3H_2O \\ MgO.H_2O \\ CaO.H_2O \end{array}\right\} \text{infusible, very slightly soluble.}$$

Those which are easily fusible are also easily soluble, as the following :—

$$\begin{array}{ll} BaO2H_2O8H_2O & \text{m.p. } 100^\circ \\ SrO2H_2O8H_2O & \text{m.p. } ? \\ K_2OH_2O & \\ Na_2OH_2O & \end{array}$$

I take such examples as these as affording an argument for the hypothesis that such compounds retain their water when they pass into solution, else how can we account for the immense difference of solubility between baryta and strontia on the one hand, and lime and magnesia on the other?

FIG. 5.



Take the converse of easy fusibility associated with no connection of composition between solvent and solid, or in a series a diminishing connection.

The lower terms of the various series of alcohols and acids show considerable similarity to water in their general behaviour, the higher terms much less. The lower terms may, in fact, be regarded fairly as formed on the same type as water:—

$$\left.\begin{matrix}CH_3\\H\end{matrix}\right\}O,\quad \left.\begin{matrix}C_2H_6\\H\end{matrix}\right\}O,\ \&c.$$

But when the hydrocarbon radicle becomes very large and complicated it is much nearer the truth to say that the resulting substances are formed on the type of hydrocarbons, in which H is replaced by the water residue, the latter forming so small a portion of the whole that it fails to impress on the compound its own characteristics. We have, then, among the alcohols—

$$\left.\begin{array}{l}CH_3HO\\C_2H_5HO\\C_3H_7HO\end{array}\right\}\begin{array}{l}\text{resembling water and miscible with water}\\\text{in all proportions.}\end{array}$$

$$\left.\begin{array}{l}C_4H_9HO\\C_5H_{11}HO,\ \&c.\end{array}\right\}\text{not miscible in all proportions.}$$

$$\left.\begin{array}{ll}C_{16}H_{33}HO & \text{m.p. }50^\circ\\C_{27}H_{55}HO & \text{m.p. }97^\circ\\C_{30}H_{61}HO & \text{m.p. }85^\circ\end{array}\right\}\begin{array}{l}\text{fusible, waxy solids, insoluble in water, but soluble}\\\text{in ether and hydrocarbons, resembling the hy-}\\\text{drocarbon } C_{16}H_{34}\ \text{ m.p. } 21^\circ.\end{array}$$

Again—

		Solubility in Water.
Benzene .	.	C_6H_5H insoluble, though fusible.
Phenol .	.	C_6H_5OH slightly soluble.
Catechol .	.	$C_6H_4(OH)_2$ easily soluble.
Quinol .	.	
Resorcinol	.	
Pyrogallol	.	$C_6H_3(OH)_3$ still more soluble.

And—

		Order of Solubility in Water.	
Phenol .	. C_6H_5OH .	. 1	All easily soluble in alcohol, ether, and especially benzene.
Naphthols	. $C_{10}H_7OH$.	. 2	
Anthrols .	. $C_{14}H_9OH$.	. 3	

Dr. Carnelley has taken up the question of the relation between atomic constitution and solubility from a different point of view, and he has shown by reference to many examples, drawn chiefly, though not exclusively, from the aromatic division of carbon compounds, that of two isomeric compounds the one which has the less symmetrical constitution has the lower melting-point and the greater solubility ('Phil. Mag.' February and March 1882).

Kremers in 1854 and 1855 attempted a discussion of the relations between the constitution of salts and their solubility ('Pogg. Ann.' xcii. 497, and xciv. 87 and 255). He seems to have arrived at no very definite conclusions. One thing which he attempted to do was to trace the connection between atomic (molecular) volume and solubility, and he would probably have been more successful if he had had the advantage of a uniform and consistent system of atomic weights. As it was, he arrived at the conclusion ('Pogg.' xciv. p. 90) that 'greater atomic volume is associated sometimes with greater solubility, sometimes with less.' This part of the subject has been taken up more successfully by Dr. Nicol ('Phil. Mag' June 1884, January 1886), and he has shown that the molecular volume of certain salts is larger in strong solutions than in weak ones, and that in the cases examined the solubility is greater the more nearly the molecular volume in a saturated solution approaches the molecular volume of the salt in the solid state. But it has not, so far as I know, been shown that the molecular volume in the solid state determines the degree of solubility of the salt. Thus the molecular volume of KCl solid is 37·4, and the molecular volume of NaCl solid is 27·1. But sodium chloride is more soluble at temperatures below about 25° than potassium chloride, and silver chloride, which is insoluble, has a molecular volume, 25·8, scarcely less than that of sodium chloride. Similarly, the molecular volume of KNO_3 (solid) is 48·7, and that of $NaNO_3$, 37·9, but the latter is more soluble than the former.

Molecular volume is dependent—

(1) On the atomic weights of the elements present.

(2) On the constitution of the substance, that is, on the manner in which the constituent atoms are united together.

(3) On the density of the substance.

It has been already shown that in many cases increase of molecular weight corresponds to diminished solubility.

In the equation

$$\text{Mol. vol.} = \frac{\text{Mol. weight}}{\text{Density}}$$

the value of molecular volume is greater in proportion as molecular weight is greater, but also in proportion as density is less It is the latter which seems to correspond to increased solubility.

(4) Molecular volume is also probably connected with fusibility and perhaps with hardness as distinguished from density.[1] But neither molecular volume nor fusibility is sufficient to determine the degree of solubility of a solid. There must be another element in the question which may be, and probably is, attraction or affinity—whatever that may mean—between the substance and the solvent.

This is shown by such a case as the nitrates of potassium, sodium, and silver:—

Molecular Volume	Melting Point	Solubility			
		Parts of Salt in 100 parts of Water		Molecules in 100 mols. of Water	
		at 0°	at 100°	at 0°	at 100°
KNO_3 $\frac{101}{2\cdot07} = 48\cdot7$	339°	13·3	265	2·36	47·3
$NaNO_3$ $\frac{85}{2\cdot24} = 37\cdot9$	316°	72·9	180	15·43	38·1
$AgNO_3$ $\frac{170}{4\cdot34} = 39\cdot1$	217°	121·9	830	12·9	87·9

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[1] The mineralogists' ordinary scale of *hardness*, with the exception of talc, represents a rough scale of solubility:—1, talc; 2, rock salt; 3, calc spar; 4, fluor; 5, apatite; 6, felspar; 7, quartz; 8, topaz; 9, sapphire; 10, diamond.

SURFACE ACTION OF SOLIDS.

The absorption and condensation of gases upon solid surfaces, and more especially in porous substances, is well known. The action of the same substances upon liquids has not been studied to the same extent, but some facts are known which bear upon the question under discussion.

Graham, in 1830, published ('Pogg.' xix. 139) some experiments by which he showed that animal charcoal, purified by acids, and containing only a small quantity of silica, was capable of removing, from solution in water, not only colouring matters, a fact long previously known, but various metallic salts. Common salt was not precipitated, but solutions of nitrate of lead, acetate of lead, tartar emetic, ammonia-sulphate of copper, were completely deprived of their metal. In some cases the salt was taken up again when heat was applied. In some other cases, as solution of silver nitrate in ammonia and lead oxide in caustic potash, the metal was more or less reduced, being first precipitated as oxide. The quantity of lead oxide precipitated was so great as to be recognisable by its white colour in the charcoal.

In 1845 Warrington ('Phil. Mag.,' xxvii. 269) drew attention to the power possessed by charcoal of removing bitter substances and alkaloids from aqueous solutions.

Many other solid substances, when in a state of fine subdivision, exert a similar action. Precipitated sulphide of lead, oxide of iron, alumina, clay, &c., possess this power as well as platinum in the state of sponge or deposited upon asbestos (Stenhouse).

Cotton immersed in solution of alum was observed many years ago by Chevreul to be capable of withdrawing a liquid containing less alum than the original solution, and it has long been known to possess the power of abstracting oxide of lead, tannin, and various soluble colouring matters from their respective solutions (see Crum on the manner in which cotton combines with colouring matter, 'Phil. Mag.' April 1844; and 'J. Chem. Soc.' 1862).

Other porous insoluble substances are said to possess similar powers. Thus sand is said to be capable of removing acetic acid from the first portions of vinegar filtered through it (Gmelin, i. 114), and similarly to remove salt from sea-water ('Ure's Dict.' 1878, Art. Water, Sea). I confess to have tried this experiment without success. Solutions of common salt, and of alum of different strengths, were filtered through about twelve feet of dry white sand. The first portions of liquid running through were collected separately, but the quantity of salt present was not appreciably less than in the original solution.

However, it is probable that by varying the form of the experiment the result might have been somewhat different. J. Thoulet ('Compt. Rend.' xcix. 1072, c. 1002) finds that the attraction between the surface of a solid and a dissolved salt can be observed when marble, kaolin, or quartz is immersed in solutions of sodium or barium chloride, and that the action is proportional to the surface of the dissolved solid.

The action of filter paper upon saline solutions has been examined by Mr. Bayley ('Jour. Chem. Soc.' 1878). When a drop of a solution of a metallic salt is placed upon filter paper, the water spreads away into the paper, leaving a more concentrated solution in the centre of the spot. A great difference is, however, observed in the behaviour of the salts of various metals. Silver, lead, and mercuric salts give a wide water ring, as also do solutions of copper, nickel, and cobalt when dilute. But cadmium salts differ from all the rest in spreading to the edge of the blot.

The water ring was widest when dilute solutions were used.

Mr. Bayley's results have been confirmed and extended by J. U. Lloyd ('Chem. News,' li. 51–54).

Other porous substances, such as unglazed earthenware, behave in a similar manner, and are even capable of depriving salts of water of crystallisation, as observed by Potilitzin in the case of cobalt chloride ('Ber.' xvii. 276).

All these facts are undoubtedly connected, not only with the ascent of liquids in tubes, but with the property which very finely divided, though insoluble, powders generally possess of showing a rise of temperature [1] when wetted, and of remaining suspended in a liquid in a state which is sometimes referred to as pseudo-solution, until small quantities of certain soluble matters are added; that is to say, in every case there is adhesion or surface attraction manifested between the solid and the liquid, which is greater in proportion as the particles of the solid are smaller and expose a greater surface; and this adhesion is competent to separate substances which are so closely and intimately united that everyone would agree to say they were chemically combined.

SUPERSATURATION.

The fascinating character of the phenomena has attracted a host of experimenters, but no definite conclusion as to an explanation has been generally accepted.

Mr. Tomlinson, who a few years ago published many papers on the subject, has given ('Proc. R. S.' xvi. 403) a history of the chief researches up to his time. He has also arranged in five groups the salts he has investigated according as they do or do not yield supersaturated solutions, and according to the behaviour of those supersaturated solutions. The following definition of supersaturation is given by Mr. Tomlinson (*loc. cit.*): 'When water at a high temperature is saturated with a salt, and on being left to cool in a closed vessel retains in solution a larger quantity of the salt than it could take up at the reduced temperature, the solution is said to be supersaturated.'

Such solutions crystallise when brought into contact with a crystal of the same salt, or of a compound truly isomorphous with it (J. M. Thomson, 'Jour. Chem. Soc.' 1879).

Crystallisation, often in a modified form, is also in many cases brought about when the solution is cooled to a low temperature or evaporated, or when certain absorbent substances, such as paper or plaster, are introduced into the liquid under certain conditions (Jeannel, 'Compt. Rend.' lxii.; Grenfell, 'Proc. Bristol Nat. Soc.' vol. ii. Part II. 130).

It has been supposed by many chemists following the views expressed in the earlier of the well-known researches of Löwel ('Ann. Chim.' [3] xxix., xxxiii., xxxvii., xliii., xliv.) that supersaturation is due to the

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[1] Or, in the case of water, a fall in temperature, if below the temperature of maximum density. See V. d. Mensbrugghe, *Phil. Mag.*, [5] 2, p. 450, referring to Jungk's experiments. Since the above was written some interesting experiments have been published by F. Meissner (*Wiedemann's Annalen*, 1886, p. 114), upon the effect of moistening finely divided silica and other powders with water, benzene, and amylic alcohol. In every case above 0° a very notable rise of temperature was observed.

formation of peculiar hydrates containing less water, and more soluble than the normal salt. On the other hand, Löwel, in his last memoir ('Ann. Chim.' [3] xlix.), recants his earlier belief, and definitely expresses himself in favour of the opinion that a supersaturated solution (referring specially to sulphate of sodium) contains the anhydrous salt, and that no solution can be properly called supersaturated.

'Dans toutes les dissolutions, quelque riches qu'elles soient, qui ne sont pas en contact avec un excès de cristaux à 10HO ou à 7HO, les molécules salines dissoutes restent à l'état de sel anhydre, malgré les variations de température, si elles sont préservées de cette action mystérieuse de contact que l'air atmosphérique et d'autres corps ont la propriété d'exercer sur elles en déterminant la formation de cristaux à 10HO, et si leur température ne tombe pas à un degré suffisamment bas pour déterminer la formation spontanée de cristaux à 7HO' ('Ann. Chim.' [3] xlix. p. 56).

Tomlinson, de Coppet, and other writers have since adopted the same views.

De Coppet showed ('Compt. Rend.' lxxiii. 1324) that a supersaturated solution of sodium sulphate may be formed by dissolving in cold water the anhydrous salt, provided the latter had been heated above 33°, and preserved from contact with the dust of the air. He also succeeded in preparing supersaturated solutions of sodium carbonate, and magnesium sulphate by dissolving the dehydrated or partly dehydrated salt in cold water.

Nicol ('Phil. Mag.' June and Sept. 1885) has made similar observations, and has also shown from density determination of sodium sulphate and thiosulphate of various strengths that in passing the ordinary saturation point there is nothing to indicate any change in the constitution of the solution. He therefore concludes that a so-called supersaturated solution is merely a solution saturated or non-saturated of the anhydrous salt, and that in this respect it differs in no way from an ordinary solution which is not capable of supersaturation. Nicol also considers, as Löwel seems to have done, that any solution of a hydrated salt contains no hydrate, but that combination between the salt and the water takes place at the moment of crystallisation.

I thought at one time that supersaturation resulted from dissociation of the dissolved salt into water and the anhydrous salt, owing to the action of the higher temperature—above 33°—to which, by the ordinary process of making supersaturated solutions, the liquid is exposed. But before the experiments of De Coppet and Nicol had come to my knowledge I had satisfied myself that this was not so; for on saturating a solution at the temperature of the air with crystals of sodium sulphate, and then filtering the solution into a stoppered bottle and cooling to about 0°, the cold solution exhibits all the phenomena of supersaturation so long as it is kept at that lower temperature. This is difficult to explain on any hypothesis of dissociation.

Supersaturated solutions are at present only known to be formed by hydrated salts, or by anhydrous salts only at such low temperatures that hydrates are formed, *e.g.*, common salt. I am inclined to the belief that this is due to their much greater fusibility. If we compare the melting-points of those salts which are known to give supersaturated solutions readily with the melting-points of those which, although easily soluble, do not give supersaturated solutions under any conditions that have yet been tried, we see this difference plainly.

Salts which readily form Supersaturated Solutions	Melting Points Approximate	Salts which do not form Supersaturated Solutions	Melting Points
$Na_2SO_410H_2O$	34°	KNO_3	339°
$Na_2CO_310H_2O$	34°	$K_2Cr_2O_7$	400°
$Na_2HAsO_412H_2O$	28°	$NaNO_3$	316°
$Na_2HPO_412H_2O$	35°	$KClO_3$	359°
$NaC_2H_3O_2H_2O$	58·5°	$Ba(NO_3)_2$	593°
$KAl(SO_4)_212H_2O$	84·5°	&c.	
$Na_2S_2O_35H_2O$	48·5°		
$MgSO_47H_2O$	70°		

A supersaturated solution may be regarded as a mixture of a saturated solution, with an extra quantity of the salt retaining a liquid state; in fact, in the condition which is commonly spoken of as superfusion. Now, when we examine cases of superfusion, such as water, melted phosphorus, melted sulphur, phenol, acetic acid, and so on, we find that the liquid state is preserved so long as the liquid is cooled only a moderate degree below its melting-point.[1] Water may be cooled to 10° or 12° below freezing; phosphorus, which melts at 44·2°, can be cooled to the common temperature of the air, say 30° lower; but sulphur, which melts at 115°, cannot be cooled to the air temperature, which is 100° below its melting-point, save in very small drops (Faraday). Melted sulphur may, however, be kept liquid at the temperature of boiling water, if protected from dust, &c. (Gernez, 'Compt. Rend.' lxxxiii. 217). Similarly, supersaturated solutions remain liquid at the common temperature of the air, but crystallise at 20° or 30° lower when cooled by a freezing mixture. The fact is supersaturation is a case of superfusion. Gernez supposed ('Compt. Rend.' 1866, p. 218) that he had discovered a difference between the two when he made the observation that superfused phosphorus and sulphur might be made to solidify by rubbing two hard bodies together under the surface of the liquid, as when the inside of the containing vessel is scratched with a wire or a glass rod. But Mr. J. G. Grenfell showed in 1876 ('Proc. R. Soc.' xxv. 129) exactly the same phenomenon with a solution of sodium sulphate in sulphuric acid, and it appears to differ in no respect from the well-known effect when solution of platinum perchloride or of sodium hydrogen tartrate is mixed with a potassium salt and the liquid is vigorously stirred.

My view of supersaturation, then, is that it is identical with superfusion. The explanation of the one phenomenon is the explanation of the other. The case of thiosulphate of sodium is a very interesting one. This salt melts at 48·5° without addition of any water whatever beyond what it contains in chemical combination. This salt may be kept in a liquid state in an ordinary flask exposed to the air for weeks. Advocates of the theory which considers supersaturated solutions (and other solutions) to contain molecules of the anhydrous salt in a free state must regard this liquid as a solution of one molecule of $Na_2S_2O_3$ in five molecules of water. I cannot help believing that this liquid is none other than the compound $(Na_2S_2O_35H_2O)_x$ in a liquid state, just as liquid water is the compound $(H_2O)_x$.

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[1] There is a commonly recognised difference between melting and solidifying points, but this seldom amounts to more than a few degrees.

Since contraction occurs when most solids are dissolved in water, it follows that if the dissolved substance could be withdrawn again without changing the temperature of the liquid expansion would occur. Now superfused substances (and supersaturated solutions) contract as they solidify, with the single exception (so far as I know) of water, which expands when frozen. If it were not for the declaration of Professor Osborne Reynolds that 'dilatancy' is not a property that can be exhibited by ordinary matter, but only by such hypothetical stuff as consists of hard, inelastic particles devoid of cohesion and friction, one would be tempted to try and explain superfusion and supersaturation by appeal to a hypothesis of that kind. Certain it is that in a superfused liquid there exists a condition of strain which is overcome by cohesion only when the latter has been considerably increased by lowering the temperature. And relief from this strain may often be obtained in more than one way, as in the crystallisation of dimorphous substances like sulphur, and in the deposition of modified salts (such as $Na_2SO_47H_2O$, &c.) from solutions.

The fact that in some cases it is possible to reduce the temperature of small drops of a superfused liquid, such as sulphur, much below that at which larger masses can be preserved in the liquid state, seems to show that the surface tension in spheroidal masses operates against the tendency to change of state. Whether it is sufficient appreciably to retard the change is more than I can say, but Van der Mensbrugghe[1] has shown by mathematical analysis that the potential energy of a free liquid surface increases with the surface, and in this way he explains the very facts to which I have just referred.

CONCLUSION.

Such facts as these lead us to the consideration of what is meant by chemical combination. Take, for example, a common metallic salt, such as copper sulphate, $CuSO_4$. Here the law of definite proportions being rigidly observed, and the compound being very different in external characters from its ingredients, chemists have no difficulty in agreeing that this is a case of true chemical combination. But when the salt combines with water of crystallisation great difference of opinion arises as to whether the elements thus superadded are chemically combined with those of the salt, or whether a new kind of chemical affinity is called into play. The difference is one of degree, not of kind. Blue vitriol is composed of copper sulphate and water united in definite and quite simple proportions, and the chief reason for supposing the water to be combined in a manner different from the other ingredients of the salt is that it can be detached by heat or otherwise more easily, and that it occupies a relatively larger volume. But, as already stated, the water combined with such a salt is attached in different degrees of intimacy, the first molecule occupying a smaller volume than the second, and so on, the act of union of the salt with these successive molecules being attended by the loss of successively smaller amounts of energy.

Taking a step further, suppose this salt dissolved in water, the resulting liquid is produced with many of the attendant phenomena which usually accompany recognised chemical combinations—changes of

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[1] 'On the Application of Thermodynamics to the Study of the Variations of Potential Energy of Liquid Surfaces,' *Phil. Mag.*, 1876 [5], ii. p. 450; and *Phil. Mag.* 1877 [5], lv. p. 40.

volume, of specific heat, and thermal changes, positive or negative. The same may be said of the act of diluting this solution. More water (or more salt) being added, similar physical phenomena are exhibited; and it is important to notice, as already stated more than once, these changes are all continuous one with another, the specific volume of the added water constantly tending towards that of water itself. The conclusion seems inevitable that chemical combination is not to be distinguished by any absolute criterion from mere physical or mechanical aggregation, and it seems not improbable that it may ultimately turn out that chemical combination differs from mechanical combination, called cohesion or adhesion, only in the fact that the atoms or molecules of the bodies concerned come relatively closer together, and the consequent loss of energy is greater.

The researches of Müller-Erzbach, published in a long series of papers (especially 'Ber.' 1880, p. 1658, and 1881, p. 217), strongly support such a view. He has shown by numerous examples that in similarly constituted solid bodies those are the most stable in the formation of which the greatest contraction occurs. Thus when lead replaces silver, or potassium replaces sodium in the nitrate, or when chlorine replaces bromine or iodine in combination with another element, contraction occurs. And in general, contraction is observed when an element of reputed strong affinity (as indicated by the results of thermo-chemical experiment) takes the place of one of reputed smaller affinity. This is only an extension of what has already been observed in the combination of water with salts, and which in all probability applies generally in the comparison of atomic combination as distinguished from so-called molecular combination.

We are in the habit of using the word 'attraction' in a somewhat indefinite and unsatisfactory manner in referring to the hypothetical cause of the union of atoms or molecules. We do not know what this thing is which is called chemical affinity or attraction. There can be little doubt, however, that it is connected intimately with atomic or molecular motion. It does not require a great stretch of imagination to conceive that combination occurs most readily and intimately between those atoms or molecules whose motions are nearly alike. And confining our attention to the phenomena now under discussion, it seems not improbable that this may be the explanation of the selective action of solvents, and the disposition so often shown for like to dissolve in like. It may also, perhaps, go some way towards explaining the great amount of heat evolved and the great contraction which ensues when many anhydrous salts are brought into contact with water, as compared with the effects of dissolving the same salts when in the hydrated state.

On the Exploration of the Raygill Fissure in Lothersdale, Yorkshire. By JAMES W. DAVIS, *F.G.S.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

THE Raygill Fissure, in the mountain limestone in Lothersdale, about five miles south-east of Skipton, was investigated to some extent by a Committee of the Association, and a report was presented by the Committee and printed in the Annual Report for 1883. The fissure descended in a slightly diagonal direction in the form of a pothole from the surface to a depth of about 120 feet, and of this depth the lower 90 feet has been dug out and thoroughly examined, resulting in the discovery of numerous bones of animals, particulars of which are recorded in the report referred to above. The specimens are deposited in the Museum of the Philosophical and Literary Society at Leeds. Towards the close of 1883 it was found that the fissure assumed a more or less horizontal direction, and the work of excavation was rendered very difficult and laborious by the position of a large mass of limestone in front of the fissure, constituting at that time the face of the quarry. This obstruction the proprietor of the quarry very kindly engaged to remove, and operations were suspended to enable this to be done.

Since 1883 the face of the limestone has been quarried and the obstructing mass of limestone removed, and during the present summer operations have been renewed on the fissure. Its course has been traced to a distance of 114 feet, with a gradual declination in a south-easterly direction. The present entrance to the fissure is 4 feet wide: it diminishes to 2 feet 6 inches, but at a distance of 60 feet expands and forms a lofty cave, thence forwards the diameter again diminishes. The termination of the fissure so far as it has been explored appears to receive a tributary extending almost vertically in a north-westerly direction. The general direction of the fissure tends towards the hillside, forming the channel of a watercourse at present running at no great distance; and it is probable that it formerly opened into it, although no direct evidence at present exists of the exit. Borings have shown the bottom of the fissure to be filled in with clay varying from 6 inches to several feet in thickness, with slight alternating layers of sand and gravel, and occasionally fragments of grit and limestone at the bottom. A few remains of mammals have been found near the entrance to the horizontal portion of the fissure similar to those already recorded.

At the meeting at Montreal in 1884 a grant of 15*l.* was made for the further exploration of the cave. This sum has been expended in the operations described above. A very much larger grant would be required to investigate the remaining length of the fissure, because the work will be increasingly laborious, and the consequent expense proportionately heavy; and as there is no probability indicated in the work so far that the already large series of animal remains will be greatly, if at all, increased, it is not thought advisable to ask for a renewal of the Committee or grant.

In conclusion, it is desirable to render thanks to Mr. Spencer, and latterly to his son, the proprietors of the Raygill Quarries, for their permission to carry on the work, and for the uniformly kind and courteous manner in which they have always placed themselves at the disposal of the Committee; and to Mr. J. Todd, the manager of the works, for the trustworthy and careful manner, combined with much skill, in which he has superintended the operations of the workmen employed.

An Accurate and Rapid Method of estimating the Silica in an Igneous Rock. By J. H. PLAYER.

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

PREPARE a flux by intimately mixing together two parts of bicarbonate of soda, two parts of bicarbonate of potash, and one part of nitrate of potash, all finely ground.

The mixture must be heated until dry and perfectly pulverulent.

In a platinum crucible, six centimetres high, mix thoroughly half a gramme of the very finely powdered rock with one gramme of the flux, place a cover on the crucible, and heat the contents to fusion.

With a Fletcher's gas crucible furnace, the chimney being used, complete fusion can be effected in five minutes, with a small blowpipe gas furnace in three minutes. Working with rocks containing not less than 45 per cent. of silica I have never found a crucible attacked. I have not used the process with less siliceous rocks.

After fusion remove the cover from the crucible and replace it by a small glass funnel cut off at the apex of the cone; then, without waiting for the fused mass to cool, pour in it through the funnel 3 cc. of strong nitric acid. Energetic action ensues, but there is no projection of the solid or fluid contents of the crucible. Place it at once on a water bath and keep it for ten minutes at a temperature of 100° C.; at the end of that time if all hard and dark particles have not disappeared add 2 cc. of nitric acid, stir with a platinum rod, and continue to heat. As soon as the disintegration of the glass is completed wash with as little water as possible the crucible cover, funnel, and rod, then evaporate the jelly and the washings together. After having driven off the greater part of the water, when there is no longer any fear of projection, remove the crucible to a sand bath and heat just below 250° C. until all nitrous fumes shall have disappeared.

The operation has up to this point been carried on in one vessel; now turn the mass into a small glass beaker, washing the crucible, first with 5 cc. of water, then with 3 cc. of hydrochloric acid; heat the beaker to 100° C., that the bases may be quickly dissolved by the acid, until the silica left be white and free from red specks; add now more water and pour the contents of the beaker on to a 590 Schleicher and Schulls filter, placed over a filter-pump; drain as dry as possible, and calcine at once in a small crucible. Weigh the crucible and its calcined contents, consisting of silica mixed, if these bodies be present in the rock, with minute quantities of iron oxide and alumina, and a much larger quantity of titanic acid. After weighing moisten very slightly with four or five drops of strong sulphuric acid, stir the moistened silica with one gramme of perfectly pure ammonium fluoride, put a cover on the crucible, and heat it, first of all gently, then more strongly, finally to a full red heat. If the few milligrammes left in the crucible are not perfectly soft repeat the process; but this it should not be necessary to do.

The weight of the crucible and the calcined residuum having been ascertained, it must be deducted from the previously recorded weight; the difference will give the weight of the silica present in half a gramme of the rock.

Ercal Hill Granulite—Red Rock.

Sp. Gr. 2·575.

Water	·5
Silica	76·8
Titanic acid	·4
Alumina	13·4
Peroxide of iron	·6
Protoxide of iron	·1
Lime	trace
Magnesia	trace
Potash	6·2
Soda	2·2
	100·2

Ercal Hill—Grey Rock.

Sp. Gr. 2·508.

Loss by calcination, ? water	1·5
Silica	79·6
Titanic acid	·3
Alumina	11·1
Peroxide of iron	1·4
Protoxide of iron	·3
Lime	trace
Magnesia	·2
Potash	2·3
Soda	2·9
	99·6

Lea Rock Rhyolite.

Sp. Gr. 2·590.

Water	·7
Silica	75·4
Titanic acid	·2
Alumina	13·
Peroxide of iron	·8
Protoxide of iron	·6
Lime	·4
Magnesia	·2
Potash	7·
Soda	1·1
	99·4

Quartz Felspar, Malvern—Red Rock, Coarse Granitic Texture.

Sp. Gr. 2·594.

Water	·7
Silica	75·2
Titanic acid	·2
Alumina	13·0
Peroxide of iron	·7
Protoxide of iron	·4
Lime	·4
Magnesia	·3
Potash	7·1
Soda	1·9
	99·9

Quartz Felspar, Malvern, North Hill.

Sp. Gr. 2·601.

Water	·8
Silica	74·6
Titanic acid	none
Alumina	14·2
Iron peroxide	1·2
Iron protoxide	trace
Lime	·4
Magnesia	·3
Potash	4·9
Soda	3·7
	100·1

Quartz Felspar, Malvern—Red Rock (fine-grained).

Sp. Gr. 2·604.

Water	·9
Silica	75·2
Titanic acid	·2
Alumina	13·7
Peroxide of iron	1·3
Protoxide of iron	·6
Lime	·4
Magnesia	·3
Potash	4·0
Soda	2·6
	99·2

On some points for the Consideration of English Engineers with reference to the Design of Girder Bridges. By W. SHELFORD, *M.Inst.C.E., and* A. H. SHIELD, *Assoc.M.Inst.C.E.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

ENGINEERS with an eye for bridge-building cannot fail to be struck by the difference in general appearance between English, German, and American bridges. The ordinary plate-girder unquestionably finds more favour in England than elsewhere, while in Germany it seems to have been more or less discarded in modern practice, and is replaced by lighter structures, designed with a more scientific disposition of the material, and constructed chiefly of angle and bar iron.

Both in Germany and in America the modern practice appears to be to adopt large panels and great depth—a system of construction which has been greatly facilitated by the use of steel, owing to the greater length of the bars and plates procurable in that metal, and the consequent diminution in the number of joints.

In America, also, pin-jointed bridges are the rule, and riveted joints the exception—exactly the reverse, in fact, of the English practice—and the deep pin and link truss, with a straight top boom and long panels, there almost the universal method of construction for spans over 75 feet, differs in a striking manner from both English and German bridges. Its construction has been brought to considerable perfection, and appears to be eminently suitable for a country where distances are great, labour scarce and expensive, and rapid construction of the utmost importance. By this system the Americans are able to turn out a bridge with the greatest accuracy and expedition, and can erect it without previous erection in the shops, and with little staging, in an incredibly short space of time.

In England, on the other hand, a strong bias among engineers in favour of riveted joints has led to the absence of special appliances for the manufacture of pin and link bridges; and the practical advantages of the system are less esteemed, as English engineers do not push forward their railways so rapidly as the Americans.

As most English railway engineers must now look chiefly to the development of new countries for future work these general facts should be sufficient ground for an examination of their practice; but if more definite reasons are sought, reference may be made to the case of Canada, where English engineers, who built the first bridges, have since been superseded by Americans.

The design of a bridge of exceptional span is almost invariably the subject of special study, to an extent which is inadmissible in the case of bridges of ordinary size. These are usually constructed in accordance with a limited number of standard types, which experience has shown to be suitable; and it is to these only that such general considerations as have been suggested properly apply.

The economic importance of smaller bridges is also greater, and it is to bridges of spans less than 200 feet, which, with reference to the American system, may be termed 'merchantable' sizes, that the scope of this paper is therefore limited.

In order to ascertain the extent to which the weight of such bridges is affected by their design, seven designs were chosen for bridges of 140 feet span for a double line of railway. The designs were selected to represent leading English and American types; their strength was determined by a rolling load of $1\frac{2}{3}$ ton per lineal foot for each track; and their weights were estimated, including flooring, rail bearers and cross girders, and the necessary stiffening or bracing for wind pressure and lateral oscillations. Particulars of the design and weight of each bridge are given in the following table:—

No.	Description	Length of panel	Depth of girder	Estimated weights		
				Main girders (*a*)	Plat-form	Total
				Tons	Tons	Tons
1	'N' or 'Pratt' (riveted)	8 ft.	12 ft.	104	86	190
2	Bowstring (riveted) .	8 ft. 8 in.	18 ft. (*b*)	95	86	181
3	'Whipple' (pin connected)	8 ft.	18 ft.	89	86	175
4	'Neville-Warren' (partly riveted)	8 ft. 9 in.	18 ft.	83	86	169
5	'N' (pin connected), ordinary American type	17 ft. 6 in.	24 ft.	75	81	156
6	Polygonal (riveted) .	20 ft.	26 ft. 3 in. (*b*)	(*c*)	(*c*)	154
7	'N' (pin connected .	24 ft.	24 ft.	68	84	152

(*a*) includes wind-bracing; (*b*) at centre; (*c*) inseparable.

Plate floors were adopted in all these bridges in order to enable a comparison to be made between their weights, although in America they would be replaced by heavy timber decks with diagonal bracing of iron rods. Nos. 1 and 2 derive lateral stiffness entirely from the plate floor, and owe their transverse stability to the connection of the verticals to the cross girders by knee pieces, aided in the case of the bowstring girder by light overhead stays at the centre. In Nos. 3 and 4 the depth (18 feet) admits of a complete system of lateral bracing between the top booms, so that the transverse stiffening is confined to the ends; their relative advantages are discussed at length by Mr. C. Bender in his recent book on the Economy of Metallic Bridges,[1] and preference is given by him to the Whipple truss. No. 5 is an ordinary type of American bridge; the lateral stiffness of the bottom is derived from the plated floor, and it has top lateral bracing and transverse stiffening at the ends, as in Nos. 3 and 4. No. 6 represents an attempt to apply to the conditions of the problem the principles enunciated by Mr. Max am Ende in a paper recently read before the Institution of Civil Engineers.[2] The girders are polygonal; lateral stiffness is derived entirely from the floor; and transverse stiffness is obtained by combining each of the cross girders with the verticals and overhead stays into a rigid frame. No. 7 was suggested by the central span of the Niagara Cantilever bridge, and has a wind system similar to that of Nos. 3, 4, and 5.

From these examples it will be seen that the difference in weight of good designs of the same depth is comparatively trifling, and is not greater than might be compensated by local considerations; such as the relative cost of labour and material; facilities for erection; and the difference in cost of various methods of construction; while the fundamental principle that the weight of a girder decreases as the depth increases is generally applicable to an extent which, if recognised in theory by English engineers, has not hitherto found general expression in their practice.

The extra depth required for the rail-bearers in bridges with long panels is, however, in England, where the headway is frequently very

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[1] *The Principles of Economy in the Design of Metallic Bridges.* By Charles B. Bender. New York, 1885.

[2] *Minutes of Proceedings Inst. C.E.*, lxiv. 243.

limited, more often than elsewhere prohibitory of the adoption of the most economical form for the main girders; and although the question of design requires careful study, there is no evidence of the existence of inherent national errors or prejudices in design which would be likely to place English engineers at a disadvantage in dealing with colonial work, or to account for the fact that they have lost it in Canada, and recently in one case in Australia.

It has been suggested that the position of the designer in America is more favourable to economy of construction.

In America when a bridge is required the railroad company invite tenders for its construction and erection in accordance with their specification, which generally states the class of bridge preferred, the load which it is to carry, and the quality of the material, and defines in considerable detail the stress to which its parts may be subjected. The design is left to the bridge company tendering for its construction, but it is required that sufficient information shall be supplied with each tender to enable the railroad engineer to examine the proposal and determine whether it fulfils the required conditions.

The designer, who is consequently employed by the bridge company, has in the first place to produce the most economical structure, while the primary responsibility for its safety lies with the railroad engineer who has prepared the specification, and will be enabled to check the correspondence of the design with his requirements before the tender is accepted, and to make the necessary modifications—a work of considerable difficulty unless the design is a good one to begin with.

The English designer, on the other hand, has in the first place to design a safe structure, since he is seldom immediately subject to competition in respect to its economy, and is entirely responsible for its security.

The English system has advantages with respect to security; while its economic disadvantages are that the engineer is seldom able to ascertain either the exact cost of his designs, or the relative economy of their details, nor has he any personal interest to serve, or any other inducement to reduce the cost to the lowest point. The system moreover entails a want of correspondence between the design and the appliances of the manufactory, where it is afterwards executed, especially if the work is let by open tender. These disadvantages are accidental rather than essential in their nature, and this should suggest their remedy in detail rather than the condemnation of the system under which they arise.

Much could be effected by manufacturers to promote economy in design by the publication of particulars of the relative cost of different details of construction, in such a way as not to injure their commercial interests.

It is also an open question whether standard sections could not be adopted for the usual sizes of angle, tee, and other rolled bars, so that no difficulty need arise—in this respect at least—in making the design in accordance with the scantling of the materials readily available for its manufacture.

Both the design of bridges generally, and the personal position which the designer should occupy, are matters which may be left entirely to the discretion of those concerned; but engineers are in England very properly subject to a certain degree of Government supervision in regard to structures which directly affect the safety of the travelling public.

The Board of Trade have exercised since 1840 a statutory power of inspecting and testing bridges on railways for passenger traffic, and have issued rules for the guidance of engineers in designing these structures, which have been generally accepted as applicable to all bridges, and exercise a strong influence over English engineers in their use of iron and steel in all permanent engineering structures either at home or abroad.

It is provided by these rules that the greatest strain produced by the combined moving and dead load on any part of a structure shall not exceed, for wrought iron five tons, and for steel six and a half tons, per square inch.

No defined quality or strength is required in order that either material may be subjected to these stresses, but in the case of steel the engineer must certify that it is possessed of considerable toughness and ductility, and state the tests to which it has been subjected.

It is also provided that the heaviest engines, boiler trucks, and travelling cranes in use on railways shall be a measure of the load to which bridges may be subjected.

For convenience the strength of bridges is usually measured by an assumed uniform load per foot run, intended to cover the weights of the heaviest engines and trucks. [The manner in which this equivalent—for the same actual load—varies with the span of the bridge, was shown by a diagram.[1]]

This diagram showed how important the rolling load becomes in small girder bridges, and in the floors of large bridges—matters which have certainly not been properly considered in numerous existing examples in England. The determination of the greatest load to which a bridge may be subjected, also affords an excellent example of the insufficiency of any rules, however perfect, to relieve the engineer of a large amount of responsibility.

The origin of the rules may be traced in the Parliamentary Reports of the Board of Trade, and of the Railway Commissioners who from 1846 to 1851 exercised the powers of the Board of Trade with respect to railways.

From these reports it does not appear that previous to 1849 the inspecting officers had a defined rule for the strength of bridges either of wrought or cast iron.

In 1847, however, a Royal Commission was appointed in the following terms:—

'To enquire into the conditions to be observed by engineers in the application of iron to structures subject to violent concussions and vibrations' and 'to endeavour to ascertain such principles, and to form such rules, as may enable the engineer and mechanic to apply the metal with confidence, and to illustrate by theory and experiment the action which takes place under varying circumstances in iron railway bridges which have been constructed.'

The terms of this Commission clearly indicate that the interest of the engineer was to be studied as well as the safety of the public.

The Commissioners were Lord Wrottesley, then President of the Royal Society; the Rev. Robert Willis, M.A., an eminent mathematician;

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[1] The results deduced from this diagram are given in the Appendix in Schedules A and B.

Capt. Henry James, of the Portsmouth Dockyard; and three civil engineers, Messrs. George Rennie, William Cubitt, and Eaton Hodgkinson.

After examining the leading engineers and ironfounders of the day as to their experience and practice, and making numerous and elaborate experiments, the Commissioners reported that 'legislative enactments which would fetter scientific men in the development of a subject as yet so novel and rapidly progressive would be highly inexpedient.'

They, however, made certain recommendations with respect to cast-iron bridges, which are substantially the same as the present rule for cast-iron structures—that the breaking weight should be six times the moving load added to three times the dead load.

They also made a further recommendation, applicable to all elastic horizontal bridges, that provision should be made for the increase of strain in bridges under 40 feet long when subject to a rapidly moving load, as indicated by the increased deflection in such cases—a recommendation which until recent years was lost sight of.

These recommendations were, immediately upon the publication of their report, embodied by the Railway Commissioners in a circular letter of instructions to their inspecting officers.

On the day following the date of this letter Capt. Simmons inspected the Torksey Bridge, a wrought iron box-girder bridge of two continuous spans of 130 feet, designed by Mr. (now Sir) John Fowler, and objected to it as of insufficient strength.

Its rejection was discussed by the Institution of Civil Engineers, and the Railway Commissioners were accused of applying to wrought iron the recently published recommendation of the Commission on Iron, requiring a factor of safety of six for cast iron bridges.

At the same time a lengthy correspondence took place between Mr. Fowler and the Commissioners, and Captain Simmons decided—after the examination of such examples as were available—that the bridge should be strengthened so that the strain should not exceed five tons per square inch.

In fixing this he admitted that there was no decided authority upon the subject, and that the variation in the circumstances of the construction of bridges prevented the application of an invariable law. He recognised as a principle the variation of the admissible strain in a bridge according to the proportion of live to dead load—a point which has been recently revived.

In the end—after a special examination to test the continuity of the spans—the bridge was accepted with a strain under the most favourable estimate of slightly over six tons per square inch.

Between 1850 and 1858 the rule for cast iron bridges appears to have found general acceptance, while there is conclusive evidence of the absence of a defined limit for the strain in wrought iron structures.

In 1858 a wrought iron tubular girder bridge over the Spey was brought before Captain (now Sir) Henry Tyler some time before its completion, and a lengthy correspondence ensued between Captain Tyler and Mr. Fairbairn with reference to its strength. This correspondence Captain Tyler laid before the Board of Trade, who, on March 30, 1859, issued a circular letter of instructions fixing five tons per square inch as the proper limit of strain for wrought iron. Upon this Captain Tyler based his rejection of the bridge on April 30.

It is very important to note that this rule was explained at the time by Captain Tyler to represent a factor of safety of four for combined moving and dead load. It has not since been altered, and in practice it is assumed to be applicable to all wrought iron, whether the quality be good or not.

Among the numerous considerations suggested by the survey (after the lapse of over 25 years) of the period of which a brief sketch has been given, the most striking is the confirmation which experience has given to the conclusions of the Commission of 1847. Derived from the interpretation by skilled mathematicians of the results of experiments conducted by practical engineers, combined with the evidence of the ablest engineers of the time, their conclusions were based upon a solid foundation of fact and experience.

Their recommendations, although jealously resented by civil engineers at first, notwithstanding the avoidance of legislative interference, by which freedom was secured for the development of engineering science, led, under the judicious interpretation of the inspecting officers, to the present rule for cast iron structures. This rule is good in principle because it derives the load—and consequently the stress—to which the structure may be subjected, from the actual strength of the material.

The present rule for wrought iron has no such foundation, and it is indeed only due to the high professional attainments of the inspecting officers, and the sound judgment and great moderation with which they dealt with the difficulties which naturally arose when wrought iron first became generally used, that the present rule, introduced without special experimental research, has endured so long that it has obtained the sanction of what—to younger engineers at least—is an immemorial usage, taken for granted and stereotyped beyond reach of improvement.

Its principal fault is in allowing a fixed limit of stress without regard to the quality of the material. This does not lead to serious results so long as the limit of five tons per square inch is understood to represent a factor of safety of four applied to iron having a breaking strength of not less than twenty tons, as explained by Captain Tyler in 1859; but it must not be forgotten that the rule itself is used by many who do not know its origin, and the absence of any stipulation as to the strength of the material leads naturally to the assumption that five tons represents the safe working stress for any quality of iron in the market; and many inexperienced engineers do so interpret and use it.

It is hardly necessary to state that there are many qualities of iron for which such an assumption would be attended with considerable danger, but it is not so apparent that a bridge made of utterly untrustworthy material might not, under the ordinary tests, afford any indication of its insecurity. Such is, however, the case, and the safety of the public depends, in this respect, very much more upon the choice of a suitable material by the engineer than upon the Board of Trade rule.

A fixed limit of stress without regard to the quality of the material also restricts the engineer in the development of economic design in the direction of a greater use of better material, such as angle and bar iron of superior strength and ductility. Nor does a fixed stress offer any inducement to the manufacturer to improve the quality of plates.

These considerations apply with much greater force to the present rule for steel. As a material, steel is much more variable in its strength than iron, which renders the application of an invariable coefficient more objectionable.

It is true that the Board of Trade, in accordance with a recommendation of the Committee of 1877 appointed at the instance of the British Association, allow in special cases the use of steel with a higher stress, but exceptions of this nature are naturally ill-adapted to the design of bridges of ordinary spans.

The rules cannot be regarded as suited to the nature of the material, and there can be little doubt that they have operated to hinder the application of steel to uses for which it is admirably suited, and have thus exercised a prejudicial effect upon one of the leading industries of the present day.

Unless the rules which determine limiting stresses or coefficients for iron and steel can be brought into conformity with modern knowledge of the properties of materials, and of the laws by which their application to construction should be regulated, their entire abolition would be preferable, because it would conduce to the advancement of engineering science, and the development of the bridge-building industries. The safety of the public need in no respect be compromised by the abolition of the limiting stresses, if the rules requiring the engineer to certify the quality of the material used were retained (and extended to apply to iron as well as steel) in order to provide the inspecting officer with all the information requisite to enable him to judge whether the stress to which a structure was subjected was within safe limits.

Freed from the deadening influence of the fixed coefficients, private enterprise would establish standard rules for the determination of the stress to which different materials under varying conditions might safely be subjected; to the great advantage of the professions and trades interested in bridge-building, and having in future to compete with the Americans.

On the other hand, there are many objections to such a course, which would practically amount to a reversion, after the experience of thirty years, to the conditions of 1850. It is also to be feared that during the time which must necessarily elapse before any rules obtained the sanction of a common assent, differences of opinion causing much inconvenience would probably arise between civil engineers and the inspecting officers of the Board of Trade—which is much to be deprecated.

A course more worthy of the scientific attainments of English engineers would be the amendment of the rules; so that, while leaving to the engineer the greatest possible freedom in the choice of design and material, and leaving in his hands the responsibility for the correct determination of every effect of the loading of a structure which the most modern methods render calculable, they should determine for his guidance by coefficients based upon experience, or where practicable upon experimental research, the proper allowance to be made severally for each of all those effects which are usually understood to be covered by the present arbitrary factor of safety.

Rules so designed could not fail to exercise an elevating effect on the professional knowledge and skill of engineers, by affording a more distinct conception of the effects for which the factors of safety provide; and by abolishing the use of coefficients, of which neither the origin, scope, nor intent is known to the user.

The division of the factor of safety into many separate coefficients, some of which would vary with the quality of the material and character of the workmanship, would encourage good workmanship and the use of materials of a high class, without restricting the use of materials of a lower class and less perfect workmanship for purposes to which they are adapted; and would thus be in the highest degree beneficial to the manufacturers' interest.

These results can hardly be attained otherwise than by rules framed upon the recommendations of a Royal Commission, who could bring to their aid the experience of the inspecting officers and of the leading engineers and manufacturers, and institute special experimental research to elucidate any doubtful questions. Such a Commission would indeed be but a revival of that of 1847, to complete the work which the former Commissioners were compelled to abandon in 1849, because the application of wrought iron to engineering structures was yet in its infancy, and steel in its modern form unknown; and the scope of their enquiry could hardly be better defined than in the terms of the former Commission.

The draft rules appended have been prepared to show that the views above expressed are capable of taking a practical form, and to render more easily apparent the advantages claimed for them.

Abstract of Suggested Rules for the Control by the Board of Trade of the Design of Structures of Wrought Iron and Steel.

NOTE.—The formulæ and numerical values inserted are intended merely as suggestions of theories requiring further investigation for their establishment, or as estimates of the values which experimental research or experience would assign to the various coefficients.

RULE 1.—Structures of wrought iron or steel to be so proportioned that the calculated stress in any part due to the weight of the structure, together with the moving load set at rest upon the structure, shall not exceed that specified under Schedule D. Stresses due to wind alone not to exceed $1\frac{1}{2}$ times, and stresses due to the combined effect of wind and load $1\frac{1}{4}$ times the specified stresses.

RULE 2.—Provision to be made for moving loads upon main girders, platforms, and bracing, according to Schedules A, B, and C.

RULE 3.—All structures to be designed to resist lateral forces, including not less than 30 lbs. per square foot for wind pressure. In lofty or exposed situations greater allowance to be made for wind.

RULE 4.—Engineer to certify, both for iron and steel, that the material used is, in his opinion, suitable for the purpose to which it is applied; and to supply a statement of all the tests to which it has been subjected, including in all cases those required for the determination of the working stress under Schedule D.

Schedule A.

Equivalent uniformly distributed load for designing girders of which the cross section is varied, based upon the formulæ

$$w = 1{\cdot}60 + \frac{25}{S}$$

in which S=span in feet, and w=load in tons per lineal foot for one track estimated to produce at any point in a beam a moment of flexure equal to or greater than that produced by any arrangement of the heaviest engines and boiler trucks.

Span in feet . .	8	10	15	20	30	40	50	60	80	100
Load in tons per foot run .	4·72	4·10	3·27	2·85	2·43	2·23	2·10	2·02	1·91	1·85

Schedule B.

Equivalent uniformly distributed load for designing bridges of uniform section and depth, based upon the formulæ

$$\text{For spans under 12 feet } w=\frac{36}{S}$$

$$\text{For spans of 12 feet and upwards } w=1{\cdot}60+\frac{25}{S+5}$$

in which w=load in tons per lineal foot for one track estimated to produce a maximum moment of flexure equal to or greater than that produced by any arrangement of the heaviest engines and boiler trucks.

Span in feet	8	10	15	20	25	30	40	50	60
Load in tons per foot run .	4·50	3·60	2·85	2·60	2·43	2·31	2·16	2·05	1·99

Schedule C.

Table of the greatest 'panel' or cross-girder loads derived from the formula

$$\text{For panels over 6 feet in length } W=1{\cdot}60\,P+\frac{25}{2+\frac{5}{P}}$$

in which W=panel load in tons for one track, and P=length of panel in feet.

Length of panel in feet .	0 to 5	6	8	10	12	20	25
Load in tons	18·0	18·4	22·3	26·0	29·6	43·1	51·4

The above represent the maximum load on a single panel, but the greatest mean load on N consecutive panels might be taken as

$$W=1{\cdot}60\,P+\frac{25}{N+1+\frac{5}{P}}$$

Schedule D.

Admissible stress in wrought iron and steel under varying circumstances.

1. In cases where the material is subject to stress of one character only.

(*a*) Limiting working stress under any conditions

$$a=\frac{t}{NC}$$

in which a is the greatest stress to which the material may be subject under any conditions of loading; t is the ultimate tensile strength of the material determined by experiment; C, product of all the tabular coefficients of safety (Table, p. 483) applicable to the particular case; N, a coefficient intended to ensure that the greatest actual stress, in the extreme case of the coincidence of all the conditions detrimental to the resistance of the material represented by the tabular coefficients, shall not reach the limit of elasticity.

					N
For wrought iron					2·25
For steel, tensile strength under		30	tons per	square inch .	2·00
”	”	32	”	” .	2·04
”	”	35	”	” .	2·11
”	”	40	”	” .	2·22
”	”	45	”	” .	2·35
”	”	50	”	” .	2·50

As it is of the utmost importance that steel should be uniform in strength, if the greatest tensile strength when tested exceed the least by more than 15 per cent., the limiting stress shall be reduced.

Percentage of variation in tensile strength	16,	20,	30,	40,	50, or more.
Percentage by which the limiting working strength should be reduced (arbitrary)	$1\frac{1}{2}$,	$7\frac{1}{2}$,	$22\frac{1}{2}$,	$37\frac{1}{2}$,	50.

(*b*) Ductility required in order that any material may safely be subjected to the limiting working stress (*a*), to vary with the proportion in which the stress is caused by a varying or live load; and may be determined from

$$\delta = 50\,(1-\phi)$$

in which δ = percentage of contraction of area of fracture under tensile test, and ϕ (as in the Launhardt-Weyrauch Formulæ) denotes ratio of constant to total load.

ϕ	=1·00	0·80	0·60	0·50	0·40	0·30	0·20	0·10	0·00
$1-\phi$	=0·00	0·20	0·40	0·50	0·60	0·70	0·80	0·90	1·00
δ	=0	10	20	25	30	35	40	45	50

Materials which do not exhibit the ductility required by the conditions under which they are strained are only to be subjected to a stress $b = a\,k$, in which b is the admissible stress in a material of which the actual contraction of area is Δ, used under conditions of loading for which the required ductility is δ, and k is a coefficient derived from the empirical formula

$$k^{\frac{2}{k}} = \frac{\Delta}{\delta}.$$

TABLE OF VALUES OF *k*.

Ratio of actual to required ductility $\frac{\Delta}{\delta}$	Ratio of admissible to limiting stress k	$\frac{\Delta}{\delta}$	k	$\frac{\Delta}{\delta}$	k
1·00	1·000	0·65	0·836	0·30	0·667
0·95	0·976	0·60	0·813	0·25	0·640
0·90	0·950	0·55	0·790	0·20	0·612
0·85	0·928	0·50	0·766	0·15	0·578
0·80	0·905	0·45	0·743	0·10	0·537
0·75	0·882	0·40	0·719	0·05	0·483
0·70	0·859	0·35	0·694	0·00	0·000

2. In cases where the material is subject to tension and compression alternately.

The admissible stress to be less than when subject to tension or compression alone, and may be determined from the formula

$$b' = b_0 \left(1 - \tfrac{1}{2} \frac{\text{Max. B}'}{\text{Max. B}}\right)$$

in which b' is the admissible stress in a bar subject to alternate stresses of which Max. B$'$ is the numerically lesser, and Max. B the numerically greater, and b_0 the admissible stress in the material for $\phi = 0$. This expression is derived from that of Dr. Weyrauch by substituting for the coefficient derived from the primitive strength of the material by an arbitrary factor of safety, the value of b_0, determined by the preceding formula with respect to the ductility of the material.

Table of Coefficients of Safety.

1. For vibration, shock, and other dynamic effects. For wrought iron or steel; minimum 1·33 for structures over 25 feet span, for 20 feet span 1·42, for 15 feet span 1·60, for 10 feet span 1·75.
2. For unequal distribution of stress and secondary stresses. Minimum for wrought iron 1·20, for steel 1·40. Additional for bracings generally:—In pin-jointed structures 1·05; in riveted structures where the breadth of bars is less than $\frac{1}{12}$th length of bay or depth of girder, depth of girder is greater than $\frac{1}{8}$th span, and bars are not joined at crossings 1·10; in riveted structures otherwise 1·15. Additional for steel plate girders 1·10.
3. For ambiguity of stress or failure of continuity. Minimum 1·00. For ambiguous systems of bracing 1·33, for continuous girders generally 1·16.
4. For errors in design and workmanship. Minimum, 1·03. Additional for punched holes:—In iron plate girders 1·05, in iron framed structures 1·15, in steel plate girders 1·15, in steel framed structures 1·30.
5. For irregularities in section and rusting generally 1·03.

(Product of minima coefficients for iron 1·70, for steel 1·98.)

The specified coefficients of safety are not intended to include provision for increase of stress due to an obvious want of symmetry in the attachments or section of members; bending stress due to their weight, or liability of struts to buckling: these and other calculable additions to be made to the stresses estimated from external loading.

In the case of solid beams or plate girders, the admissible stress to represent the extreme fibre stress; accepting the ordinary theory of bending.

Experimental determination of resistance to flexure is recommended in the case of solid beams of unusual section.

For solid round pins the extreme fibre stress may exceed the specified stress by 33 per cent. in iron and soft steel, and 20 per cent. in hard steel.

Shearing stress in general to be taken as $\frac{4}{5}$ths the admissible tensile stress in the same material, but when of different materials the shearing strength of rivets and pins to be based upon the strength of the materials of which they are made.

Coefficients applicable to members joined to be applied to joints.

Pressure on bearing area not to exceed 1·5 times the admissible tensile strength of the weaker material, whether of rivet, or pin, or that in which the hole occurs.

The Sphere and Roller Mechanism for Transmitting Power.

By Professor HELE SHAW *and* EDWARD SHAW.

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

[PLATES VIII. and IX.]

A PAPER was read by Professor Hele Shaw before Section A at the Montreal meeting of the British Association, in which the principle of the 'sphere and roller' mechanism was explained, and certain applications of it suggested (see p. 631, Report for 1884). A subsequent paper on the 'sphere and roller' friction gear was read last year before Section G at Aberdeen (see p. 1193, Report for 1885). The latter paper gave the results of actual trial of the mechanism, and described a machine for transmitting 2 H.P., but it specially dealt with the modes of obviating the various difficulties experienced in the course of bringing the mechanism into practical operation.

Since that time Mr. Edward Shaw has been engaged in the development of the mechanism, and the present paper contains (1) a brief description of the various machines constructed since the reading of the previous papers; (2) an account of certain details of construction which have been introduced in these machines in order to meet novel difficulties; (3) certain data derived from actual work and from special experiments by both the authors in connection with points concerning which little appears to have been previously known.

Although a complete account of the theory of the mechanism for mathematical purposes has been published in the 'Philosophical Transactions of the Royal Society' (Part II. 1885), and a new machine exhibited at the Inventions Exhibition has been described and illustrated ('Engineering,' 1885), yet so much new work has been done in designing and testing the machines since made that the authors believe the following account of the results will prove of interest and value, especially as the question of friction gearing is one about which few facts are published, and much uncertainty exists as to proper proportions of surfaces in contact, dimensions of the various working parts, power transmitted, and actual loss in its transmission.

1. DESCRIPTION OF MACHINES.

In the first two machines made for the transmission of power, the weight of the ball was utilised for obtaining pressure on the rolling surfaces.

In one of these the driving and driven surfaces of the wheels were of cast iron; in the other oak was tried, which proved to be useless owing to its distortion, and secondly raw hide, which was found not sufficiently rigid for the pressures required. Neither machine was of any use, the efficiency being too small. Their failure was due both to the smallness of the pressures and the vibration set up, which latter kept the ball away from the wheels.

The next machine[1] was designed so that any required pressure could be brought to bear on the rolling surfaces, and which, while transmitting considerable force, should not occupy much space. The diameter

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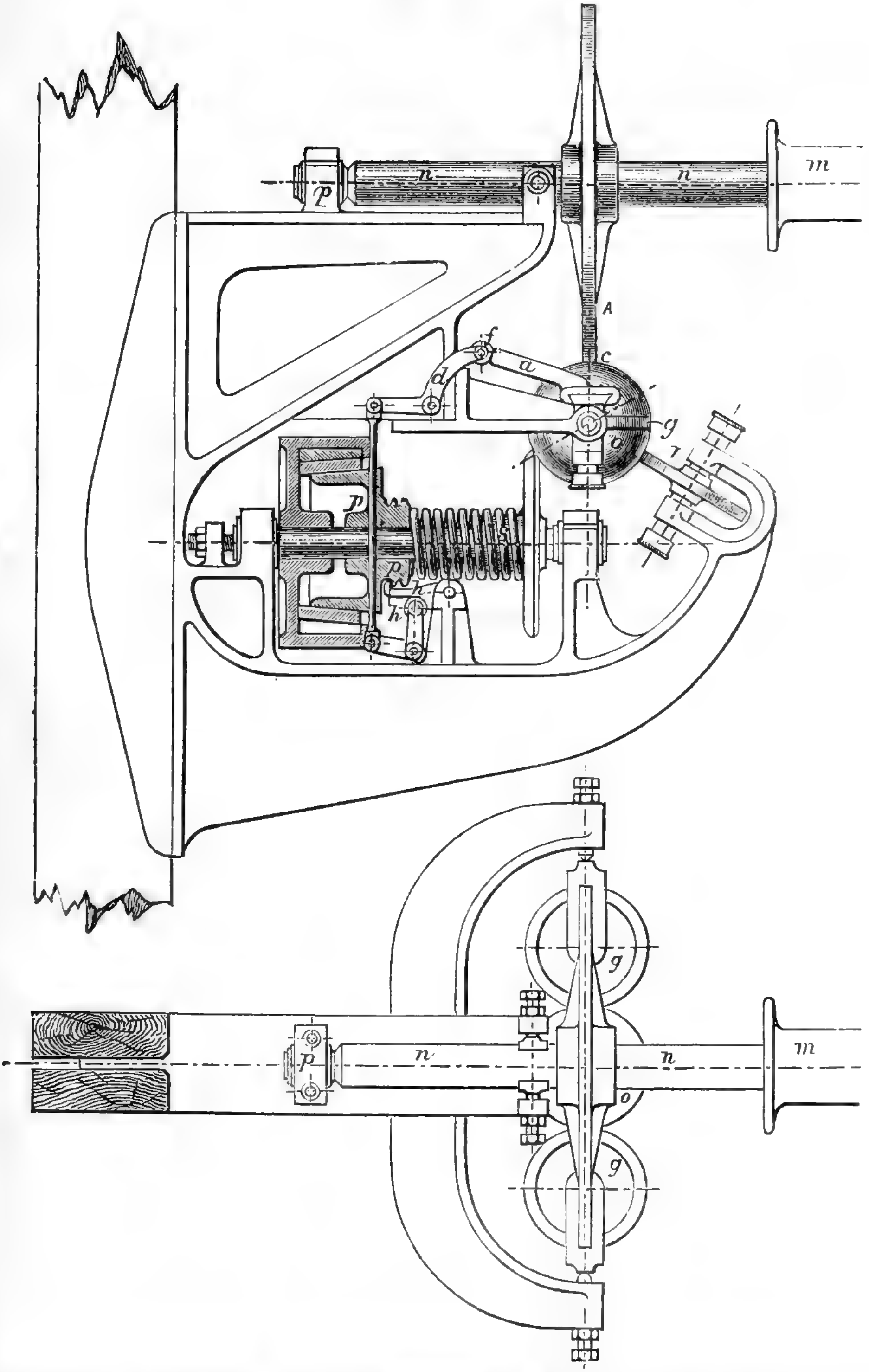
[1] For a full account with illustration see *Engineering*, Nov. 27, 1885. This machine is now on loan at the South Kensington Museum.

FIGS. 1 & 2.



of the ball was 6″. This machine was exhibited at the International Inventions Exhibition, where it successfully worked for several months, and gained a Gold Medal award. It was, however, fatally defective in one respect, for there was no provision to prevent the ball from revolving whilst its axis of rotation passed through the point of contact made with the driven wheel.

Figs. 1 and 2 show a hoist in which this defect was obviated, and which was designed so that the pressure on the driving and driven wheels should vary with the load to be raised. This arrangement ensured a greater efficiency than could otherwise be obtained.[1] The framing of the hoist was made to bolt to a pair of vertical posts. A drum (*m*), which replaces the differential arrangement originally used, is carried on one end of a shaft (*n*), which by means of a wheel (A) placed at the centre of its length receives the motion from the ball (*o*). The other end of the shaft is held in a bearing (*p*); and therefore, since there is no centre support for it except the ball, the pressure on the ball must be due to the constant weight (due to the shaft-wheel, &c.) *plus* the load multiplied by a constant quantity. The hoist is started, stopped, reversed, or has its speed changed by simply pulling one or other of two ropes which hang in a convenient position.

This machine has worked most satisfactorily for more than half a year, and has given no trouble. It works at present thoroughly well, and seems likely to last many years. Experimental data as to its efficiency are given hereafter.

There is great difficulty in making the framing of these machines light and compact, and at the same time sufficiently rigid to withstand the heavy pressures used. One chief source of difficulty is the part of the frame necessary to carry the pressure-wheel (fig. 1). Figs. 3 and 4 show a machine in which this wheel is dispensed with. Two balls are employed in contact with each other at the point (*o*). The driving-shaft (A) is of cast iron and is hollow, having two flanges, which at the points (*n n*) press against the two balls. The drum (B) has also two corresponding flanges, which touch the balls at the points (*l l*). The guide-wheels for each ball are moved simultaneously, so that the axes of the two balls move symmetrically; hence for each ball there is always the same ratio between the speeds of the surfaces at *n*, *l*, and *o*; and since the speed at *n* is the same in each case, the other speeds must also respectively be equal, and therefore all the surfaces roll freely upon each other.

This machine is extremely compact, and works well. It is now at the Liverpool Exhibition, and with two 6″ balls transmits over 2 horse-power.

2. SPECIAL DETAILS OF CONSTRUCTION.

Mode of Preventing Injury to Sphere when its Axis of Rotation passes through a Point of Contact.

The chief advantage of the sphere and roller mechanism is the power of varying the velocity ratio of the driving and driven wheels by the mere motion of a lever. As is fully set forth in the papers above referred to, this result is obtained by causing the axis of rotation of the sphere to assume different positions relatively to the driving and driven wheels. When, however, the latter is required to move at a very slow speed, or to actually come to rest, the axis of rotation passes so close to the driven wheel that the sphere spins upon the point of contact, and there is con-

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[1] This machine was briefly alluded to in the paper read before the British Association, Aberdeen meeting, by Professor Hele Shaw.

siderable danger of flats being ground upon the surfaces in contact. This frequently occurred when the machine was running, and it therefore became absolutely necessary to devise some means to stop the machine when the axis was in the critical position. Fortunately it was found that stopping the machine in that position had a great advantage, because it was impossible for the load to run down, the driven wheel being then

Fig. 3.

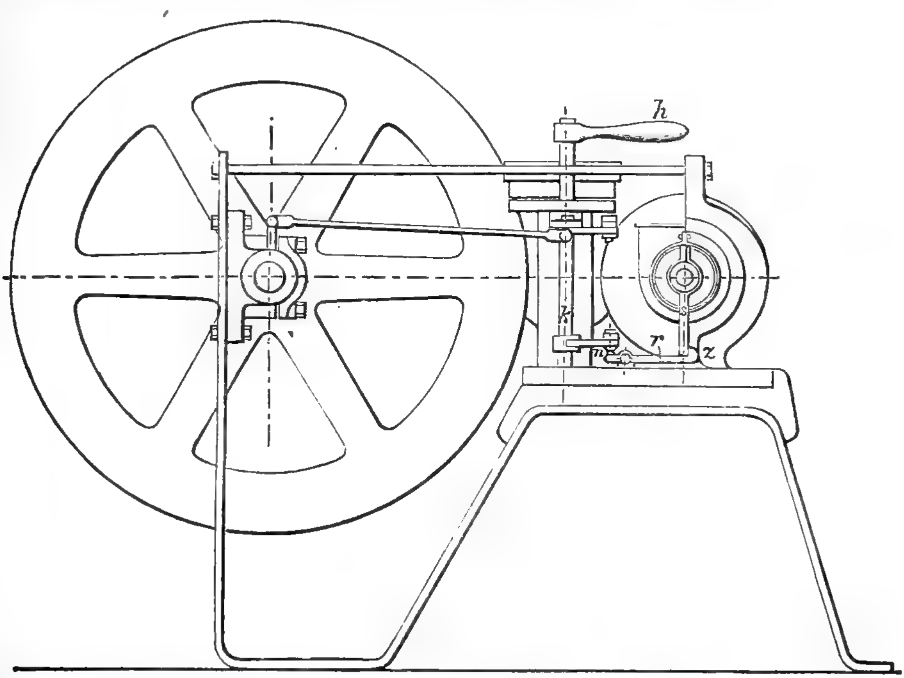
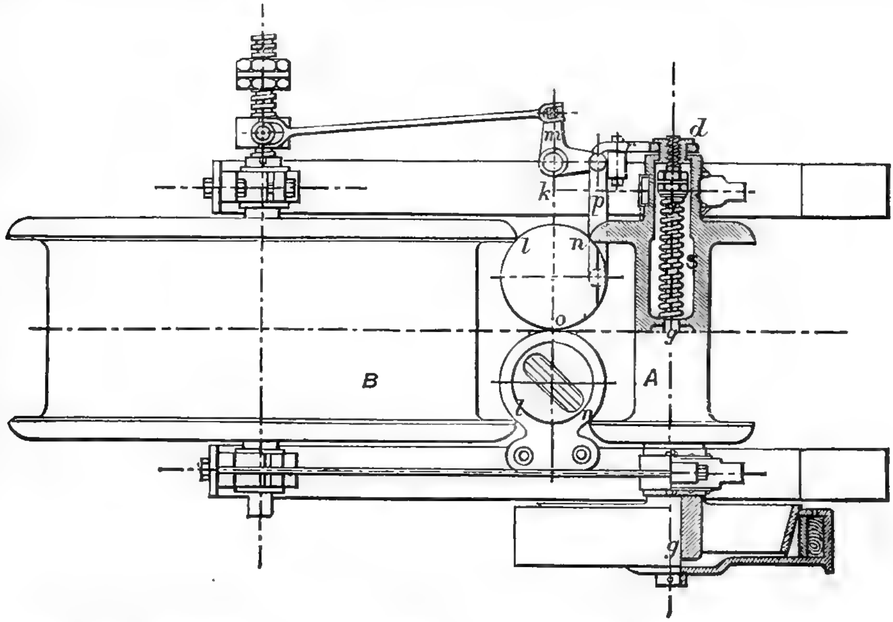


Fig. 4.



unable to drive the sphere, and the only other way for the load to fall was by the wheel sliding over it. By arranging so that the machine should always stop at this point, and nowhere else, the danger to the ball was averted, a brake could be dispensed with, and starting and stopping easily arranged.

The manner in which the difficulty was overcome is clearly shown in fig. 1. The rigid arm (*a*) connecting the two guide-wheel frames (*g*) has a lug cast on it. When the axis of the ball passes through the point *c*, the lug throws back the end (*f*) of the bell-crank lever (*d*), and thus, by means of a connecting rod and two other levers, throws up an arm (*h*), with a tooth on its free end. This tooth engages in a thread of coarse pitch on the sliding part of the clutch (*p*). As the clutch revolves the screw draws out the sliding part, thus stopping the machine. When the machine is started the arm (*a*) is moved, the bell-crank lever returns to its former position, the tooth (*h*) falls away from the thread, and the spring (*s*) forces the clutch into gear, and the ball again revolves, but with its axis now in a safe position.

There is the objection to this arrangement that only at one point of the revolution of the clutch can the arm be moved so as to reverse the driven shaft, and this causes delay in working.

In the hoist next made (figs. 3 and 4) a much better device is used, whereby it is only possible to stop the machine at one point of the revolution of the driving-shaft, and thus there is little fear of stopping when it is desired to reverse the motion. If, however, the axes of the balls are left so as to pass through (*l l*), not more than one or two revolutions can take place before they stop, and there is not sufficient time for any harm to be done.

Referring to figs. 3 and 4, the handle (*h*) attached to the vertical shaft (*k*) controls the change of axes of the balls. When at the right position a nipple on the bell-crank lever (*m*) moves the lever (*r*), and lifts the end (*z*). Meanwhile the revolution of the driving-shaft brings the arm (*s*) against (*z*), (*s*) and the nut (*d*) thus cease to revolve, and the rod (*g*), being advanced through the nut, throws the clutch out of gear. On turning the handle the arm is released, and the spring (S) moves the rod axially, and brings the clutch into gear. This arrangement answers perfectly, allowing a free movement of the axes of the balls, with quick reversal of motion and change of speed.

Bearings.—Great attention has necessarily been bestowed on the bearings, the following conditions being required:—

(*a*) Diameter as small as possible, to reduce the loss in friction.

(*b*) Such arrangements for lubrication as shall be as far as possible perfect.

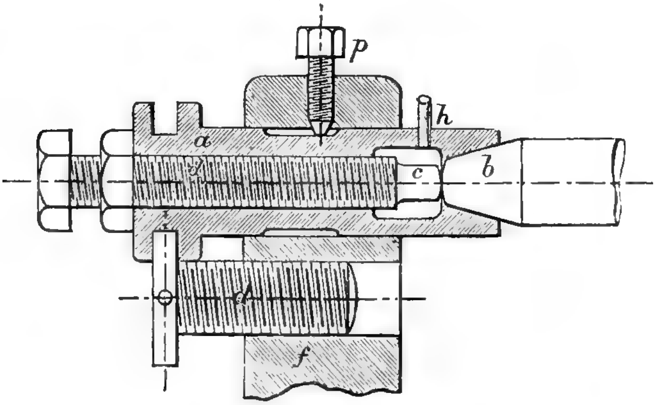
(*c*) Security from escape of lubricant on to the rolling surfaces.

The conditions of working are unusually severe, and the bearings, which have been found to work satisfactorily, are therefore described in detail, and illustrated in figs. 5, 6, 7, 8, 9, and 10.

Fig. 5 shows a bearing suitable for taking an oblique thrust. The part (*f*) is a portion of the framing of the machine. The bush (*a*) is of phosphor bronze, both the ends of the shaft (*b*) and set screw (*c*) have steel points, made as hard as possible, with a small hole drilled in the centre of each. Stauffer lubricant is introduced through the tube (*h*) into the inside space.

The bearing is first adjusted by means of the screw (*d*), which has a large flat head, forcing the bush (*a*) in, and taking up all the slack on the conical part of the bearing. The set screw (*c*) is next turned until it takes all the end thrust on the shaft (*b*). The bush is now locked by means of the set screw (*p*). This makes a very efficient though expensive bearing.

FIG. 5.



Figs. 6 and 7 illustrate the manner in which an oil bath was applied to the bearings of the driving-shaft in fig. 3. The shaft in question works under a pressure of about 1,200 lbs., the size of the bearing being 3″ diameter by $1\frac{1}{4}''$ wide, the surface speed of the journal being about 150 feet per minute. Referring to the figure, *s* is the shaft, *a* the cast-iron bearing, the surface of *s* is also cast iron. A light brass framing with leather lining is attached to the bearing (*a*) by the flanges (*b b b*), and makes a joint round the shaft at *c c c c*. The chamber *e* contains the oil. This bearing has worked continuously without heating, and gives most satisfactory results, the only defect being a slight leakage of oil round the flanges *c c c c*, fig. 7; the amount is, however, very small. It was designed from data given by Mr. Beauchamp Tower in his account

FIG. 6.

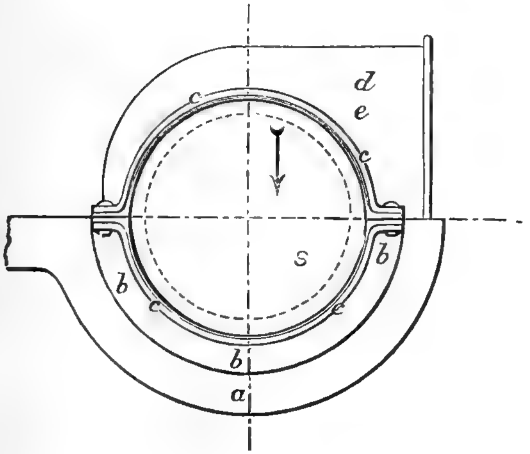
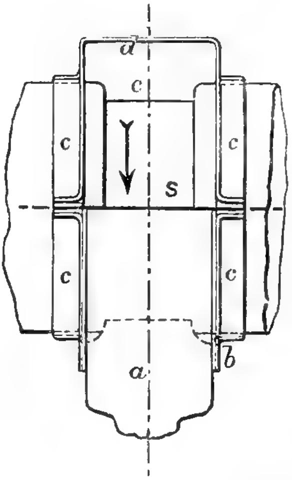


FIG. 7.



of experiments on oil-bath bearings, conducted for the Institution of Mechanical Engineers.

Figs. 8 and 9 show the form of bearing used for the guide-wheels on the machine, fig. 3. They were adopted as the best of a number which were tried for the purpose. A fixed spindle (*a*) is secured to the frame (*k*) by the bolts (*d*). On (*a*) is a fixed collar (*b*), with a projecting rim (*e e*), and also a loose collar screwing on it with a similar rim (*e e*). These rings fit into recesses turned in the wheel (*h h*); the bottoms of the recesses are packed with leather rings (*f f*). It is obvious that on screwing up the collar (*c*), the rims on both sides of the wheel are forced into the leather, thus making a running joint, the oil having to escape past the leather before it can get out.

Fig. 8.

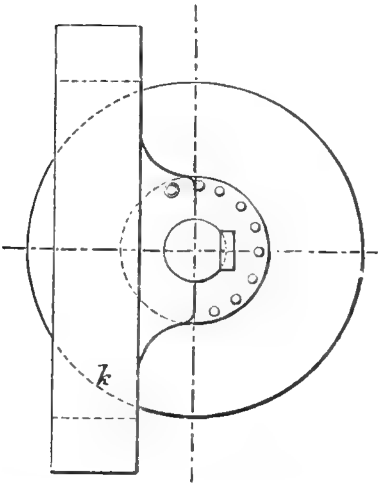
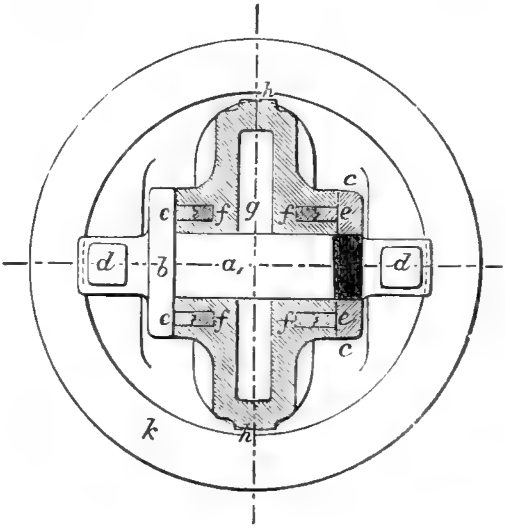


Fig. 9.



This device answers fairly well, for the wheel (*g*) being hollow and filled with oil, perfect lubrication is ensured, although in this case also a slight amount of oil escapes.

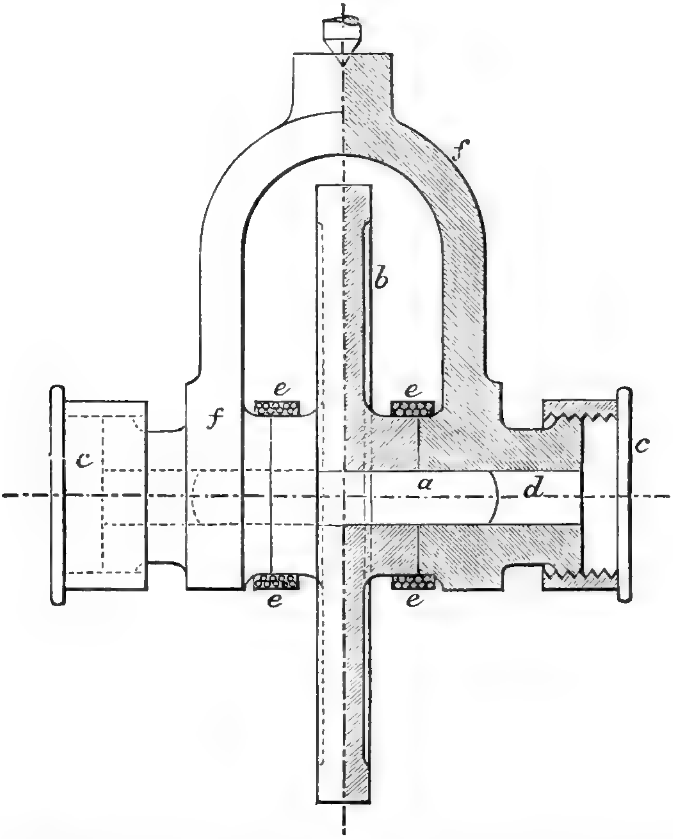
Some experiments just made show that even the best of leathers are very porous and spongy, absorbing oil very readily, and when employed as a packing for bearings this material seems to act as a pumping apparatus, continually sending oil in the wrong direction. Leather is not therefore a safe material for packing a running joint against oil; and in spite of numerous tests, so far, no really suitable material has been found.

Fig. 10 shows the arrangement of bearing adopted for the guide and pressure wheels on the machine at the Inventions Exhibition, 1885, and also on that shown in figs. 1 and 2. A steel spindle is keyed to the wheel *b*, and runs in bearings bored in the phosphor bronze, or cast-iron frame (*f*). Caps (*c c*) are screwed on (*f*), thus forcing the semi-lubricant which fills (*c*) and (*d*) into the bearing. Rings of packing (*e e*), made of strips of leather and cotton wick, are sufficient to prevent the escape of the lubricant at the running joint. These bearings run for months without requiring attention.

The Material and Construction of Spheres.

The production of balls at a low cost, and yet suitable for standing the heavy pressures without excessive wear, has been one of the chief difficulties encountered.

FIG. 10.



In first small models the balls were made of boxwood, lignum-vitæ, ivory, oak, gutta-percha, india-rubber, and brass, of which the last was most satisfactory. In the large machines, lead, mixtures of lead, zinc, and tin, cast iron, phosphor bronze, and hollow unhardened cast steel have been tried. Of these, hollow cast-iron balls have proved the best. With solid cast iron it seems almost impossible to get spheres quite free from flaws; as many as sixteen balls, cast by four different founders, only left, on turning up, two which were fairly good. But this material stands the wear and tear much better than was expected. In one case a hollow cast-iron ball 8″ diameter has been in frequent use in a $\frac{1}{2}$-ton hoist (figs. 3 and 4) for eight months; careful callipering fails to show any loss in diameter.

Unhardened cast steel is too soft. Hardened and ground cast steel and phosphor bronze are too expensive.

It might be mentioned here that, though with absolutely rigid material the surface of contact between the balls and the wheels would be reduced to a point, yet according to the pressure and material a considerable facet is formed. The amount by which the centre of the surface of contact is depressed is, however, extremely small. Thus in a 6″ ball in contact with a plane surface this depression is only ·0017″ for a facet $\frac{1}{5}$″ diameter.

Experience shows that the harder the material the less is the loss due to rolling friction, no greater normal pressure being required. Some experiments recently made show that two chilled iron spherical surfaces 6″ diameter rolling on each other give at about 1,500 lbs. normal pressure a coefficient of friction of over ·25. For some time past experiments have been proceeding with the object of procuring perfectly sound chilled balls. So far not one has been obtained, though some twenty to thirty have been cast.

3. DATA DERIVED FROM EXPERIMENTS WITH SPHERE HOIST AND WITH SPECIAL APPARATUS.

The hoist shown in figs. 1 and 2 has been in daily use in the works of Mr. Edward Shaw at Bristol for more than six months. Two sets of experiments have recently been made upon it, the results of which are given below (Tables I. and II.), and have also been plotted (Plate IX.). In both cases the driving-belt was replaced by a cord on which weights were hung, so that the force required to raise the load could be ascertained. The first set of experiments (Table I.) shows the forces required to overcome the friction of the machine, and raise the load from a position of rest. The second set of experiments shows the forces required when the machine is in motion to lift the load at a constant speed. In both cases the efficiency of the machine has been worked out for every experiment in the following way:—

Let W = load on hoist in lbs.
P = weight hanging over the driving-pulley.

$$\text{V.R.} = \text{velocity ratio} = \frac{\text{distance moved through by P}}{\text{distance moved in same time by W}}.$$

$$\text{Then efficiency} = \eta = \frac{W}{P} \div \text{V.R.} = \frac{W}{P \times \text{V.R.}}.$$

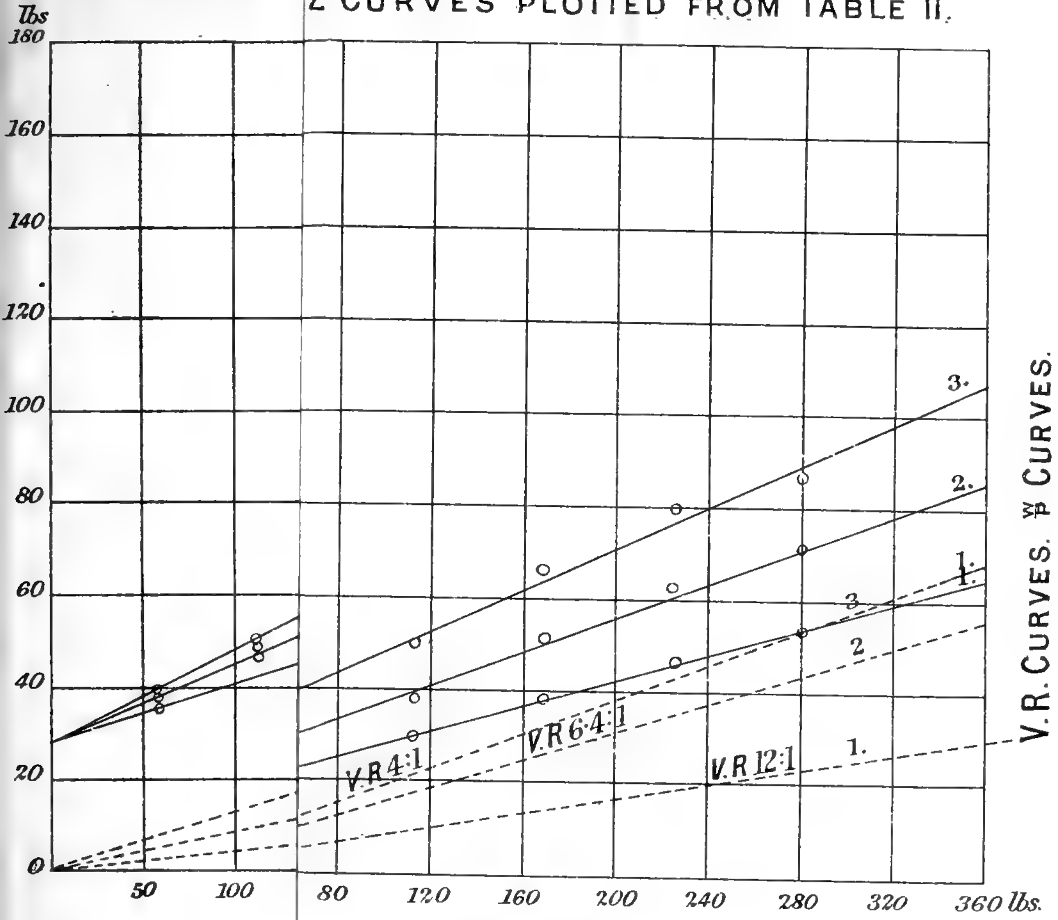
TABLE I.—STATICAL RESISTANCE OF FRICTION. EXPERIMENTS ON SPHERE HOIST AT CANONS MARSH, BRISTOL, April 13, 1886.

Weight of pan, 22 lbs.
Diameter of large pulley, 17 in.

Diameter of small pulley, $8\frac{3}{4}$ in.
„ driving „ $13\frac{3}{4}$ in.

No. of Experiment	Load on Hoist W	Position 1, V.R.=8		Position 2, V.R.=12		Position 3, V.R.=24		Position 4
		Weight=P		Weight=P	η	Weight=P	η	P
1	0	29	0	29	0	29	0	32
2	56	39	·18	36	·13	35	·07	38
3	112	52	·26	49	·19	47	·10	43
4	168	61	·34	56	·25	52	·13	50
5	224	72	·36	66	·28	59	·16	55
6	280	83	·42	79	·30	64	·18	57
7	336	94	·44	85	·33	71	·20	61
8	392	106	·45	95	·34	77	·21	64
9	448	119	·47	105	·35	85	·23	70
10	504	128	·49	112	·37	89	·24	74
11	560	140	·5	122	·39	98	·24	78
12	616	153	·49	133	·39	110	·24	84
13	672	164	·51	149	·38	113	·25	90

2 CURVES PLOTTED FROM TABLE II.



. EFFICIENCY CURVES FROM TABLE I.

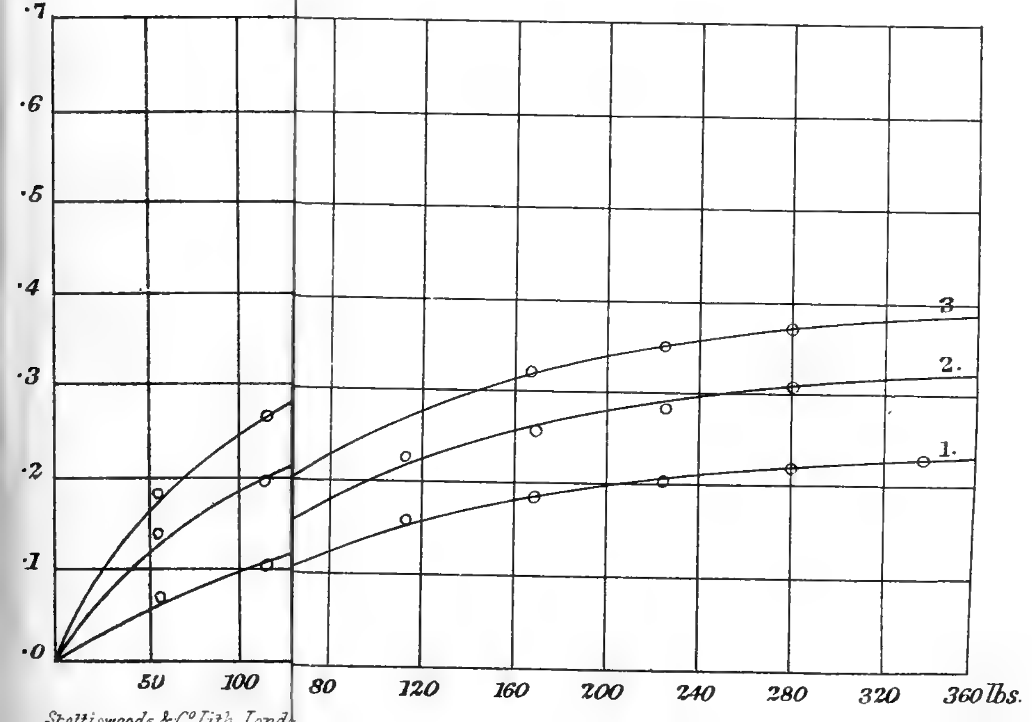


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FIG I CURVES PLOTTED FROM TABLE I

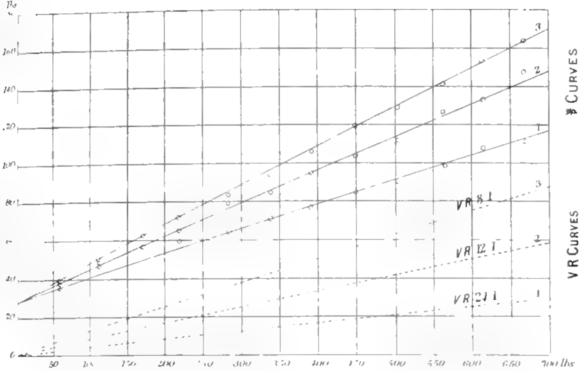


FIG 2 CURVES PLOTTED FROM TABLE II

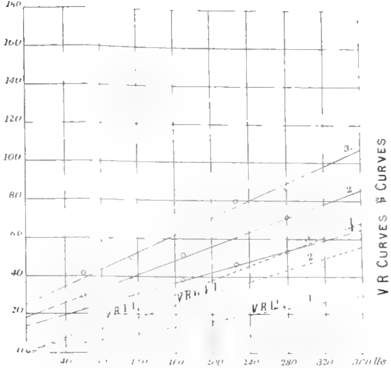


FIG IE EFFICIENCY CURVES FROM TABLE I

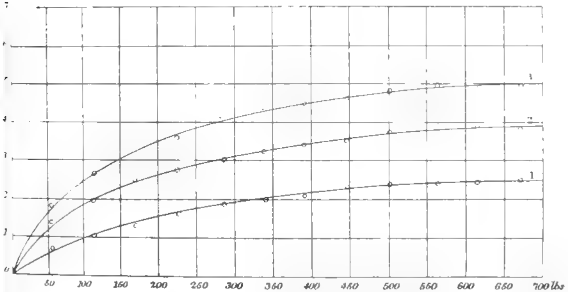
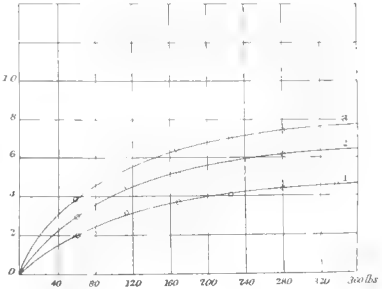


FIG 2E EFFICIENCY CURVES FROM TABLE I



Illustrating Professor Hele Shaw and Mr Edward Shaw's Paper on the Sphere and Roller Mechanism for Transmitting Power

TABLE II.—RESISTANCE OF FRICTION WHEN HOIST WAS RUNNING. EXPERIMENTS ON SPHERE HOIST MADE AT CANONS MARSH, May 10, 1886.

Load lifted direct from barrel, 5½ in. diameter.

No. of Experiment	Load on Hoist W	Position 1, V.R.=4		Position 2, V.R.=6·4		Position 3, V.R.=12	
		Weight=P	η	Weight=P	η	Weight=P	η
1	0	14	0	14	0	14	0
2	56	42	·385	30	·293	24	·2
3	112	50	·566	38	·467	30	·317
4	168	66	·641	52	·509	39	·364
5	224	80	·704	63	·560	47	·401
6	280	96	·733	72	·612	54	·436
7	336	—	—	88	·60	63	·448

The different positions of the lever of the hoist in the above experiments, resulting in different velocity ratios, are easily understood from the tables, with the exception of the position 4 (Table I.), which was the position when the velocity ratio was as great as it could be made, this being the limiting position in which the load could be raised.

The above tables of results are plotted as curves on Plate IX., the loads raised being measured (in lbs.) as abscissæ in all the four figures. The dotted lines in figs. 1 and 2 show the velocity-ratio curves, points on which are obtained by setting up as ordinates the forces theoretically required for various loads, supposing no loss in friction to take place. The three cases of velocity-ratio are respectively numbered 1, 2, and 3, and all the dotted lines representing them necessarily pass through the origin of co-ordinates. The centres of the small circles are points obtained by setting up as ordinates the forces actually required. The results are not perfectly regular, but the irregularity obviously arises from the difficulty of conducting such experiments with very great accuracy, although every care was taken to obtain trustworthy results.

It is, however, not difficult to see that the curves which practically represent the results are straight lines drawn in full on figs. 1 and 2. Although in the first set of experiments these lines all pass through one point, showing that the friction of the machine when starting from rest is independent of the velocity-ratio, yet they do not in either set of experiments pass through the origin, since this could only occur for the case of a frictionless machine. Thus the equations representing the curves are—

(1) For velocity-ratio,

$$y=mx.$$

(2) For actual results of experiment,

$$y=nx+c,$$

where m, n, and c are constants which can easily be obtained.

The curves in figs. 1E and 2E are those of efficiency obtained by plotting the corresponding results given in Tables I. and II., the equations of the various efficiency curves being of the form

$$y=\frac{mx}{nx+c};$$

and since $y=0$ when $x=0$, they evidently all pass through the origin.

Experiments with Special Apparatus.

In designing the sphere and roller machines it was assumed that between the rolling surfaces the coefficient of friction was

$$\mu=0{\cdot}1,$$

and consequently that the pressure required between the ball and the disc must be ten times as great as the force to be transmitted. During the experiments above recorded it was found that the coefficient of friction was not constant, but increased with the pressures, the highest value being about

$$\mu=0{\cdot}16.$$

The machine at the Liverpool Exhibition gave results even higher than this, and, generally speaking, it has been observed that the value of the coefficient at the high pressures used increases slightly with the pressure. It is evident that the circumstances of the case are peculiar, and that even the few published experiments upon rolling friction—such as those upon locomotive tyres—did not furnish satisfactory data for guidance. It was therefore determined to conduct a series of experiments with special apparatus, and for this purpose the machine shown in figs. 11 and 12 was designed. This apparatus consists of two discs (a) and (b), six inches in diameter, the edges of which are in contact, and which can be replaced by other similar discs of different material. One of these discs (a) is driven

Figs. 11 & 12.

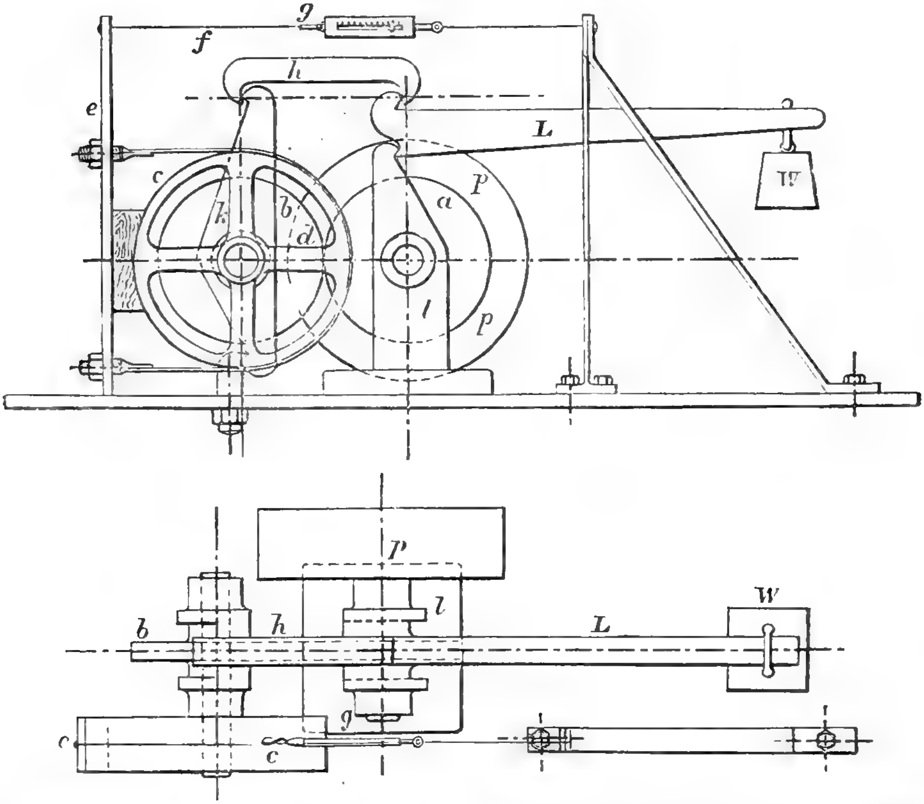
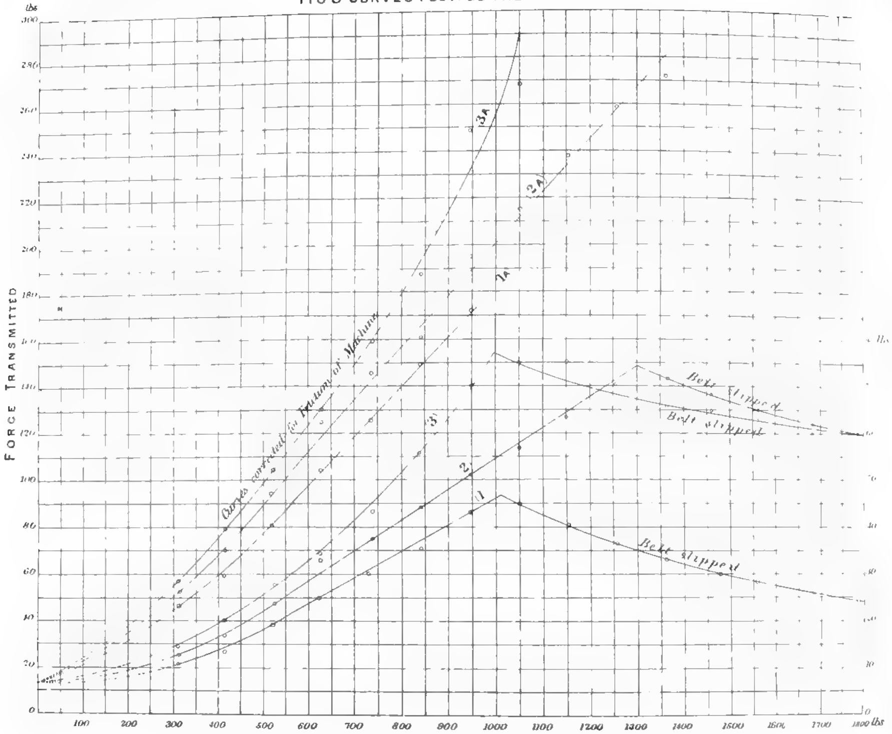


FIG 3 CURVES PLOTTED FROM TABLE III



Illustrating Professor Hele Shaw and Mr Edward Shaw's Paper on the Sphere and Roller Mechanism for Transmitting Power directly from a motor by means of a pulley (*p*), the other (*b*) being driven by friction at their point of contact. The latter disc is connected directly to a dynamometer brake (*c*), the resistance of which is shown by means of a lever (*e*) and a rod (*f*). At the same time the normal pressure at the point of contact (*d*) is measured by means of a combination of levers (L and *k*). These levers act thus. A weight (W) being hung upon the end of the lever (L), which has its fulcrum at the top of the support (*l*), acts by means of a link (*h*) upon a second lever (*k*), which has its fulcrum at the lower end. The lever (*k*) carries the bearings of the shaft of the disc (*b*), and thus the weight (W) is an exact measure of the horizontal forces between the discs, the leverage being such as to make this latter just twenty-one times as great as the weight in question.

The resistance overcome by the belt was threefold :—

(A) The brake friction.
(B) The bearing ,,
(C) The rolling ,,

The first only of these could be accurately determined, the sum of the others being estimated in the following way. Up to a certain point the belt was powerful enough to overcome all the friction and to make the wheels skid over each other, but beyond that the sum of the resistances was sufficient to make the belt slip, which it did at a fairly constant point. Thus for a definite increase of pressure the increase of (B) and (C) could be determined by the diminished reading of (A). By this means the forces transmitted to the driven wheel were approximately estimated.

Three sets of experiments were made :—

(i.) Cast-iron discs with flat faces, $\frac{3}{16}$ in. wide.
(ii.) Cast-iron discs with flat faces, $\frac{1}{16}$ in. wide.
(iii.) Chilled cast-iron discs with spherical faces ground true.

The results of these experiments are given in the following Table III.

TABLE III.—RESULTS OF EXPERIMENTS WITH SPECIAL APPARATUS FOR TESTING THE FORCES TRANSMITTED BY ROLLING CONTACT.

		No. 1. Cast-iron wheels Flat faces $\frac{3}{16}$ in. wide			No. 2. Cast-iron wheels Flat faces $\frac{1}{16}$ in. wide			No. 3. Chilled iron wheels Spherical faces ground true		
Weight in lbs. on Lever W	Pressure in lbs. between surfaces	Spring Reading	Force transmitted to driven wheel	Remarks	Spring Reading	Force transmitted to driven wheel	Remarks	Spring Reading	Force transmitted to driven wheel	Remarks
15	315	10	45	Wheels skid	12	51	Wheels skid	14	57	Wheels skid
20	420	13	59	,,	17	70	,,	20	79	,,
25	525	19	81	,,	24	96	,,	27	105	,,
30	630	25	105	,,	32	124	,,	34	130	,,
35	735	30	125	,,	38	146	,,	42	158	,,
40	840	37	149	,,	44	161	,,	56	186	,,
45	945	43	172	Do. and Belt slipped	51	195	,,	70	248	,,
50	1050	45		,,	56	215	,,	75	268	Do. and Belt slipped
55	1155	41		Belt slipped	62	237	,,	75		,,
60	1260	37		,,	67	258	,,	70		Belt slipped
65	1365	33		,,	71	272	,,	66		,,
70	1470	30		,,	68		Belt slipped	65		,,
75	1575	28		,,	65			63		,,
80	1680	26		,,	62			60		,,
85	1785	24		,,	60			60		,,

The above results are plotted in the form of curves (Plate X.), the pressures between the surfaces being taken as abscissæ, the corresponding forces transmitted as ordinates.

From these curves it is clearly seen that by reducing the area of the surface in contact a less pressure is required to transmit a given force; thus the curves 1, 2, and 3 rise above each other in regular order (3 being the curve corresponding to the chilled iron spherical surfaces); and, moreover, that while the two first are straight lines the last rises more rapidly as the pressure increases, and, in fact, gives at last a coefficient of friction

$$\mu=0{\cdot}262.$$

Finally it may be remarked that, whereas at lower pressures and with larger surfaces in contact the presence of oil upon the latter causes considerable variations in frictional resistance, it was found that at the highest pressures used in the last set of experiments *oil poured continuously* upon the rolling surfaces had *no appreciable effect whatever.*

On Improvements in Electric Safety Lamps.

By J. Wilson Swan, *M.A.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

I showed an Electric Safety Lamp in this Section last year. I have now improved the lamp in various ways, and I propose to describe and exhibit the improvements.

The objects I had in view in altering the original design were :—

1st. To reduce the weight as much as possible consistently with the giving of sufficient light.

2nd. To simplify the construction, with a view to minimising the cost of manufacture and the cost of keeping in order.

3rd. To make the lamp better able to resist a blow.

4th. To seal in the liquid, so that the lamp could be held in any position.

5th. To add a fire-damp indicator.

The lamps on the table embody these improvements, and are here for the inspection of members.

The details of construction and the record of experiments are given in the diagram.

With regard to the first point—namely, the size and weight of the apparatus—that, of course, depends, in a great degree, on the amount and duration of the light. Guided by the fact that the best of the oil safety lamps scarcely gives the light of one standard candle, and that most of those in common use give only a quarter or half a candle, I have assumed that an average light of one candle, over 12 hours for datal men, and $1\frac{1}{4}$ candle over 9 hours for hewers, is sufficient, and I have fixed the size of the battery in the new lamps on this assumption. No alteration of the design is necessary when more or less light than this is required, but merely an increase or decrease of the size and weight of the battery contained within the lamp body.

In this respect the Electric Safety Lamp has a marked advantage over all safety lamps of the ordinary kind, which depend on the combustion of oil; *they* cannot be made to give a much larger light without radical alteration, if at all. If the Electric Safety Lamp is required to give 5 or even 10 candle-light, it is only necessary to proportionally increase the size and weight of the battery. Safety is not in the slightest degree impaired.

There is nothing easier than to be deceived as to the amount of light that can be obtained from a certain size and kind of battery applied to an incandescent lamp. If the lamp is constructed so as to allow such a large current to pass through the carbon filament as will heat it to the enormously high temperature at which disintegration rapidly takes place, ten times as much light is produced as when, by the use of a different lamp, the current is diminished, and the temperature of the filament thereby lowered to a degree which will prolong the life of the lamp to an economical point.

In the case of a miner's safety lamp, it is very desirable to get as much light as possible from a given weight of battery, and hence it is allowable to subject the lamp filament to what may be termed a rather high pressure, but not such a high pressure as will prevent the lamp from lasting about 700 hours. Subject to this condition I find I can obtain an average light of one standard candle during 12 hours, and 1¼ candle during 9 hours, from a battery, which, with all the appurtenances of the lamp attached to it, weighs altogether 5½ lbs. The same battery, with a different lamp filament, will, of course, give either more light for a shorter time, or less light for a longer time than that I have mentioned.

The battery cells are slightly different in construction from those in last year's lamp. They consist, as before, of a central solid cylinder of peroxide of lead, with a conducting core of lead wire, fixed concentrically, by means of guide rings of india-rubber, within a tube of lead, the internal surface of which is in the spongy state. The annular space between the peroxide of lead cylinder and the lead tube is filled with dilute sulphuric acid. Four such elements are fitted into four ebonite lined holes in a block of wood saturated with paraffin. The lead wire connections between cell and cell are covered with india-rubber, and embedded in channels in the wood, and covered with Chatterton's compound. Over the buried connecting wires is fixed a veneer of ebonite, which further protects them, and also forms a level seat for the cushion of india-rubber, which, when pressed down by the cover-disc makes the cells liquid-tight, so that the whole block may be laid on its side, or inverted, without leakage.

In the form of lamp I showed last year the cover of the case which contained the battery had to be screwed off to get at the battery terminals, for the purpose of putting them in connection with the charging circuit. In the new design the removal of the cover is avoided by bringing down the battery terminals to the bottom. Access is given to these through two small holes, within which fit two pins connected with the positive and negative charging wires. Charging is effected by simply placing the lamp on a bench fitted with charging pins, in connection with wires from a dynamo, so that the charging pins enter the two holes at the bottom of the lamp case. The lamps remain on the dynamo circuit, receiving their charge during the time the men who have used the lamps are resting, and they become fully charged by the time these men return to work.

It is a point in favour of this kind of lamp that the operation of renewing the charge is effected with little trouble and cost—far less than is involved in replenishing and cleaning ordinary safety lamps. For example: one horse power is sufficient to charge one hundred lamps at a time; that item of cost will, therefore, not exceed a farthing a lamp per week.

The total cost will not exceed fivepence per week, where several hundred lamps are in constant use. That amount will, I estimate, cover the total weekly cost per lamp, including renewal of lamp-bulbs, the cost of fuel, wages for keeping the lamps charged and in repair, and interest at ten per cent. on the capital outlay for the whole plant, including the lamps themselves.

In one of the modifications of the lamp the light is fixed upon the top of the case, with a view to the illumination of the roof and sides of the mine.

This form of lamp is intended for the use of over-men while travelling in the workings.

The bull's-eye form, with the light on one side, is intended for the use of the hewer. While the hewer is at work the lamp will be hung up on a hook as usual.

Where low workings have to be traversed the lamps can be fastened to the breast of the miner by a strap across the shoulder.

The only other point requiring explanation is the fire-damp indicator. The want in the lamp I showed last year, of the means of showing the presence of fire-damp, was urged as an objection to it. I have met the objection by adding an indicator. This will not be required on every lamp, but only on lamps used by over-men. I have made the indicator in three forms; two of these act on the same principle as Liveing's fire-damp indicator. A spiral coil of thin platinum wire is arranged so that it can be heated to a low red heat by switching through it the current generated by the lamp battery. If this takes place in an atmosphere in which fire-damp is present, the wire becomes hotter than when heated in pure atmospheric air, because combustion of the fire-damp with the oxygen of the air, brought about by the electrically heated wire, produces additional heat, and, consequently, increases the temperature of the wire, so that it is sensibly brighter whan heated in air containing fire-damp than when heated in air in which there is no fire-damp.

In one form of the indicator I have followed Mr. Liveing's idea of having a comparison wire, shut up, air-tight, in a glass tube containing pure air. In another I have deviated from Liveing's construction in two ways; namely, by having only one wire (the test wire), and instead of this being in a wire gauze cage, always exposed to the atmosphere in which the lamp is placed, it is in a tube which, when the current is turned on to heat the wire, is completely closed. It is not easily conceivable, even if the test were made in an atmosphere of air and fire-damp of maximum explosiveness, that flame would pass the fourfold lining of fine copper wire gauze of the Liveing indicator; still it is, perhaps, more consistent with the absolute safety of the lamp itself to make the test in a closed vessel. With the double wire arrangement, when fire-damp is present in the air, even in so small a proportion as half a per cent., the *exposed* wire glows with perceptibly greater brightness than the *enclosed* comparison wire. With the single wire arrangement, under the same atmospheric conditions, the wire would glow for an instant with extra brightness, and then, after the small quantity of enclosed fire-damp is consumed, would die down to normal redness.

The third form of indicator acts upon a different principle. In it there is a platinum wire within a small tube, and the means of turning on the current from the lamp battery to heat the wire, as before; but here the hot wire is employed only to effect the combustion of any fire-damp that may be present, with a view to the production of a partial vacuum resulting from the condensation of the watery vapour of the burnt gases. The degree of vacuum or shrinkage is shown by the rise of liquid in an adjacent gauge-tube, and from this the exact percentage of fire-damp present in the air may be ascertained. This form of test is also, and necessarily, made in a closed vessel. The hot wire is completely cut off from contact with the outer air.

I think it will appear to the Section that I have produced a miner's lamp having the advantage of absolute safety, and which is, at once, more efficient and more economical than any other miner's lamp yet constructed.

On the Birmingham, Tame, and Rea District Drainage.
By William Till.

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

The author in submitting this paper begs to state that he has not entered into any discussion of the relative merits of the various systems of sewage purification now in operation, nor has he advanced any theory of his own in relation thereto, but has confined himself to a practical and historical account of the work of the Birmingham, Tame, and Rea District Drainage Board, merely adding from time to time such remarks as seemed needful for the proper explanation of the subject under consideration.

In giving an account of the formation and work of the Drainage Board, the works of sewage purification previously undertaken by the Corporation of Birmingham form so important a part that any general description of the Drainage Board would be incomplete without some reference thereto; but inasmuch as the efforts of the Birmingham Corporation to deal with the sewage difficulty have been so prominently before the various bodies interested in sanitary work, both from the proceedings in Parliament and from several published statements, it has not been thought necessary to make further allusion thereto than may be required for giving a complete history of the position and work of the Board.

It may perhaps be desirable to glance briefly, in the first instance, at the sanitary condition of the district generally prior to the formation of the Board, with a view of setting forth more clearly the advantages the various authorities now comprising the Board were intended to derive from their union.

The borough of Birmingham, together with the towns of Walsall, West

Bromwich, Wednesbury, Darlaston, Tipton, part of Wolverhampton, and a number of other urban or rural sanitary districts, forming the major part of what is known as the 'Black Country,' is situated near the summit of one of the great watersheds of England—that of the Trent—being drained by the River Tame, which, with its various feeders, forms a small stream, discharging into the Trent about midway between Tamworth and Burton. Whatever may have been the benefits derived by the large population of the Black Country from being situated high up in the watershed, one great disadvantage—that of sewage pollution—soon became apparent owing to the naturally diminutive character of the watercourses and the large amount of liquid refuse poured into them. The Corporation of Birmingham, as the principal local authority, was early made aware of the responsibility thus incurred, and was earnestly combating the sewage difficulty at a time when the authorities of many towns considered it, if not exactly the right thing to do, at any rate only a venial offence, to discharge their sewage into the rivers or streams that flowed in their vicinity.

At the time the formation of the Drainage Board was suggested none of the authorities of the towns or districts draining into the Tame had made, so far as the author is aware, any really systematic attempt at sewage purification except those of Birmingham and Wolverhampton.

The Corporation of Birmingham constructed, as far back as 1853, two main intercepting sewers whereby the sewage from those portions of the borough draining to the River Rea and Hockley Brook was conveyed to the general outlet at Saltley, where subsequently a system of tank purification had been adopted, and which was developed from time to time, until at the period when the Drainage Board was formed the Corporation possessed land and works thoroughly capable of purifying, so far as precipitation by lime could purify, the sewage of the borough. The Manor of Aston Local Board had caused plans to be prepared in 1874 for the intercepting sewers for diverting the sewage of its district from the River Tame and the Hockley Brook, and by agreement the Handsworth Local Board, whose district is situated on the same watersheds but higher up, became joint owners of such sewers. These sewers were constructed in 1876, and although the sewage was thus diverted in detail it was only to cast it into the Tame again in one united volume, pending the decision of these boards as to the method of sewage treatment to be adopted; a problem that threatened to be very difficult of solution had not the Drainage Board about that time been formed, and so relieved those authorities of further trouble. The authorities of the district of Balsall Heath, a small but somewhat thickly inhabited area draining to the Rivers Rea and Cole immediately above the Borough of Birmingham, had established some precipitating works of an elementary character at the outlet in the River Cole area, but owing to the great increase of population all around the use of these works had become objectionable, and as the only outlets for this district lay through the Borough of Birmingham, it became necessary, if great expense were to be avoided, that some arrangement should be made for the Corporation to provide the requisite outlets. The district of Harborne, likewise situated in the watershed of the Rea above the Borough of Birmingham, had also established a system of tank purification, but open to similar objections to those above named in Balsall Heath, this district also suffering from precisely the same difficulties as to outlet. These, then, were the only districts in the neighbourhood of

Birmingham of which the authorities had made any efforts to deal with their sewage, whilst on the other hand there were several districts urgently in need of sanitary reform that had been unable, owing to their positions in relation to other districts, to take independently the necessary step except at a prohibitive cost.

Birmingham and its sewage farm holding by virtue of its position the key of the situation, and the Corporation anticipating that great expense and inconvenience must ultimately arise if some united action were not taken, it was decided to apply to the Local Government Board, under the Public Health Act, 1875, for an order to form the following urban and rural sanitary districts or portions of them into a united district for the purpose of sewage disposal, viz., the Borough of Birmingham, the Local Government Districts of Aston Manor, Handsworth, Smethwick, Balsall Heath, Harborne, and Saltley; the contributory places of Aston, King's Norton and Northfield, and Perry Barr; and portions of the districts of the West Bromwich Improvement Commissioners, and of the Solihull Rural Sanitary Authority; the principle of selection adopted being to choose only those districts lying round Birmingham which were restricted in their outlets, or which had no reasonable facilities for establishing purification works of their own.

An inquiry lasting several days was held by J. T. Harrison, Esq., the Government Inspector, at the Public Offices, Birmingham, in which the West Bromwich Commissioners proved to the Inspector's satisfaction that they were in a position to establish their own purification works, and the Rural Sanitary Authority of Solihull, having also recently prepared a scheme, was likewise omitted by the Inspector.

All the other districts were formed into a united district, under the title of the Birmingham, Tame, and Rea Main Sewerage District, the Provisional Order coming into operation on September 29, 1877.

The Joint Board consisted at first of twenty elective members, chosen from the members of the various constituent authorities, of which the Borough of Birmingham sent eleven and the others one each; and two *ex-officio* members, viz., the Mayor of Birmingham and the Chairman of the Aston Manor Local Board. The district was enlarged in 1881 by the addition of the parish of Sutton Coldfield, but no alteration was made in the constitution of the Board until Sutton Coldfield was incorporated early in the present year, when the number of members was increased to 24, Sutton Coldfield sending one member and the representation of the borough being increased to the same extent.

The first meeting of the Board was held December 6, 1877, when Mr. Alderman Avery, a gentleman well known in connection with the sanitary work of the Borough of Birmingham, was elected Chairman, a position he still occupies.

The duties of the Board are the acquiring of such lands and the construction and maintenance of such outfall works as may be necessary for the purification of the sewage of the various constituent authorities, so that it may be discharged into any streams or watercourses without breach of the Rivers Pollution Act, 1876. It is incumbent on each of the constituent authorities either to construct such intercepting sewers as may be required for conveying the sewage of its district to the outfall works, or otherwise to arrange terms with one or other of the constituent authorities for the user of such sewers as may be necessary for that purpose. The Joint Board exercises supervision over the size, character, and direction of new intercepting sewers, so that they may be laid down with general reference to the requirements of the united district at large, and in the case of its being desirable that one constituent authority should use the existing intercepting sewers of another constituent authority, it devolves on the Joint Board to say whether such sewer can and ought to be so used to the extent of, but not exceeding, 40 gallons per head per day of the population of the district.

The costs of the Joint Board are divided into the costs of management and the costs of outfall works (outfall works being the land, tanks, and works for purifying the sewage).

All the constituent authorities, with the exception of Perry Barr, are liable to the costs of management, but no constituent authority is liable to the expenses of outfall works until some portion of such authority's district has been placed in connection with any of the said outfall works.

The various districts contribute to the expenses of the Board in proportion to the number of rated tenements in each district or contributory place, such number being ascertained from the poor-rate made last before the times for issuing the Board's precepts.

The total area of the drainage district is 47,275 acres; the population in 1885 was estimated at 619,693; and the ratable value 2,401,093*l*. Appendix A gives a detailed statement of the area, population, and ratable value.

In accordance with the Provisional Order, the Drainage Board purchased as going concerns all existing lands and works for treatment of sewage owned by the various constituent authorities, such being Birmingham, Aston Manor, Harborne, and Balsall Heath. Of these the works at Harborne and Balsall Heath were abandoned as soon as arrangements for outlets had been carried into effect, and the sites of such works were ultimately sold. From the Borough of Birmingham the Board acquired about 159 acres of freehold and 103½ acres of leasehold land, together with the extensive system of tanks, machinery, plant, farm implements, and stock situated at the general outlet at Saltley; and from Aston Manor about six acres of land, also situated at Saltley and surrounded by the Corporation farm.

As the outlet at Saltley is the natural point of discharge for fully nine-tenths of the total population of the Drainage District, one of the first cares of the Drainage Board after its formation was to assist the various constituent authorities in their endeavours to put themselves in communication with the outfall works purchased from the Birmingham Corporation. Accordingly arrangements were speedily made for the Corporation to receive into their main sewers the sewage from the districts of Harborne and Balsall Heath, on payment of an annual sum for user; the Manor of Aston Local Board entered into a contract for the construction of the sewer for conveying its sewage from the temporary outlet into the Tame to the Board's tanks, the Aston Rural Sanitary Authority becoming joint owner with Aston Manor and Handsworth, and thereby procuring an outlet for the Erdington and Witton portions of its district; the Handsworth Local Board extended one of the Aston and Handsworth joint sewers, so as to accommodate the northern portion of its district, and has since, in conjunction with Smethwick, extended the other joint sewer, thereby completing for the present the intercepting sewers of its own district and providing for Smethwick an outlet for the larger portion of that district. The Saltley Local Board constructed the intercepting sewers, and the Rural Sanitary Authority of King's Norton, after arranging with the Corporation of Birmingham for an outlet through their main sewer, constructed the intercepting sewers for the drainage of portions of its district. For those portions of the Drainage District that could not conveniently be brought down to the common outlet at Saltley, the Corporation of Birmingham constructed the sewer for accommodating the area draining to the Cole comprised in the districts of Birmingham, Balsall Heath, King's Norton, and Aston Rural, this sewer being tunnelled across the ridge dividing the watersheds of the Tame and Cole, and discharging on to the new farm. The Aston Rural Sanitary Authority constructed the sewer for the drainage of Sutton Coldfield, this sewer also discharging on to the new farm.

As the result of the intercepting works just described, the whole of the populated areas of the Drainage District, with one exception, are now placed in communication with the outfall works. The one exception is the district of Smethwick, which, being situated at the summit of the watershed, has had to await the development of the intercepting system; but it is believed that arrangements are contemplated whereby this difficulty will be shortly removed.

In the meantime, pending the completion of these intercepting arrangements, the Drainage Board had been proceeding with the very important duty of extending its outfall works so as to meet efficiently the additional strain that would in due course be brought upon them. It had been generally understood at the time the Board was formed that an extension of the outfall works would be necessary, and after due consideration it was decided that the application of the sewage to land after partial treatment by lime, and in the tanks, would be the most satisfactory method of purification. The Board accordingly directed its attention to the acquisition of the required area of land. An opportunity that presented itself in 1880 of obtaining the unexpired term of 102 years of a lease of 96 acres of suitable land at Tyburn, about 2½ miles below the existing tanks, was embraced, and shortly after a lease for 99 years of 123 acres of adjoining land was obtained, while 250 acres of freehold from the Right Honourable the Earl of Bradford, 350 acres from the trustees of W. W. Bagot, Esq., and 118 acres from various other owners were acquired by mutual arrangement, and more recently a further plot of 18½ acres has been leased from the Right Honourable Lord Norton for 21 years, thus making a total of 955½ acres of additional land, or, including the land already occupied by the Board at Saltley, a total area of 1,227 acres available for works of sewage disposal. The rent of the leasehold land is at the rate of 4*l.* per acre, and the average cost of the freehold, including timber, buildings, mill rights, tenants' compensation, law charges, &c., 152*l.* per acre.

The nature of the land is very favourable for the purification of sewage, the natural surface of the ground being, as a rule, even and unbroken, and the level such as to admit of the irrigation of the whole by gravitation, with the exception of about 100 acres. The subsoil is gravel and sand, varying from 6 feet to 10 feet in thickness. To reduce the risk of flooding from the river the Board removed the mills and weir, and straightened the river at Minworth at the lower end of the farm lands, thereby lowering the water-level of the river several feet, and by the construction of outfall cuts, carried to suitable outlets into the river, the subsoil drains are placed beyond the influence of backwater, the result being that no inconvenience is experienced from the proximity of the river, except during unusual floods. For conveying the sewage to the land a conduit 8 feet in diameter and about $2\frac{3}{4}$ miles long has been constructed, capable of discharging 38 million gallons per day when running half-full, or double that quantity running full, the fall being 2 feet per mile. This conduit commences at the outlet end of the large tanks at Saltley and terminates at Tyburn, valves being placed at suitable intervals for discharging the sewage on to the land passed through. Below Tyburn the capacity of the conduit has been reduced, a conduit 3 feet 6 in. in diameter being sufficient for the remainder of the farm. The sewage is drawn from these conduits into open brick carriers, which again discharge into secondary carriers of earth, and thence into the flooding carriers. The brick carriers are constructed with a slight fall, steps being provided in the inverts at suitable intervals for drawing down the water. The land is drained to a minimum depth of 4 feet 6 in., but in many cases, owing to the level nature of some of the land, a greater depth has been found necessary at the lower ends of the drains. The subsoil drainage consists of 3-in. and 4-in. agricultural drain-pipes placed from $\frac{1}{2}$ to $\frac{3}{4}$ of a chain apart, and discharging into main drains of 9-in., 12-in., 15-in., and 18-inch stoneware socket pipes, which in turn discharge into the outfall channels. Roads generally 12 feet wide, with passing places at intervals, have been laid out with the view of meeting the requirements of the steam cultivating operations as well as for the conveyance of produce. In addition to the farm buildings at Saltley, purchased from the Corporation, farm buildings in a central position at Tyburn have been erected, together with entrance lodge, manager's house, and six labourers' cottages; also smaller buildings at Minworth and four labourers' cottages. The various farmhouses and buildings originally existing have also been repaired and extended.

The total cost of the land and works to the present has been 403,695*l.*, of which the purchase of original land and works is 170,544*l.*, new land 110,800*l.*, new works 113,299*l.*, farming stock and implements for new land 9,052*l.* The details of cost are given in Appendix B.

The method of treating the sewage as now carried on is as follows:—

The sewage on arriving near the liming sheds at the upper end of the works is mixed with lime, both to neutralise the acids (present to an unusual extent in Birmingham sewage) and also to assist precipitation, which, however, is not now necessary to so great an extent as formerly; the sewage then passes through the large or roughing tanks, where the grosser impurities are precipitated, and thence it is conveyed by the main conduit to the land and disposed of by ordinary irrigation. The sixteen small tanks required at one time for completing the precipitation process are still used under certain circumstances, and are a valuable auxiliary when rainfall has increased the normal quantity of sewage. The sludge from the tanks is elevated by bucket dredgers and pumps into movable wooden carriers, and flows into beds formed in the land at the Saltley or western end of the farm. The sludge contains about 90 per cent. of water as it comes from the tanks, but after lying on the ground for about fourteen days much of this water drains away or is evaporated, leaving the sludge in a layer about 10 inches thick and of a consistency that admits of its being trenched into the land. Crops are then planted, and after a time the sludge becomes pulverised and capable of being irrigated. About forty acres of land were required for the sludge last year, and the same land may receive a coating of sludge every two to three years.

A few words may be said as to the difficulty at one time experienced in dealing with the mud from the tanks. After the construction of the first two large tanks in 1859 the mud therein deposited was dredged out and run on to the adjacent land, where it accumulated for some years, forming at one time a large mass of foul matter about seven acres in area and over four feet deep. In consequence of the nuisance arising therefrom proceedings were taken, about 1871, by the residents in the vicinity, and an injunction obtained restraining the Corporation from depositing the mud so as to cause a nuisance. Great efforts were made by the Corporation to reduce the amount of mud, large quantities being conveyed away in boats, but it was not until the experiment had been tried of trenching the mud into the land, and found perfectly satisfactory, that the present system was adopted, about the end of 1872, and the difficulty finally overcome.

Practically the whole of the sewage of the Drainage District, amounting to sixteen million gallons per day, flows by gravitation to the outfall works. Only a very small area requires its sewage lifted by pumping, the cost of such pumping being 104*l.* per annum.

The Board farms the whole of the land, no portion of it being sub-let.

Of the produce milk is a large and increasing item, 128,995 gallons, realising 4,406*l.*, being sold last year. During the present year about 280 acres of land are devoted to mangolds, swedes, and kohl rabi; 250 acres to market garden produce, 100 acres to Italian rye grass, 130 acres to cereals, and about 340 acres are pasture.

The total amount realised last year from the sale of stock and produce was 20,008*l.* During the same time stock was purchased to the extent of 7,760*l.*

With regard to the financial aspect of the Board's work it is perhaps needless to say that a considerable sum of money has annually to be obtained from the rates. The total amount raised by the Board's precept last year was 33,089*l.*, of which interest and repayment of loans absorbed 17,516*l.*; management expenses, rent, rates, taxes, &c., 5,594*l.*; the balance of 9,979*l.* representing the loss on the year's working of the farm.

Appendix C is a detailed statement of the actual income and expenditure of the farm and works during 1885. The great loss, as will be seen from the statement, is in the work at the outlet (which comprises the lime, wages, machinery expenses, and other charges connected with intercepting and dealing with the mud from the tanks). The amount expended under this head (exclusive of rent) was 10,715*l.*, for which sum 4,778 tons of lime were provided for precipitation, and 135,476 cube yards of mud were arrested in the tanks and dug into the land; the corresponding income is practically *nil.* Since the opening out of the irrigation land the expenses at the outlet have undergone some reduction, and there is every prospect not only of a further reduction in the future, but also of a gradual increase in the receipts from the irrigation land as the demand for the farm produce is developed; but bearing in mind the large initial outlay in purchase of land and the construction of works, and the annual working expenses in disposing of so large a volume of sewage, it is not to be expected that assistance from the rates can be dispensed with, until, in the somewhat distant future, the large annual sum now required for interest and repayment of loans shall cease. It should, however, be remembered in dealing with sewage farm accounts that after all the great item on the credit side of the balance-sheet (although it is one that cannot be represented by a money value) is the satisfactory disposal of the sewage.

In conclusion, it is only fair to observe, with reference to remarks made in the first part of this paper as to the sanitary condition of the Tame Valley, that since the date then referred to considerable progress has been made in sewage purification, Walsall, West Bromwich, Wednesbury, Darlaston, and other towns and places having taken up the question in a practical and energetic manner.

APPENDIX A.

Name of District	Area in Acres	Estimated Population in 1885	Ratable Value in 1885
			£
Borough of Birmingham	8,420	427,769	1,621,701
Smethwick, Local Government District of . .	1,882	26,000	113,667
Harborne „ „ „ . .	1,412	7,422	31,334
Balsall Heath „ „ „ . .	453	25,300	69,803
Saltley „ „ „ . .	1,039	7,100	47,514
Aston Manor „ „ „ . .	943	62,510	171,875
Handsworth „ „ „ . .	3,638	27,300	125,601
Aston Union, Contributory Place of Aston . .	8,916	10,552	63,198
King's Norton Union, Contributory Places of King's Norton and Northfield	3,500	15,275	84,476
West Bromwich Union, Contributory Place of Perry Barr	4,042	1,655	19,208
Borough of Sutton Coldfield	13,030	8,810	52,716
Total	47,275	619,693	2,401,093

APPENDIX B.

OLD FARM.

	£ s. d.	£ s. d.
Land	56,337 0 0	
Works, Tanks, &c.	91,479 0 0	
Stock and Plant	22,728 0 0	
		170,544 0 0

NEW FARM.

LANDS.—*Re* Wiley's Lease	1,500 0 0	
„ Perkins'	164 0 0	
„ Housman (Freehold)	6,249 0 0	
„ Earl of Bradford (Freehold)	38,484 0 0	
„ Bagot (Freehold)	49,498 0 0	
„ Newton (Freehold)	11,173 0 0	
„ Goldingay (Freehold)	3,732 0 0	
		110,800 0 0
WORKS.—Main Conduit	33,256 0 0	
3 ft. 6 in. Conduit	3,544 0 0	
Laying out and Draining	46,979 0 0	
New Buildings	20,119 0 0	
Repairs to Old Buildings	599 0 0	
Permanent Carriers	8,802 0 0	
		113,299 0 0
Live Stock and Farm Implements		9,052 0 0
		403,695 0 0

APPENDIX C.

INCOME AND EXPENDITURE FROM JANUARY 1st TO DECEMBER 31st, 1885.

INCOME.

OUTLET.

Sale of Manure	7	0	0
Pumping Sewage	104	0	0
Sundries	0	4	9
	£111	4	9

FARM.

Sale of Rye Grass and other Crops and Cattle Ley	4,960	15	10
Sale of Milk	4,406	18	7
Sale of Stock	10,641	0	3
	£20,008	14	8

EXPENDITURE.

OUTLET.

Wages, including Lime for Disinfecting	9,025	12	0
Horse Keep, Veterinary Attendance, Repairing Harness, Carts, &c.	356	11	6
Timber, Ironwork, Bricks, Tools, Coal, Coke, and Repairs to Machinery	1,064	14	7
Horse Hire, Boat Hire, and Tonnage	174	9	5
Rent, Rates, Taxes, and Gas	787	0	9
Miscellaneous	94	2	9
	£11,502	11	0

FARM.

Wages	5,047	1	5
Seeds, Plants, &c.	508	18	11
Horse Hire, Keep, and Cattle Keep	4,768	14	5
Stock Purchased	7,760	7	6
Miscellaneous, including Tools	930	8	2
Rent, Rates, and Taxes	3,806	18	5
	£22,822	8	10

TRANSACTIONS OF THE SECTIONS.

TRANSACTIONS OF THE SECTIONS.

SECTION A.—MATHEMATICAL AND PHYSICAL SCIENCE.

PRESIDENT OF THE SECTION—Professor G. H. DARWIN, M.A., LL.D., F.R.S., F.R.A.S.

THURSDAY, SEPTEMBER 2.

The PRESIDENT delivered the following Address:—

A MERE catalogue of facts, however well arranged, has never led to any important scientific generalisation. For in any subject the facts are so numerous and many-sided that they only lead us to a conclusion when they are marshalled by the light of some leading idea. A theory is then a necessity for the advance of science, and we may regard it as the branch of a living tree, of which facts are the nourishment. In the struggle between competing branches to reach the light some perish, and others form vigorous limbs. And as in a tree the shape of the young shoot can give us but little idea of the ultimate form of the branch, so theories become largely transformed in the course of their existence, and afford in their turn the parent stem for others.

The success of a theory may be measured by the extent to which it is capable of assimilating facts, and by the smallness of the change which it must undergo in the process. Every theory which is based on a true perception of facts is to some extent fertile in affording a nucleus for the aggregation of new observations. And a theory, apparently abandoned, has often ultimately appeared to contain an element of truth, which receives acknowledgment by the light of later views.

It will, I think, be useful to avail myself of the present occasion to direct your attention to a certain group of theories, which are still in an undeveloped and somewhat discordant condition, but which must form the nucleus round which many observations have yet to be collected before these theories and their descendants can make a definitely accepted body of truth. If I am disposed to criticise some of them in their actual form, I shall not be understood as denying the great service which has been rendered to science by their formulation.

Great as have been the advances of geology during the present century, we have no precise knowledge of one of its fundamental units. The scale of time on which we must suppose geological history to be drawn is important not only for geology itself, but it has an intimate relation with some of the profoundest questions of biology, physics, and cosmogony.

We can hardly hope to obtain an accurate measure of time from pure geology, for the extent to which the events chronicled in strata were contemporaneous is not written in the strata themselves, and there are long intervals of time of which no record has been preserved.

An important step has been taken by Alfred Tylor, Croll, and others, towards the determination of the rate of action of geological agents.[1] From estimates of

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[1] Geikie, *Textbook of Geology*, 1882, p. 442.

the amount of sediment carried down by rivers, it appears that it takes from 1,000 to 6,000 years to remove one foot of rock from the general surface of a river basin.

From a consideration of the denuding power of rivers, and a measurement of the thickness of stratified rock, Phillips has made an estimate of the period of time comprised in geological history, and finds that, from stratigraphical evidence alone, we may regard the antiquity of life on the earth as being possibly between 38 and 96 millions of years.[1]

Now while we should perhaps be wrong to pay much attention to these figures, yet at least we gain some insight into the order of magnitude of the periods with which we have to deal, and we may feel confident that a million years is not an infinitesimal fraction of the whole of geological time.

It is hardly to be hoped, however, that we shall ever attain to any very accurate knowledge of the geological time scale from this kind of argument.

But there is another theory which is precise in its estimate, and which, if acceptable from other points of view, will furnish exactly what is requisite. Mr. Croll claims to prove that great changes of climate must be brought about by astronomical events of which the dates are known or ascertainable.[2] The perturbation of the planets causes a secular variability in the eccentricity of the earth's orbit, and we are able confidently to compute the eccentricity for many thousands of years forward and backward from to-day, although it appears that, in the opinion of Newcomb and Adams, no great reliance can be placed on the values deduced from the formulæ at dates so remote as those of which Mr. Croll speaks. According to Mr. Croll, when the eccentricity of the earth's orbit is at its maximum, that hemisphere which has its winter in aphelion would undergo a glacial period. Now, as the date of great eccentricity is ascertainable, this would explain the great ice-age and give us its date.

The theory has met with a cordial acceptance on many sides, probably to a great extent from the charm of the complete answer it affords to one of the great riddles of geology.

Adequate criticism of Mr. Croll's views is a matter of great difficulty on account of the diversity of causes which are said to co-operate in the glaciation. In the case of an effect arising from a number of causes, each of which contributes its share, it is obvious that if the amount of each cause and of each effect is largely conjectural the uncertainty of the total result is by no means to be measured by the uncertainty of each item, but is enormously augmented. Without going far into details it may be said that these various concurrent causes result in one fundamental proposition with regard to climate, which must be regarded as the keystone of the whole argument. That proposition amounts to this—that climate is unstable.

Mr. Croll holds that the various causes of change of climate operate *inter se* in such a way as to augment their several efficiencies. Thus the trade-winds are driven by the difference of temperature between the frigid and torrid zones, and if from the astronomical cause the N. hemisphere becomes cooler the trade-winds on that hemisphere encroach on those of the other, and the part of the warm oceanic current, which formerly flowed into the cold north zone, will be diverted into the S. hemisphere. Thus the cold of the N. hemisphere is augmented, and this in its turn displaces the trade-winds further, and this again acts on the ocean-currents, and so on; and this is neither more nor less than instability.

But if climate be unstable, and if from some of those temporary causes, for which no reasons can as yet be assigned, there occurs a short period of cold, then surely some even infinitesimal portion of the second link in the chain of causation must exist; and this should proceed as in the first case to augment the departure from the original condition, and the climate must change.

In a matter so complex as the weather, it is at least possible that there should be instability when the cause of disturbance is astronomical, whilst there is stability

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[1] Phillips, *Life on the Earth.* Rede Lecture, 1860, p. 119.

[2] *Climate and Time.*

in an ordinary sense. If this is so, it might be explained by the necessity for a prolonged alteration in the direction of prevailing winds in order to affect oceanic currents.[1]

However this may be, so remarkable a doctrine as the instability of climate must certainly be regarded with great suspicion, and we should require abundant proof before accepting it. Now there is one result of Mr. Croll's theory which should afford almost a crucial test of its acceptability. In consequence of the precession of the equinoxes the conditions producing glaciation in one hemisphere must be transferred to the other every 10,000 years. If there is good geological evidence that this has actually been the case, we should allow very great weight to the astronomical theory, notwithstanding the difficulties in its way. Mr. Croll has urged that there is such evidence, and this view has been recently strongly supported by M. Blytt.[2] Other geologists do not, however, seem convinced of the conclusiveness of the evidence.

Thus Mr. Wallace,[3] whilst admitting that there was some amelioration of climate from time to time during the last glacial period, cannot agree in the regular alternations of cold and warm demanded by Mr. Croll's theory. To meet this difficulty he proposes a modification. According to his view large eccentricity in the earth's orbit will only produce glaciation when accompanied by favourable geographical conditions. And when extreme glaciation has once been established in the hemisphere which has its winter in aphelion, the glaciation will persist, with some diminution of intensity, when precession has brought round the perihelion to the winter. In this case, according to Wallace, glaciation will be simultaneous on both hemispheres.

Again he contends that, if the geographical conditions are not favourable, astronomical causes alone are not competent to produce glaciation.

There is agreement between the two theories in admitting instability of climate at first, when glaciation is about to begin under the influence of great eccentricity of the orbit, but afterwards Wallace demands great stability of climate. Thus he maintains that there is great stability in extreme climates, either warm or cold, whilst there is instability in moderate climates. I cannot perceive that we have much reason from physical considerations for accepting these remarkable propositions, and the acceptance or rejection of them demands an accurate knowledge of the most nicely balanced actions, of which we have as yet barely an outline.

Ocean currents play a most important part in these theories, but at this moment our knowledge of the principal oceanic circulation, and of its annual variability, is very meagre. In the course of a few years we may expect a considerable accession to our knowledge, when the Meteorological Office shall have completed a work but just begun—viz., the analysis of ships' logs for some sixty years, for the purpose of laying down in charts the oceanic currents.

With regard to the great atmospheric currents even the general scheme is not yet known. Nearly thirty years ago Professor James Thomson gave before this Association at Dublin an important suggestion on this point. As it has been passed over in complete silence ever since, the present seems to be a good opportunity of redirecting attention to it.

According to Halley's theory of atmospheric circulation, the hot air rises at the equator and floats north and south in two grand upper currents, and it then acquires a westward motion relatively to the earth's surface, in consequence of the earth's rotation. Also the cold air at the pole sinks and spreads out over the earth's surface in a southerly current, at first with a westerly tendency, because the air comes from the higher regions of the atmosphere, and afterwards due south, and then easterly, when it is left behind by the earth in its rotation.

Now Professor Thomson remarks that this theory disagrees with fact in as far as that in our latitudes, the winds, though westerly, have a poleward tendency, instead of the reverse.

In the face of this discrepancy he maintains that 'the great circulation already described does actually occur, but occurs subject to this modification, that a thin

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[1] Zöppritz, *Phil. Mag.* 1878.

[2] *Nature*, July 8 and 15, 1886.

[3] *Island Life.*

stratum of air on the surface of the earth in the latitudes higher than 30°—a stratum in which the inhabitants of those latitudes have their existence, and of which the movements constitute the observed winds of those latitudes—being, by friction and impulses on the surface of the earth, retarded with reference to the rapid whirl or vortex motion from west to east of the great mass of air above it, tends to flow towards the pole, and actually does so flow to supply the partial void in the central parts of that vortex, due to the centrifugal force of its revolution. Thus it appears that in the temperate latitudes there are three currents at different heights—that the uppermost moves towards the pole, and is part of a grand primary circulation between the equatorial and polar regions; that the lowermost moves also towards the pole, but is only a thin stratum forming part of a secondary circulation; that the middle current moves from the pole, and constitutes the return current for both the preceding; and that all these three currents have a prevailing motion from west to east.'[1]

Such, then, appears to be our present state of ignorance of these great terrestrial actions, and any speculations as to the precise effect of changes in the annual distribution of the sun's heat must be very hazardous until we know more precisely the nature of the thing changed.

When looking at the astronomical theory of geological climate as a whole, one cannot but admire the symmetry and beauty of the scheme, and nourish a hope that it may be true; but the mental satisfaction derived from our survey must not blind us to the doubts and difficulties with which it is surrounded.

And now let us turn to some other theories bearing on this important point of geological time.

Amongst the many transcendent services rendered to science by Sir William Thomson, it is not the least that he has turned the searching light of the theory of energy on to the science of geology. Geologists have thus been taught that the truth must lie between the cataclysms of the old geologists and the uniformitarianism of forty years ago. It is now generally believed that we must look for a greater intensity of geologic action in the remote past, and that the duration of the geologic ages, however little we may be able mentally to grasp their greatness, must bear about the same relation to the numbers which were written down in the older treatises on geology, as the life of an ordinary man does to the age of Methuselah.

The arguments which Sir William Thomson has adduced in limitation of geological time are of three kinds. I shall refer first to that which has been called the argument from tidal friction; but before stating the argument itself it will be convenient to speak of the data on which the numerical results are based.

Since water is not frictionless, tidal oscillations must be subject to friction, and this is evidenced by the delay of twenty-four to thirty-six hours, which is found to occur between full and change of moon and spring-tide. An inevitable result of this friction is that the diurnal rotation of the earth must be slowly retarded, and that we who accept the earth as our timekeeper must accuse the moon of a secular acceleration of her motion round the earth, which cannot be otherwise explained. It is generally admitted by astronomers that there actually is such an unexplained secular acceleration of the moon's mean motion.

No passage in Thomson and Tait's 'Natural Philosophy' has excited more general interest than that in which Adams is quoted as showing that, *with a certain value for the secular acceleration*, the earth must in a century fall behind a perfect chronometer, set and rated at the beginning of the century, by twenty-two seconds. Unfortunately this passage in the first edition gave an erroneous complexion to Adams's opinion, and being quoted, without a statement of the premisses, has been used in popular astronomy as an authority for establishing the statement that the earth is actually a false timekeeper to the precise amount specified.

In the second edition (in the editing of which I took part) this passage has been rewritten, and it is shown that Newcomb's estimate of the secular acceleration only gives about one-third of the retardation of the earth's rotation, which resulted from Adams's value. The last sentence of the paragraph here runs as follows:—

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[1] *Brit. Assoc. Report,* Dublin, 1857, p. 38–9.

'It is proper to add that Adams lays but little stress on the actual numerical values which have been used in this computation, and is of opinion that the amount of tidal retardation of the earth's rotation is quite uncertain.' Thus, in the opinion of our great physical astronomer, a datum is still wanting for the determination of a limit to geological time, according to Thomson's argument.

However, subject to this uncertainty, with the values used by Adams in his computation, and with the assumption that the rate of tidal friction has remained constant, then a thousand million years ago the earth was rotating twice as fast as at present. In the last edition of the 'Natural Philosophy' the argument from these data runs thus:—

'If the consolidation of the earth took place then or earlier, the ellipticity of the upper layers (of the earth's mass) must have been $\frac{1}{230}$ instead of about $\frac{1}{300}$, as it is at present. It must necessarily remain uncertain whether the earth would from time to time adjust itself completely to a figure of equilibrium adapted to the rotation. But it is clear that a want of complete adjustment would leave traces in a preponderance of land in equatorial regions. The existence of large continents and the great effective rigidity of the earth's mass render it improbable that the adjustment, if any, to the appropriate figure of equilibrium would be complete. The fact, then, that the continents are arranged along meridians, rather than in an equatorial belt, affords some degree of proof that the consolidation of the earth took place at a time when the diurnal rotation differed but little from its present value. It is probable, therefore, that the date of consolidation is considerably more recent than a thousand million years ago.'

I trust it may not be presumptuous in me to criticise the views of my great master, at whose intuitive perception of truth in physical questions I have often marvelled, but this passage does not even yet seem to me to allow a sufficiently large margin of uncertainty.

It will be observed that the argument reposes on our certainty that the earth possesses rigidity of such a kind as to prevent its accommodation to the figure and arrangement of density appropriate to its rotation. In an interesting discussion on subaërial denudation, Croll has concluded that nearly one mile may have been worn off the equator during the past 12,000,000 years, if the rate of denudation all along the equator be equal to that of the basin of the Ganges.[1] Now, since the equatorial protuberance of the earth when the ellipticity is $\frac{1}{230}$ is fourteen miles greater than when it is $\frac{1}{300}$, it follows that 170,000,000 years would suffice to wear down the surface to the equilibrium figure. Now let these numbers be halved or largely reduced, and the conclusion remains that denudation would suffice to obliterate external evidence of some early excess of ellipticity.

If such external evidence be gone,[2] we must rely on the incompatibility of the known value of the precessional constant with an ellipticity of internal strata of equal density greater than that appropriate to the actual ellipticity of the surface. Might there not be a considerable excess of internal ellipticity without our being cognisant of the fact astronomically?

And, further, have we any right to feel so confident of the internal structure of the earth as to be able to allege that the earth would not through its whole mass adjust itself almost completely to the equilibrium figure?

Tresca has shown in his admirable memoirs on the flow of solids that when the stresses rise above a certain value the solid becomes plastic, and is brought into what he calls the state of fluidity. I do not know, however, that he determined at what stage the flow ceases when the stresses are gradually diminished. It seems probable, at least, that flow will continue with smaller stresses than were initially

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[1] Croll, *Climate and Time*, 1885, p. 336.

[2] I find by a rough calculation that $\frac{55}{150}$ths of the land in the N. hemisphere is in the equatorial half of that hemisphere, viz. between 0° and 30° N. lat.; and that $\frac{46}{55}$ths of the land in the S. hemisphere is in the equatorial half of that hemisphere, viz. between 0° and 30° S. lat. Thus for the whole earth, $\frac{101}{205}$ths of all the land lies in the equatorial half of its surface, between 30° N. and S. lat. In this computation the Mediterranean, Caspian, and Black Seas are treated as land.

necessary to start it. But if this is so, then, when the earth has come to depart both internally and externally from the equilibrium condition a flow of solid will set in, and will continue until a near approach to the equilibrium condition is attained.

When we consider the abundant geological evidence of the plasticity of rock, and of the repeated elevation and subsidence of large areas on the earth's surface, this view appears to me more probable than Sir William Thomson's.

On the whole, then, I can neither feel the cogency of the argument from tidal friction itself, nor, accepting it, can I place any reliance on the limits which it assigns to geological history.

The second argument concerning geological time is derived from the secular cooling of the earth.

We know in round numbers the rate of increase of temperature, or temperature gradient, in borings and mines, and the conductivity of rock. These data enable us to compute how long ago the surface must have had the temperature of melting rock, and when it must have been too hot for vegetable and animal life.

Sir William Thomson, in his celebrated essay on this subject,[1] concludes from this argument that 'for the last 96,000,000 years the rate of increase of temperature underground has gradually diminished from about $\frac{1}{10}$th to about $\frac{1}{50}$th of a degree Fahrenheit per foot. . . . Is not this, on the whole, in harmony with geological evidence, rightly interpreted? Do not the vast masses of basalt, the general appearances of mountain ranges, the violent distortions and fractures of strata, *the great prevalence of metamorphic action* (which must have taken place at depths of not many miles, if so much), all agree in demonstrating that the rate of increase of temperature downwards must have been much more rapid, and in rendering it probable that volcanic energy, earthquake shocks, and every kind of so-called plutonic action, have been, on the whole, more abundantly and violently operative in geological antiquity than in the present age?'

Now, while I entirely agree with the general conclusion of Sir William Thomson, it is not unimportant to indicate a possible flaw in the argument. This flaw will only be acknowledged as possible by those who agree with the previous criticism on the argument from tidal friction.

The present argument as to the date of the consolidation of the earth reposes on the hypothesis that the earth is simply a cooling globe, and there are reasons why this may not be the case. The solidification of the earth probably began from the middle and spread to the surface. Now is it not possible, if not probable, that after a firm crust had been formed, the upper portion still retained some degree of viscosity? If the interior be viscous, some tidal oscillations must take place in it, and, these being subject to friction, heat must be generated in the viscous portion; moreover the diurnal rotation of the earth must be retarded. Some years ago, in a paper on the tides of a spheroid, viscous throughout the whole mass,[2] I estimated the amount and distribution of the heat generated, whilst the planet's rotation is being retarded and the satellite's distance is being increased. It then appeared that on that hypothesis the distribution of the heat must be such that it would only be possible to attribute a very small part of the observed temperature gradient to such a cause. Now, with a more probable internal constitution for the earth in early times, the result might be very different. Suppose, in fact, that it is only those strata which are within some hundreds of miles of the surface which are viscous, whilst the central portion is rigid. Then, when tidal friction does its work the same amount of heat is generated as on the hypothesis of the viscosity of the whole planet, but instead of being distributed throughout the whole mass, and principally towards the middle, it is now to be found in the more superficial layers.

In my paper it is shown that with Thomson's data for the conductivity of rock and the temperature gradient, the annual loss of heat by the earth is one 260 millionth part of the earth's kinetic energy of rotation.

Also, if by tidal friction the day is reduced from D_0 hours to D hours, and the

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[1] Republished in Thomson and Tait's *Natural Philosophy*, Appendix D.

[2] *Phil. Trans.* Part II. 1879

moon's distance augmented from Π_0 to Π earth's radii, the energy which has been converted into heat in the process is

$$\left(\frac{D}{D_0}\right)^2 - 1 - 8{\cdot}84\left(\frac{1}{\Pi} - \frac{1}{\Pi_0}\right) \text{ times the earth's kinetic energy of rotation.}$$

From these data it results that the heat generated in the lengthening of the day from twenty-three to twenty-four hours is equal to the amount of heat lost by the earth, at its present rate of loss, in 23,000,000 years.

Now if this amount of heat, or any sensible fraction of it, was actually generated within a few hundred miles of the earth's surface, the temperature gradient in the earth must be largely due to it, instead of to the primitive heat of the mass.

Such an hypothesis precludes the assumption that the earth is simply a cooling mass, and would greatly prolong the possible extension of geological time. It must be observed that this view is not acceptable unless we admit that the earth can adjust itself to the equilibrium figure adapted to its rotation.[1]

It seems also worthy of suggestion that our data for the average gradient of temperature may be somewhat fallacious. Recent observations[2] show that the lower stratum of the ocean is occupied by water at near the freezing temperature, whilst the mean annual temperature of the earth's surface, where the borings have been made, must be at least 30° higher. It does not then seem impossible that the mean temperature gradient for the whole earth should differ sensibly from the mean gradient in the borings already made.

The foregoing remarks have not been made with a view of showing Sir William Thomson's argument from the cooling of the earth to be erroneous, but rather to maintain the scientific justice of assigning limits of uncertainty at the very least as wide as those given by him. Professor Tait[3] cuts the limit down to 10,000,000 years; he may be right, but the uncertainties of the case are far too great to justify us in accepting such a narrowing of the conclusion.

The third line of argument by which a superior limit is sought for the age of the solar system appears by far the strongest. This argument depends on the amount of radiant energy which can have been given out by the sun.

The amount of work done in the concentration of the sun from a condition of infinite dispersion may be computed with some accuracy, and we have at least a rough idea of the rate of the sun's radiation. From these data Sir William Thomson concludes:—[4]

'It seems, therefore, on the whole most probable that the sun has not illuminated the earth for 100,000,000 years, and almost certain that he has not done so for 500,000,000 years. As for the future, we may say, with equal certainty, that inhabitants of the earth cannot continue to enjoy the light and heat essential to their life for many million years longer unless sources now unknown to us are prepared in the great storehouse of creation.'

This result is based on the value assigned by Pouillet and Herschel to the sun's radiation. Langley has recently made a fresh determination, which exceeds Pouillet's in the proportion of eight to five.[5] With Langley's value Thomson's estimate of time would have to be reduced by the factor five-eighths.

In considering these three arguments I have adduced some reasons against

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[1] Since the meeting of the Association Sir William Thomson has expressed to me his absolute conviction that, with any reasonable hypothesis as to the degree of viscosity of the more superficial layers, and as to the activity of tidal friction, the disturbance of temperature gradient through internal generation of heat must be quite infinitesimal.

[2] 'Challenger' Expedition.

[3] *Recent Advances in Physical Science* (1885).

[4] Thomson and Tait, *Nat. Phil.* Appendix E.

[5] Langley (*Ann. Rep. R. A. S.* 1885) estimates that 3 calories per minute are received by a square centimetre at distance unity. This gives for the total annual radiation of the sun $4{\cdot}38 \times 10^{33}$ calories. Thomson gives as Pouillet's estimate 6×10^{30} times the heat required to raise 1 lb. of water 1° Cels., or $2{\cdot}72 \times 10^{33}$ calories.

the validity of the first argument, and have endeavoured to show that there are elements of uncertainty surrounding the second; nevertheless they undoubtedly constitute a contribution of the first importance to physical geology. Whilst, then, we may protest against the precision with which Professor Tait seeks to deduce results from them, we are fully justified in following Sir William Thomson, who says that 'the existing state of things on the earth, life on the earth, all geological history showing continuity of life, must be limited within some such period of past time as 100,000,000 years.'

If I have carried you with me in this survey of theories bearing on geological time, you will agree that something has been acquired to our knowledge of the past, but that much more remains still to be determined.

Although speculations as to the future course of science are usually of little avail, yet it seems as likely that meteorology and geology will pass the word of command to cosmical physics as the converse.

At present our knowledge of a definite limit to geological time has so little precision that we should do wrong to summarily reject any theories which appear to demand longer periods of time than those which now appear allowable.

In each branch of science hypothesis forms the nucleus for the aggregation of observation, and as long as facts are assimilated and co-ordinated we ought to follow our theory. Thus even if there be some inconsistencies with a neighbouring science we may be justified in still holding to a theory, in the hope that further knowledge may enable us to remove the difficulties. There is no criterion as to what degree of inconsistency should compel us to give up a theory, and it should be borne in mind that many views have been utterly condemned when later knowledge has only shown us that we were in them only seeing the truth from another side.

The following Papers and Report were read:—

1. *Communication from the Grenada Eclipse Expedition.*
By DONALD MACALISTER, *M.A., M.D., B.Sc.*

2. *First Report on our Experimental Knowledge of the Properties of Matter.*
By P. T. MAIN, *M.A.*—See Reports, p. 100.

3. *On the Critical Mean Curvature of Liquid Surfaces of Revolution.*
By Professor A. W. RÜCKER, *M.A., F.R.S.*

Let a mass of liquid or a liquid film be attached to two equal circular rings, the planes of which are perpendicular to the line joining their centres.

It will form a surface of revolution, the equation of which is, according to Beer,

$$\begin{aligned} y^2 &= \alpha^2 \cos^2 \phi + \beta^2 \sin^2 \phi, \\ x &= \alpha \mathrm{E} + \beta \mathrm{F}, \end{aligned}$$

where F and E are elliptic integrals of the first and second kinds respectively, the amplitude being ϕ, and the modulus $\kappa = \sqrt{\alpha^2 - \beta^2}/\alpha = \sin \theta$.

If θ be conceived as increasing from 0, when it is in the first quadrant the figure will be an unduloid lying between the cylinder and the sphere, in the second quadrant a nodoid, the limits of which are the sphere and a circle. In the third and fourth quadrants the figure will be dice-box-shaped with a contraction in the middle, being a nodoid in the third and an unduloid in the fourth quadrant. The one passes into the other through the catenoid.

If now we suppose the rings to be at a fixed distance apart and the volume of the surface to be altered, the curvature will change, and the direction of the change will depend on the diameter and distance apart of the rings, and on the magnitude of the maximum or minimum ordinate (the *principal ordinate*), which lies halfway between them. The object of the paper is to investigate the general relation between these quantities when the mean curvature is a maximum or minimum, if the changes in the form of the film take place subject to the conditions that the diameter and distance of the rings are constant.

It has been recently shown by Professor Reinold and the author that, if these conditions hold,

$$(a^2\mathrm{E}-\beta^2\mathrm{F}+a^2\Delta_1 \cot\phi_1)\delta a+a^2(\mathrm{F}-\mathrm{E}+\Delta_1 \tan\phi_1)\delta\beta=0,$$

where ϕ_1 is the upper limit of the integrals and $\Delta_1=\sqrt{1-\sin^2\theta\sin^2\phi_1}$.

Writing this in the form $\mathrm{A}\delta a+\mathrm{B}\delta\beta=0$, it is proved that the curvature has in general a critical value when $\mathrm{A}-\mathrm{B}=0$; so that

$$2\mathrm{E}-\mathrm{F}(1+\cos^2\theta)+2\Delta_1\cot 2\phi_1=0$$

is a condition which must be satisfied by θ and ϕ_1.

To find values of ϕ_1 corresponding to given values of θ the equation must be solved by trial; but it is proved that, if a pair of corresponding values is given when θ lies (say) in the first quadrant, the values of ϕ_1 can be at once found which correspond to $\pi-\theta$, $\pi+\theta$, and $2\pi-\theta$.

The values of ϕ_1 corresponding to θ and $\pi-\theta$ are equal, and, if ϕ_2 be the value corresponding to $\pi+\theta$ and $2\pi-\theta$, it is given by the equation

$$\tan\phi_1\tan(\pi-\phi_2) = \sec\theta.$$

By means of these equations a curve can be drawn, showing the relations between ϕ_1 and θ, and thence are found the values of p/Y, X/p and X/Y, where $2\mathrm{Y}$, $2\mathrm{X}$, and $2p$ are the diameter and distance of the rings and the magnitude of the principal diameter.

If we now conceive the two rings gradually to approach or recede from each other, and the principal diameter to be altered so that the condition of critical curvature is always fulfilled, it is proved that the changes in its form would be as follows:—

Beginning with the cylinder the distance of the rings is (as has been shown by Maxwell, Art. *Capillarity*, 'Enc. Brit.') half their circumference. As the diameter increases the rings move apart, and the distance between them is a maximum when $\theta=64{\cdot}2^\circ$, being 17 per cent. greater than in the case of the cylinder. When $\theta=90^\circ$, the figure is a sphere, and the distance between the rings is about 4 per cent. less than in the case of the cylinder. The sphere has a larger diameter than any other figure of critical curvature. The surface next becomes a nodoid, and the distance between the rings diminishes till when $\theta=180^\circ$ they touch, and thus the surface reduces to a circle. In the next quadrant the rings separate, but the figure is now dice-box-shaped, and the pressure exerted by the film is outwards. When $\theta=270^\circ$, the figure is the catenoid. The principal ordinate is then less than that of any other figure of critical curvature, and the radius of the rings is a mean proportion between this minimum ordinate and the maximum which was attained in the case of the sphere. The same relation holds between the principal ordinates of any two figures which correspond to values of θ which differ by 180°. In the fourth quadrant the figure becomes an unduloid, the pressure is inwards, the rings continue to separate, and the ratio of the distance between the rings to the principal ordinate is a maximum when $\theta=298^\circ$.

In the paper tables and curves are given to illustrate the 'march' of these functions.

To secure continuity the problem is discussed without reference to the question as to whether the surfaces are in stable equilibrium.

In conclusion it is shown that by means of the curves we can solve a number of problems with sufficient accuracy for practical purposes. Thus, if any two of the three quantities, the diameter of the rings, the distance between them, and the diameter of the surface of critical curvature, are given, the third can be found.

4. *A Mercurial Air-pump.* *By* J. T. Bottomley, *M.A., F.R.S.E.*

The primary object of the pump described in this paper is the removal of the mercury which works the pump from contact with the external atmosphere. When the Sprengel pump is used for producing and maintaining a nearly complete vacuum during a course of experimenting which lasts over a good many days or weeks, it is found that the mercury running down through the pump and discharging into the open air takes up minute quantities of air, which it carries with it in a state of very intimate mixture. This intimately mixed air the mercury does not lose in passing through the air-traps, but the air is deposited along the walls of the pump head, and collects into bubbles which are at first exceedingly minute, and gradually increase to a sensible size. These bubbles ultimately escape from contact with the glass and deteriorate the vacuum.

The pump described consists of a combination of a single fall Sprengel with a Geisler pump, and in addition the movable reservoir is furnished with an air-tight stopcock, by means of which the air is got rid of from that reservoir and prevented from re-entering.

In using the pump it is first worked as an ordinary Geisler pump till nearly all the air of the enclosure to be exhausted has been removed. In this way advantage is taken of the comparatively great speed of the Geisler pump. When a good exhaustion has been obtained the stopcocks and the lift of the movable reservoir are so managed that the pump is thereafter used as a Sprengel—the small remaining traces of air being pumped by the Sprengel into the exhausted chamber of the Geisler; and when a sufficient quantity of air has been collected in this chamber it can be removed by a single Geisler operation.

5. *On the Cutting of Polarising Prisms. By* Professor SILVANUS P. THOMPSON, *D.Sc.*

The author described a method of cutting Nicol prisms analogous to that communicated in 1885, the end faces being inclined at 70° to a natural face of the crystal, and having a line of mutual intersection at right angles to the natural long edges. The author also described a new method devised by Mr. Ahrens of cutting the triple polarising prism described by the author at the Aberdeen meeting. The new method of cutting effects a great saving of spar, and depends upon finding a certain characteristic plane in the crystal which defines the external longitudinal faces of the prisms.

6. *On a Varying Cylindrical Lens. By* TEMPEST ANDERSON, *M.D., B.Sc.*

A cylindrical lens of continuously varying power has long been a desideratum, and one was constructed and described by Professor Stokes, Pres. R.S., at page 10 of the Report of the British Association for 1849. He points out that—

'If two plano-cylindrical lenses of equal radius, one concave and the other convex, be fixed one in the lid and the other in the body of a small round box with a hole in the top and bottom, so as to be as nearly as possible in contact, the lenses will neutralise one another when the axes of the surfaces are parallel, and by merely turning the lid round an astigmatic lens may be formed, of a power varying continuously from zero to twice the astigmatic power of either lens.'

This very beautiful optical contrivance has the disadvantage that the refraction varies from zero in both directions at once, the refraction at any given position of the lenses being positive in one meridian, and negative or concave to an equal degree in a meridian at right angles to the first; moreover, there is no fixed axis in which the refraction is either zero or any other constant amount. It has in consequence never come into extensive use in the determination of the degree of astigmatism.

The author has planned a cylindrical lens in which the axis remains constant in direction and amount of refraction, while the refraction in the meridian at right angles to this varies continuously.

A cone may be regarded as a succession of cylinders of different diameters graduating into one another by exceedingly small steps, so that if a short enough portion be considered, its curvature at any point may be regarded as cylindrical.

A lens with one side plane and the other ground on a conical tool is therefore a concave cylindrical lens varying in concavity at different parts according to the diameter of the cone at the corresponding part. Two such lenses mounted with axes parallel and with curvatures varying in opposite directions produce a compound cylindrical lens whose refraction in the direction of the axes is zero, and whose refraction in the meridian at right angles to this is at any point the sum of the refractions of the two lenses. This sum is nearly constant for a considerable distance along the axis so long as the same position of the lenses is maintained. If the lenses be slid one over the other in the direction of their axes, this sum changes, and we have a varying cylindrical lens. The lens is graduated by marking on the frame the relative position of the lenses when cylindrical lenses of known power are neutralised.

It was found by a practical optician to be impossible to work glasses on a cone of large diameter, consequently a conical tool was constructed with an angle of 45° at the apex, and 8 inches diameter at the base.

A glass about 4 inches long was ground on the sides of this near the base, and as the resulting lens if ground on plane glass would have been too concave for most purposes, the outer side of the glass was previously ground to a convex cylindrical curve, and its axis applied parallel to the generating line of the cone in the plane of the axis of the cone.

The result was concavo-convex cylinders of varying power suitable for the practical measurement of astigmatism.

Lenses were exhibited varying from 0 to -6DCy, and from 0 to $+6$DCy.

7. *On the Law of the Propagation of Light.*
By Professor J. H. Poynting, *M.A., and* E. F. J. Love, *B.A.*

The authors describe a new method of proving that the intensity of illumination of a screen varies inversely as the square of the distance from the source. The same experimental arrangement with slight modification allows us also to prove the law of absorption of light—a law which we believe has hitherto been assumed without verification by experiment. The arrangement is as follows:—Two illuminating surfaces at different distances are viewed through a narrow blackened tube, each surface occupying half the field of view. The illuminating powers of the two surfaces are adjusted till for a given distance of the tube they appear equally bright. They then appear equally bright for any other distance of the tube. This was verified both for air and for an absorbing medium consisting of a dilute alkaline solution of phenol-phthalein, which coloured the transmitted light violet.

From this it can be shown that if I be the intensity of illumination of a screen at distance 1 from the source, the illumination at a distance x is $\frac{\mathrm{I}\,e^{-c(x-1)}}{x^2}$. When $c=0$ the medium is transparent. When c differs from 0, e^{-c} is the 'coefficient of absorption.'

8. *On a new form of Current-weigher for the Absolute Determination of the Strength of an Electric Current.* *By* Professor James Blyth.

The object of this paper is to describe a method of absolutely determining the strength of an electric current by measuring in grammes' weight the electro-magnetic force between two parallel circular circuits, each carrying the same current.

For convenience of calculation the circles have the same radius, and are placed with their planes horizontal.

The construction of the instrument is as follows:—A delicate chemical balance is provided, and the scale-pans replaced by two suspended coils of wire. Each of these is made of a single turn of insulated copper wire (No. 16 about) fixed in a groove round the edge of an annular disc of glass or brass of suitable diameter. The disc is made as thin and light as possible consistent with perfect rigidity. By means of two vertical pillars of brass this annulus is attached to a rigid cross-bar of dry wood or vulcanite, in the middle of which is placed a hook for suspending the whole from one end of the balance-beam. On each side of the hook, and equally distant from it, two slender rods of brass are screwed into the wooden bar, which support two small platinum cups for holding mercury or dilute acid. The position of these cups is so adjusted that when the whole hangs freely the cups are in line with the terminal knife-edge of the balance-beam, and have their edges just slightly above its level. The free ends of the insulated wire surrounding the disc, after being firmly tied together for a considerable length and suitably bent, are soldered to the brass supports of the platinum cups, which thus serve as electrodes by means of which a current may be sent through the suspended coil. A precisely similar coil is suspended from the other end of the balance-beam.

We now come to the arrangement by means of which a current is led through the suspended coils, so as to interfere as little as possible with the sensibility of the balance. This constitutes the essential peculiarity of the instrument, and is effected in the following way:—An insulated copper wire, having its ends tipped with short lengths of platinum, is run along the lower edge of the beam, and is firmly lashed to it by well-rosined silk thread. The ends of this wire, bent twice at right angles, are so placed that their platinum tips dip vertically into one of each pair of the platinum cups which are attached to the vertical rods of the suspended coils. From the other cup of each pair proceed two similarly tipped copper wires, which run along the upper edge of the beam, and are also firmly tied to it. These wires, however, only proceed as far as the middle of the beam, where they are bent, first outwards, one on each side of the beam, at right angles to it, and then downwards, so that the platinum tips are vertical. The latter dip into two platinum cups attached to two vertical rods, which spring from the base-board of the balance. These rods are placed at equal distances on each side of the beam, and are of such length that the platinum cups are in line with the central knife-edge of the beam, and have their edges just a little above its level. There are thus in all six cups and six dipping wires. Three of these are in line on one side of the beam, and three on the other. Also the line joining the points of each pair of dipping wires is made to coincide with the corresponding knife-edge; and, further, the edges of the cups are all in the same plane when the balance is in equilibrium.

From this it will be obvious that any motion of the beam in the act of weighing causes only a very slight motion of the platinum wires, which dip into the fluid contained in the cups. The resistance, due to the viscosity of the fluid, is thus very small, even in the case of mercury, and much smaller when dilute acid is used. In point of fact, the diminution of sensibility due to this cause is less than in the case of determining the specific gravity of solids by weighing in water in the ordinary way. With clean mercury it is quite easy to weigh accurately to a milligramme.

The fixed coils, constituting two pairs, have the same diameter as the suspended coils, and, like them, are made of single turns of insulated wire wound round the edges of circular discs of glass or brass. The discs of each pair are fixed, at the requisite distance apart, to a cylindrical block of wood, so as to have their planes exactly parallel and their centres in the same straight line. To ensure this they are turned up and finished on the same cylindrical block on which they are finally to rest. When in position they are so placed that, when the balance is in equilibrium, each suspended coil hangs perfectly free to move with its plane horizontal and exactly midway between a pair of fixed coils. For this purpose, as will be seen, it is necessary that two large holes be drilled in the upper disc of each pair, so as to allow the brass pillars of the corresponding annular disc to pass freely through. When the connections are made, the current is led through the entire apparatus in such a way that, while the electro-magnetic force acting on the one suspended coil causes it to descend, the electro-magnetic force acting upon the other causes it to ascend. The total force tending to disturb the equilibrium of the balance is thus exactly four times that due to an equal current circulating in two parallel circles of the same diameter and with their planes at the same distance apart. The current-strength is estimated from the number of grammes required to restore the balance to equilibrium, the weights being placed in small scale-pans attached to the movable part of the apparatus.

The electro-magnetic force between each fixed and the corresponding suspended coil is calculated from the formulæ given by Clerk Maxwell (vol. ii. p. 308), viz.:—

$$\frac{dM}{db} = -2\pi \cos\gamma \left\{ 2F_\gamma - (1+\sec^2\gamma)E_\gamma \right\}$$

where M = the potential energy between two parallel circles, each carrying unit current,

b = distance between their planes,

a = radius of each coil,

$$\sin\gamma = \frac{2a}{\sqrt{4a^2+b^2}},$$

F_γ and E_γ = first and second complete elliptic integrals to modulus $\sin\gamma$.

In one of the instruments constructed

$$a = 10{\cdot}8 \text{ inches}, \; b = {\cdot}566 \text{ inch},$$

which give

$$\gamma = 87^\circ, \; F\gamma = 4{\cdot}338653976, \; E\gamma = 1{\cdot}005258587;$$

from which, if G denote the constant of the instrument and $g = 981$, we have

$$G = 4 \, . \frac{dM}{db} \, . \frac{1}{g} = {\cdot}4818.$$

This gives for 1 ampère a force = ·04818 gramme weight.

Besides the one exhibited I have constructed several modifications of the instrument, only one of which, however, need be particularly mentioned. In it both the fixed and movable coils are replaced by flat spirals of wire, each of eleven turns. Here the practical construction is more difficult, and the calculation of the constant somewhat more laborious, unless one is content with merely integrating over the area of both the fixed and suspended spirals. This is, I think, however, hardly legitimate, at least with thickish wires, as we thereby suppose that electricity is circulating in the insulating spaces between the wires as well as in the wires themselves. To avoid this I have actually calculated the force exerted by each one of the coils of the fixed spiral upon each coil of the suspended spiral. This entails great labour, as the elliptic integrals have to be calculated for values of the modulus differing very slightly from each other. The labour, however, is worth the taking, as the attractive or repulsive force between two flat spirals is so much greater than that between two simple circles.

9. *On the Proof by Cavendish's Method that Electrical Action varies inversely as the Square of the Distance.* *By* Professor J. H. Poynting, *M.A.*

The proof of the law of electrical action depending on the fact that there is no electrification within a charged conductor was first given by Cavendish. His proof was made more general by Laplace, who has been followed by other writers, including Maxwell. Maxwell and MacAlister have also verified the experimental fact, repeating an investigation of Cavendish only recently published in Maxwell's edition of the Cavendish papers. The proof may be analysed in the following way:—Take the case of a uniformly charged sphere. The action at a point within it may be considered as the resultant of the actions of the pairs of sections of the surface by all the elementary cones, with the point as vertex. If, then, the resultant action is zero for all points and for all sizes of the sphere, it follows that the action of the pair of sections by each elementary cone is zero; and, since the sections of the surfaces are directly as the squares of the distances, the two sections neutralising each other, the force per unit area must be inversely as the squares of the distances. There appear to be two objections to this proof. (1) That it takes no account of the always existing opposite charges. When the sphere, for instance, is positively charged, an equal and opposite negative charge is on the walls of the room, and the action of this should be considered. Probably this objection could be removed. (2) There is a solution still simpler than the inverse square law—viz., that no element of the surface has any action within the closed conductor. If we suppose that a conductor is a complete screen to electrical action, then, whatever the law of the force exerted across an insulator, there will be no action within the conductor. In any null proof it is not sufficient merely to show that there is no action in the null arrangement, but it is also necessary to show that on disturbing the null arrangement some action is manifested. Now, in the case here considered it is impossible to obtain any action within the conductor in any statical arrangement; it is only during changes of the system while charging or discharging that we can get a disturbance of the null arrangement. But here new phenomena come in, for we have currents, and therefore electro-magnetic action. But, even disregarding the different kind of action occurring, the only experiment which I know of on this point was that of Faraday with his electrified cube. While the most violent charges and discharges were taking place on the outside of the cube, so that the null arrangement was probably disturbed, he found no action on his electroscope within. Possibly the actions were alternating, and so rapid that no electroscope of ordinary construction would reveal them. But he himself went into the cube, and he would probably be sensitive to rapidly alternating electromotive forces. It appears to me, then, that we cannot accept this proof, and must fall back upon the more direct proof of Coulomb. I do not know whether Maxwell was aware of this objection; but it is worthy of note that in the remarkable fragment published since his death, as 'An Elementary Treatise on Electricity,' he returned to Coulomb's proof, and was apparently building up the mathematical theory of electricity in a way quite different from that followed in his larger work.

10. *On the Electrolysis of Silver and Copper, and its Application to the Standardising of Electric Current- and Potential-Meters.* *By* THOMAS GRAY, *B.Sc., F.R.S.E.*[1]

This paper contained an account of a large number of experiments on the electrolysis of silver and copper, and its application to the standardising of electrical current- and potential-meters which have been made during the past year in the Physical Laboratory of Glasgow University. It forms a summary of the reports made from time to time to Sir William Thomson on this subject.

In the earlier experiments pure silver sheet and solutions of pure silver nitrate were used for the electrolytic cells. The results obtained with these cells confirmed those obtained by Kohlrausch, Lord Rayleigh, and other observers as to the great accuracy obtainable with silver, and also as to the nature of the deposit and the care required in the manipulation of the experiment. The cathode plate consisted in almost all cases of a sheet of pure silver, placed, with its plane vertical, between two parallel sheets of the same metal. In a few experiments a platinum bowl was used very much in the same manner as that described by Lord Rayleigh in his paper to the Royal Society, but generally the plates of sheet silver were preferred. The mode of treating the plates both before and after the deposit was upon them is fully described, and it is pointed out that when the plate is made thoroughly clean, and its size properly proportioned to the strength of the current to be measured, the deposit is finely crystalline, and adheres very firmly to the plate. The best results were obtained when the current density at the cathode is between $\frac{1}{200}$ and $\frac{1}{600}$ of an ampère per square centimetre of the surface on which the deposit is taking place, the solution being supposed to contain five per cent. of silver nitrate. It is also pointed out that the loss of silver from the anode can be used satisfactorily as a check on the amount of silver deposited on the cathode, but that the current density at the anode must be considerably smaller than that which will give good deposits on the cathode. About $\frac{1}{400}$ of an ampère per square centimetre is stated as the maximum current density at the anode which can be safely used if the loss of silver is to be weighed. A somewhat greater current density may be used at the cathode if the strength of the solution be increased, but the deposit is more roughly

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[1] Published in full in the *Phil. Mag.* for Nov. 1886.

crystalline and less adherent. The current density cannot be increased in nearly the same proportion as the increase in the amount of silver nitrate in the solution, and hence when sheet silver cathodes are used the most economical and most satisfactory method is to use weak solutions and large plates. Rolled silver gives unsatisfactory results until the outside skin has been removed by use, polishing, or scraping.

The later experiments described in the paper refer for the most part to copper, and include experiments on the uncertainty likely to arise from oxidation of the plate in drying, and while in the solution; the effect of the loss of weight due to direct chemical corrosion of the plate; the effect of density of solution; of size of plate, or current density; and of the addition of acid to the solution. It was found that there is no difficulty in washing and drying a plate without oxidising it sensibly, and methods are described for doing this. The loss of weight by corrosion in the liquid introduces an error which is nearly proportional to the surface of the plate exposed, and judging from Dr. Gore's experiments it is also no doubt influenced by the temperature, if that be not constant; but the effect of temperature was not investigated. The amount of corrosion is also influenced to some extent by the density of the solution, and it appears to be least when the density is between 1·15 and 1·10. It is concluded that in the use of copper for standardising purposes the current density and the density of the solution must be known, and the proper correction made on the electro-chemical equivalent to suit the particular circumstances. If this be attended to, copper is capable of giving results within a tenth per cent. of accuracy, and is much more easily managed than silver. Silver is preferable for the highest accuracy, but the accuracy which copper is capable of giving is easily obtained, and it seems sufficient for most practical purposes.

Experiments on the ratio of the electro-chemical equivalent of copper to that of silver were also made, and led to the conclusion that when the proper correction for corrosion in the liquid is made the ratio is very nearly 0·2942, which, on the assumption of ·001118 as the mass in grammes of the silver deposited by one coulomb of electricity, gives for the corresponding number for copper ·0003290.

When a nearly saturated solution of copper sulphate is used, and a current density of $\frac{1}{50}$ of an ampère per square centimetre of the cathode, the amount of copper deposited by a coulomb of electricity is ·0003287 gramme.

It is pointed out that if the solution does not contain free acid there is a danger of obtaining too great an increase of weight, due apparently to the oxidation of the copper as it is being deposited. The same remark as that made above with regard to the silver anodes applies to the copper anodes if they are to be weighed. If the copper anodes are so small as to give a current density exceeding about the fortieth of an ampère per square centimetre the current is liable to stop almost completely, even when an electromotive force of as much as 25 volts is used to produce it: this is apparently due to excessive resistance at the surface of the anode. After a few minutes the current will again resume nearly its old strength, and gases will be given off freely at the anodes. These gases are readily dissolved by the liquid, and generally as the final result the gain and loss of copper do not differ very greatly—although they always do differ—from those obtained when no gases are given off.

Lastly, the arrangements of one of the standardising tables in Sir William Thomson's laboratory are illustrated, and the different pieces of apparatus and the mode of using them described.

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11. *Description of a new Calorimeter for lecture purposes.* *By* T. J. Baker.

The instrument consists of two exactly similar metallic air-thermometers mounted side by side with their U-shaped thermometer-tubes adjacent, so that their indications can be easily compared with each other.

The air-vessel of each thermometer contains a cylindrical well, in which the substance to be experimented with is immersed. Each well is provided with a discharging tube furnished with a stopcock. The scale common to both thermometers is of milk-glass, divided into 100 equal parts, both above and below zero, and let into the stand so as to constitute a translucent window which can be illuminated from behind.

By means of this instrument many thermal problems can be demonstrated before a large audience.

FRIDAY, SEPTEMBER 3.

The following Papers and Report were read:—

1. *On the Physical and Physiological Theories of Colour-vision.*
By Lord Rayleigh, *D.C.L., LL.D., Sec.R.S.*

2. *The Modern Development of Thomas Young's Theory of Colour-vision.*
By Dr. Arthur König.—See Reports, p. 431.

3. *On the Physical and Physiological Theories of Colour-vision.*
By Professor Michael Foster, *M.D., Sec.R.S.*

4. *On Hering's and Young's Theories of Colour-vision.* *By* John Tennant.

The author briefly pointed out that, for the purposes of experiments in colour-mixture, Hering's theory, like Young's, has only three independent variables, and leads to the same *general* results.

The author then considered the subject of simultaneous contrast, and showed that the only possibility of a deception of the judgment lies in the fallibility of the memory. Hence if two patches of the same grey (say) be seen simultaneously they ought, according to the psychological explanation, to appear the same whatever their surroundings. This he showed, by an experiment with discs, is not the case. Hence simultaneous contrast is a real and not an illusory effect, and demands a physiological explanation.

The author, however, pointed out that there may be illusions of judgment in these cases owing to our habit of attributing permanence to local colour, and that this may account for some of the experiments which have been adduced in favour of the psychological explanation.

The author then considered some of the difficulties of Hering's theory, noticing—

1. That pure red and green are not complementary, as they should be.
2. A difficulty raised by Rood as to the relative intensity of a compound grey and its components.

Lastly, the author considered the subject of changes of hue under varying intensity of light. He showed that if we assume that the functional processes of assimilation and dissimilation supposed by Hering draw their materials from, and contribute them to, a common source in the blood, it is natural to suppose that they are not wholly independent.

He supposed yellow and green to correspond to the dissimilating blue, and red to the assimilating processes in their respective substances. He further supposed the red-green substance to be the most sensitive to drafts upon the common stock. These suppositions are found not only to explain the variations of hue with varying intensity of light, but also that tendency of colours when mixed with white light towards reddish violet, which has received no explanation from current theories.

The author, without accepting Hering's theory as established truth, thought it the best working hypothesis in the immediate future.

5. *Second Report of the Committee on Standards of Light.*—See Reports, p. 39.

6. *Thermopile and Galvanometer combined. By* Professor GEORGE FORBES.

7. *On the Intensity of Reflection from Glass and other Surfaces. By* Lord RAYLEIGH, *D.C.L., LL.D., Sec. R.S.*

8. *A Note on some Observations of the Loss which Light suffers in passing through Glass. By* Sir JOHN CONROY, *Bart., M.A.*

The object of the experiments was to determine the percentage of light which passed through plates of glass of the same kind but of different thickness. The amount reflected from the first surface would be the same in all cases, and, assuming, as is usually done, that the same percentage of the incident light is reflected from both surfaces, the amount reflected from the second surface would be nearly the same—the difference in the amount of light which reached the second surface, owing to the increased absorption in the thicker plates, being but slight. It was therefore thought that this method would afford a means of determining not only the amount reflected, but also the amount absorbed, without assuming the truth of the formulæ for reflection.

A photometer, similar to that described in Pickering's 'Physical Manipulation' (pt. i. p. 132), was used for most of the observations; but measurements were also made with a polarising photometer, and also with another arrangement, in which of two white surfaces illuminated by the same lamp, one was seen directly, and the other through the glass. If atmospheric absorption be neglected, which at such distances is of course insensible, the apparent brightness of an illuminated surface does not vary with the distance; no correction was therefore needed with this instrument for the optical shortening of the path of the ray, owing to the refractive power of the glass, which had to be allowed for in the experiments made with the first-mentioned photometer.

The experiments were made with plates of Messrs. Chance's lighthouse glass, varying in thickness from 6·5 to 24 millimetres, and with Field's ordinary dense flint, from 7 to 91·3mm. thick. With Messrs. Chance's glass the transmitted light ranged from 91·50 to 87·16 per cent., and with the flint-glass from 88·83 to 80·74 per cent.

The experiments are incomplete, and are being continued.

9. *On an Experiment showing that a Divided Electric Current may be greater in both branches than in the mains. By* Lord RAYLEIGH, *D.C.L., LL.D., Sec. R.S.*

SATURDAY, SEPTEMBER 4.

The Section did not meet.

MONDAY, SEPTEMBER 6.

The following Reports and Papers were read:—

1. *Report of the Committee for preparing instructions for the practical work of Tidal Observation.*—See Reports, p. 40.

2. *Fourth Report of the Committee for the Harmonic Analysis of Tidal Observations.*—See Reports, p. 40.

3. *Report of the Committee appointed to co-operate with the Scottish Meteorological Society in making Meteorological Observations on Ben Nevis.*—See Reports, p. 58.

4. *Third Report of the Committee appointed to co-operate with Mr. E. J. Lowe in his project of establishing on a permanent and scientific basis a Meteorological Observatory near Chepstow*—See Reports, p. 139.

5. *Second Report of the Committee for considering the best means of Comparing and Reducing Magnetic Observations.*—See Reports, p. 64.

6. *Third Report of the Committee for considering the best methods of Recording the direct Intensity of Solar Radiation.*—See Reports, p. 63.

7. *The peculiar Sunrise-Shadows of Adam's Peak in Ceylon.*

By the HON. RALPH ABERCROMBY, *F.R.Met.Soc.*

A great peculiarity has been noticed by many travellers about the shadow of Adam's Peak at sunrise. The shadow, instead of lying flat on the ground, appears to rise up like a veil in front of the spectator, and then suddenly to fall down to its proper level. Various theories have been propounded to account for this, and it has usually been supposed to be due to a sort of mirage. The author, in the course of a meteorological tour round the world, spent a night on the top of the peak, 7,352 feet above the sea, and obtained unmistakable evidence that the appearance is due to light wreaths of thin morning mist being driven past the western side of the mountain by the prevailing north-east monsoon up a neighbouring gorge. The shadow is caught by the mist at a higher level than the earth, and then falls to its own plane on the ground as the condensed vapour moves on. The appearance is peculiar to Adam's Peak; for the proper combination of a high isolated pyramid, a prevailing wind, and a valley to direct suitable mist at a proper height on the western side of a mountain, is only rarely met with. Any idea that the appearance could be caused by mirage is completely disproved by the author's thermometric observations.

Another curious but totally distinct shadow effect is sometimes seen from Adam's Peak just before and at the moment of sunrise. The shadow of the base of the peak stretches along the land to the horizon, and then the shadow of the summit appears to rise up and stand against the sky. The first part seems to be the natural shadow lying on the ground, and the sky part to be simply the ordinary earth shadow of twilight, so clearly projected against the sky as to show mountainous irregularities of the earth's surface. As the sun rises the shadow of the summit against the sky gradually sinks to the horizon, and then the ordinary shadow steadily grows shorter as the sun gets higher in the usual manner.

The author found a similar effect only at sunset on Pike's Peak, Colorado. Towards sunset the shadow creeps along the prairie to the horizon, and then begins to rise in the sky till the sun has just gone down, and the anticrepuscular shadow rises too high to catch the outline of the Peak.

8. *On the Distribution of Temperature in Loch Lomond and Loch Katrine during the past Winter and Spring.* *By* J. T. MORRISON, *M.A.*

The author made observations on the temperature of these lakes on or about the term day of each month from December 1885 to June 1886, in continuation of Mr. J. Y. Buchanan's researches. These included the whole length of Loch Katrine and the head and middle part of Loch Lomond, the deepest sounding, 99 fathoms, being got near Inversnaid in the latter lake.

At Inversnaid, from December till March, the water was each month of uniform temperature from surface to bottom, the temperatures being—

Dec. 22, 1885 .	. 42·8°
Jan. 21, 1886 .	. 41·2°
Feb. 23, 1886 .	. 40·05°
March 23, 1886 .	. 39·05°

In the deepest sounding obtained on Loch Katrine, 79 fathoms, a similar distribution was met with up till February, the readings being—

Dec. 23, 1885 .	. (42·3°)[1]
Jan. 22, 1886 .	. 40·4°
Feb. 24, 1886 .	. 39·0°

And, though the maximum density point was thus attained in February, uniformity still prevailed in March down to a depth of 70 fathoms, the readings on March 24 being: surface, 38·1°; 70 fathoms, 38·1°; 79 fathoms, 38·7°.

In April the temperature distribution usually found in spring had set in in both lakes, the surface being warmest, the bottom coldest, and the temperature falling more and more slowly with increase of depth. The circumstance of most interest, however, is that the warmth of the bottom layer increased monthly over the deepest parts of both lakes, as follows:—

	Mar.	April	May	June
Loch Lomond (99 fathoms) . .	39·05°	39·4°	40·3°	40·6°
Loch Katrine (79 fathoms) . .	38·7°	39·1°	40·1°	40·65°

This rise is evidently due not to the conduction of heat nor to the penetration of solar radiation, but to some drainage or oozing causing mixture. This supposition seems necessary also to explain the behaviour of Loch Katrine in March. Drainage *en masse* appears to occur chiefly in winter and spring, not in summer when the river water and the lake surface water are much warmer than the deep water of the lake.

The mean temperature of Loch Katrine probably has a greater range than that of Loch Lomond.

The shallower parts of the lakes resemble the deep parts as to uniformity of temperature up till March. But their yearly range is greater. In both lakes the mean temperature becomes uniform along the whole length about April 4.

9. *On the Distribution of Temperature in the Firth of Clyde in April and June* 1886.

By J. T. MORRISON, *M.A.*

In the latter parts of April and June of this year Mr. John Murray, Dr. Mill, and the author made serial temperature soundings throughout the Clyde district, chiefly with Negretti and Zambra's reversing thermometer.

It was found that in matter of temperature the waters of the district were divisible into four groups: I. North Channel and the plateau south of Arran; II. The Arran and Dunoon open basins; III. The deep sea lochs; IV. The shallow sea lochs. The average temperature in each group at every depth was calculated for April and June, and these averages form the basis of this paper.

In April in all groups there is a deep layer of uniform temperature overlaid by a layer of temperature rising steadily to the surface. In groups II., III., and IV. the uniform deep temperatures are almost the same, about 41·4° F.; in group I. it is 41·8° F.

In June the superficial layer of varying temperature had thickened to about 20 fathoms. The deep temperatures in the groups were now very different:—

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[1] No sounding made here in December. Above temperature is calculated from that of another part of the lake.

	I.	II.	III.	IV.
Deep temperature in April	41·8°	41·3°	41·5°	41·5°
" " June	46·7°	43·9°	43·8°	45·3°[1]
Rise of temperature	4·9°	2·6°	2·3°	3·8°

To groups III. and IV. analogues are found in a deep and a shallow basin of Loch Lomond, in both of which the bottom temperature rose between April and June. From this it is inferred that land-influences, especially drainage *en masse*, produce most of the effect noticed in III. and IV.

The great rise in the North Channel and southern plateau is evidently due to a warm oceanic current.

The rise in temperature in group II. is due to the incoming of warm water from without. As the water between 30 and 75 fathoms in this group is very uniform in temperature, and as the south plateau is 25 fathoms below the surface, it is supposed that the dense plateau water is carried into the open basins (group II.), and through convection mixes thoroughly the water below 30 fathoms there.

Loch Goil is specially remarkable for its isolation and the small rise of bottom temperature—0·6° F. in two months.

In Upper Loch Fyne a lenticular mass of water below 43·0° F. was found in June to float between two warmer layers. Its greatest thickness, 30 fathoms, was opposite Inverary. The bottom layer of 44·0° F. was not found to be in connection with any equally warm layer either inside or outside of the loch.

10. *On the Temperature of the River Thurso.*
By Hugh Robert Mill, *D.Sc., F.R.S.E., F.C.S.*

Temperature has been observed since October 1885 twice daily at three points on this the earliest salmon river in the north of Scotland. A shallow feeding lake nineteen miles from the sea, a point twelve miles from the sea, and one near the river mouth, were selected for observations. At any given time the different parts of the river preserved nearly the same temperature, varying slightly according to the amount of sunshine and direction of the wind. The water cooled down from October to January, and rose steadily in temperature as the season advanced. Diurnal variation was least in January, and increased during each subsequent month. The water, colder than the air at the time of observation during winter, became warmer than it in summer. Shallow water responds more rapidly than air to sun-heating and to chilling by radiation, a fact accountable for by its greater absorbing and conducting powers. The sea was warmer than the river during winter, and cooler than it during summer.

Most of the observations discussed were made by Mr. John Gunn, Dale, and Mr. David Gunn, Thurso.

11. *On the Normal Forms of Clouds.* *By* A. F. Osler, *F.R.S.*

The object of this paper is to explain a theory with regard to the principles that may have the greatest effect in producing the *leading* forms that clouds assume.

There are doubtless many *additional* influences that produce or propagate *further* changes and variations in these forms, but which may be regarded as exceptional or occasional, through frequent disturbances of the regular action herein specially referred to. These remarks will therefore be confined to those influences and conditions that may be regarded as constant and uniform in their effects within certain limits. They are simple and recognised physical causes, varying only in amount and intensity. They may be classed under three heads:—

1st. The diminished specific gravity of the air when more or less charged with invisible vapour.

2nd. The differential horizontal motion of the atmosphere.

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[1] Average temperature of first few fathoms above bottom.

3rd. The *vertical* motion in the atmosphere produced by the heat of the sun's rays expanding the lower air.

The first of these is universally recognised as the initial cause of all clouds, producing the *cumulus*, the firstborn or primary cloud. Its origin is so well understood that it is unnecessary to enter on the subject further than is required to make the remarks that follow more intelligible or complete.

Water, or moisture on the earth's surface, is evaporated by the sun's rays, and enters the adjoining atmosphere. Vapour being specifically much lighter than the air rises more or less rapidly, according to the rate of evaporation. In this climate it has *not* to ascend to any great elevation before the upper portion arrives in a colder and more attenuated condition of the atmosphere, where it becomes condensed, but where the lower and flatter portion of the condensed vapour with the uncondensed invisible vapour immediately beneath terminates, it is *not* possible to say, as a certain amount of the invisible vapour often extends to the earth's surface. All that can with certainty be asserted is that a large mass or bed of air charged with vapour must exist immediately beneath the newly formed cloud or it could not have risen, an amount of floating power being necessary to lift the *condensed* vapour or cumulus into a cold atmosphere, where it becomes visible. Yet when it has been so raised the friction of the surfaces of the minute globules of water of which it is composed render them unable to penetrate or force themselves downwards through the air below, or but very slowly. It is therefore only in first raising or lifting up the condensed vapour that the floating power of the uncondensed or invisible vapour beneath is required, and not in sustaining it when raised.

The *invisible* vapour, however, that has raised the cumulus or crowning head of condensed vapour, will itself become visible should the atmosphere in which it is travelling become reduced in temperature by any of the cooling influences to which it may be exposed in its travels.

The lower atmosphere being always charged with more or less vapour, the cumulus can only be formed when there is so much vapour generated as to float above condensation height.

Thus far a calm is presumed to prevail.

When, however, the atmosphere is in motion its differential horizontal movement produces the first important modification in the form of the cumulus, the height or depth of the lower current varies, and in this climate will generally much more than include the cumulus or condensation height in these latitudes. The friction of the earth from the irregularities of its surface, and the denser state of the lower air, causing it to flow less rapidly than that which is higher and more attenuated, the upper portion of a cloud moves more rapidly than the lower, and the cumulus shears over into a slanting position, and finally assumes the form of the cumulo-stratus, and, however reduced in depth or thickness the cloud may become by this flattening and somewhat attenuating process, the cumulus character, though much diminished, is seldom if ever entirely obliterated.[1] A young cloud is thus distinguishable from a long-travelled one; indeed, one that has gone but a short distance is detectable.

In this climate a large well-developed cumulus is seldom formed in the cold season, but they are frequent in the summer. The majority of the clouds of the first stage seen in this country are born in warmer latitudes, and come as travelled cumuli, and show more or less the condition of the cumulo-stratus. They may be enlarged or diminished from below, and also diminished or increased in number, according to the heat or dryness or dampness they meet with during their passage over the surface of the earth or sea, but my object is not to treat of cloud generation but only to suggest reasons for certain leading forms they assume after birth.

The *invisible* vapour, however, is subjected to the same changes of form due to

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[1] Those who have been much on the sea may probably remember occasionally seeing a large flat brown cloud of smoke in the not remote distance, that has been discharged by a previously passing steamer. This came forth from its funnel in great rounded masses far removed from a flat form. The differential action is thus most clearly and simply illustrated in the change that has taken place since its discharge.

differential motion previous to its becoming visible, but in this climate it soon rises to the small height at which it is condensed.

In summer, when the air is in sufficient motion, and especially in tropical climates, it may travel long distances in its invisible or gaseous state, so that it has time to become elongated by differential action, and when condensed it at once assumes the form of the true *stratus*, in which case it is not seen as a cumulus or cumulo-stratus at all. When it has risen to condensation height its lines more approach the horizontal, are clearly defined, and the irregularities that would be curves under more rapid decrease of temperature at an earlier stage are seen as elongated lines extending to points as the pure stratus.[1]

We will now leave the lower and denser atmosphere which contains the cumulus, cumulo-stratus, and stratus, and proceed to examine the next stratum above. We here find that a rather rapid change takes place to a drier atmosphere, as was proved by Mr. Glaisher's investigations regarding the dew-point in his balloon ascents. It is almost like starting from a new globe, and the vapour of this drier air does not become visible until a higher altitude is attained, where this diminished quantity arrives at *its* level of visibility. Here the vapour is less disturbed and carried for great distances, so that at the region of this attenuated vapour the cloud is generally level. The cumulus and cumulo-stratus have never reached this elevation, and we have instead the cirro-cumulus and cirro-stratus. The differential movement of the atmosphere, however, though much diminished, is still an important agent in its results, and effects are produced that are not possible in the more bulky and dense clouds of the lowest range. The clouds are, at this higher level, in a highly attenuated condition, and if the globules of vapour are too small in the lower clouds to break through the air that separates them, or even to descend, they are still less capable of doing so at a greater altitude, where they must be still more minute; but though they can neither coalesce nor descend, they can be spread out gently by the differential action, or if *rapidly expanded* from beneath, *broken up* into groups, larger or smaller according to the depth and density of the stratum.

Now, suppose the heat of the sun to have caused the lower atmosphere to expand considerably, the effect of it will be to lift up and spread the whole of the superincumbent air, and with it the thin upper stratum of cloud, further from the earth. The result of the *vertical elevation* or *secondary action* will be to *rend it asunder*—the uplifted air becomes more attenuated as it rises, and will spread out in all directions, and the flat cloud we are supposing to exist will of course do the same; but in so doing will be rent into fragments or small groups, and thus produce what is called a 'mackerel sky,' just as a similar result is produced, but by the reversed action, in mud that has dried up and shrunk into small patches, while the damp earth beneath remains expanded by the moisture it still contains. Should, however, the expansion in the lower atmosphere take place *very slowly*, it is *possible* that the stratum of cloud may remain intact, and not be actually ruptured; the result would then be to spread out and attenuate the cloud as a whole; all these effects are supposed to take place in a still or very slowly moving atmosphere, but supposing the same conditions take place in an atmosphere in rapid motion or current of air, the tendency will be to elongate the cloud or group of clouds in the direction in which the current is moving, and for this reason: the air is of course going to where it is in demand, it is finding its equilibrium somewhere; that which is nearest the region requiring it will move forward fastest, that which is immediately behind will follow with diminishing velocity, as it is further from the demand, the result being to elongate the stream. Let it be supposed that a thin cloud is in a current, it will have the same elongating influence communicated to *it*—this, *if accompanied with expansion from below*, will rupture the cloud into ribs or bars at right angles to the current; if, however, it is continuous *but without* expansion from below, the reverse action will take place, and longitudinal bars will be formed in the direction of the current. When, however, the main portion of a cloud is in a

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[1] In tropical or semi-tropical climates where the invisible vaporised moisture travels furthest the stratus is a most striking and important cloud, and is often very conspicuous in the evenings towards sunset as the air becomes cooler.

stationary state or moving but slowly, and a quicker current catches a portion of it, larger or smaller filaments that may be prominent are drawn out in what are popularly called 'mares-tails:' but this applies more to lower and denser clouds; indeed, it will be observed that the upper stratum of clouds generally is modified by conditions which do not sensibly affect the lower and denser clouds; their attenuated state shows the effects of vertical action as affecting their forms in a striking manner, as well as the influence of varying velocity in horizontal motion.

The principal clouds in this latitude come from the S.W., W., and N.W., and the air from these points moves most rapidly; the S.W. is much the fastest as well as the most prevalent. It is a particularly *rough* and *gusty* stream, derived from the heated tropical air which rises and is piled up as it were to a great elevation. This as it flows away has to push that which is in advance of it until it has established a stream; the supply of air being more rapid than the outflow or diffusion causes the elastic air to move in irregular gusts or masses, and hence the peculiar *violence and lulls* alternating in the manner so well known. This stream descends to the surface of the earth in the temperate zone, the latitude varying with the seasons.

The more northerly and easterly currents are *smooth*, flowing to fill up the deficiencies caused by the upward movement of the heated air, or by condensation of vapour, by the fall of rain, or by eddies that carry the lower air into the higher regions of the atmosphere, and by cyclones of various dimensions.

The principles here set forth are only applied to *two* stratifications of clouds, an upper and a lower one, but of course the same results are obtained in a larger number of strata; it is only for simplicity of description and illustration that no more than two are mentioned.[1]

12. *On a new Sunshine Recorder.* *By* W. E. WILSON.

The instrument consists of two parts, one of which, the indicator, is affected by the sunshine, and the other of which registers the indications. The former, or indicating apparatus, is a differential metallic thermometer, made of a spiral of two metals (zinc and steel) soldered together. Half of the spiral is a right-handed one, and the other half is left-handed. The complete spiral is fixed at its upper end. At its lower end a lever or pointer is attached. The upper half or right-handed portion of the spiral projects through the roof of a ventilated box, and is exposed to the sunshine. The lower or left-handed half is in the shade. Any change in the temperature of the air does not cause the lever or pointer to move, as the upper half of the spiral tends to move it as much in one direction as the lower half tends to move it in the other. When the sun shines on the exposed upper half the lever moves over and completes an electric circuit, which passes through the recording part of the apparatus.

The recorder consists of a drum driven by a clock. The drum revolves once in twenty-four hours, and is mounted on an axis with a screw of ten threads to an inch which turns in a nut. This gives the drum a longitudinal motion of $\frac{1}{10}''$ as well as its motion of rotation. The clock makes an electric contact once every minute, and the electric circuit is led through an electro-magnet which causes a pricker to strike the drum when the circuit is complete. The circuit, as previously mentioned, is led through the lever of the bimetallic indicator, and the circuit is only closed when the sunshine causes the lever to do so. When the circuit is complete the electro-magnet pricks off dots every minute, which represent so many minutes of sunshine. The drum is of such a length that it holds the daily record of sunshine for three months.

The instrument also is made to give the total time during which the sun shone in the day. The hands of the clock are not driven by it, but by an electro-magnet which works a ratchet. The electric current is led through this magnet as well as the one that works the pricker, so that as the pricker records minutes of sunshine on the drum, the hands of the clock move forward in intervals of minutes. At the

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[1] The nimbus, or rain cloud, and all other varieties and combinations, or those under electrical agencies, also eddies or whirl-storms of all sizes, are outside the object of this paper.

end of the day the clock shows the number of hours and minutes of sunshine for the day. A note is then made of the recorded total, and the hands put back to zero again.

The drum is covered with 'cyclostyle' paper, and after the three months' record is complete it is removed and put in a frame, under which can be placed ordinary white paper. Printer's ink is then rolled over it, and a great many copies of the original record can thus be printed for distribution. I think it might be of interest to print several yearly copies on the top of each other on the same paper. By the general resulting degrees of light and shade we should be able to see if there were any periods in the year which were liable to more sunshine than others.

13. *Second Report of the Committee for promoting Tidal Observations in Canada.*—See Reports, p. 150.

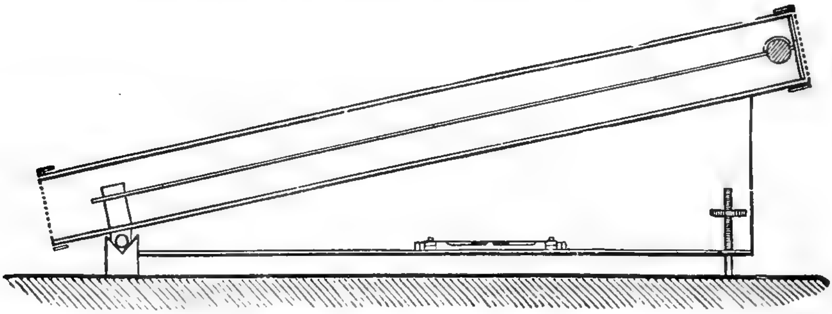
14. *Report of the Committee for inviting designs for a good Differential Gravity Meter.*—See Reports, p. 141.

15. *Description of a Differential Gravity Meter founded on the Flexure of a Spring. By* Sir W. Thomson, *LL.D., F.R.S.*

The design and construction of the instrument now to be described was undertaken on the suggestion of General Walker, of the East Indian Trigonometrical Survey. At the Aberdeen Meeting of the British Association in 1885, General Walker obtained the appointment of a committee to examine into the whole question of the present methods and instruments for the measurement of gravitational force, and to promote investigation, having for its object the production of gravitation-measuring instruments of a more reliable and accurate character than those now in use.

The secretary of this committee, Professor Poynting, has already issued a circular note to the members of the committee (of whom the author is one), stating the conditions which must be fulfilled by any gravimeter laid before the committee for examination and report.

An instrument, constructed according to the following description, promises to fulfil all the conditions mentioned in Professor Poynting's circular. Its sensibility is amply up to the specified degree. It is, of necessity, largely influenced by temperature, and it is not certain that the allowance for temperature, or the means which may be worked out for bringing the instrument always to one temperature, will prove satisfactory. It is almost certain, although not quite certain, that the constancy of the latent zero of the spring will be sufficient, after the instrument has been kept for several weeks or months under the approximately constant stress under which it is to act in regular use.



Front elevation, with one-half of Tube removed.

The instrument, which is represented in the accompanying sketch, consists of a thin flat plate of springy german silver of the kind known as 'doctor,' used for scraping the colouring matter off the copper rollers in calico printing. The piece used was 75 centimetres long, and was cut to a breadth of about 2 centimetres. A brass weight of about 200 grammes was securely soldered to one end of it, and the spring was bent like the spring of a hanging bell, to such a shape that when held firmly by one end the spring stood out approximately in a straight line, having the weight at the other end. If the spring had no weight the curvature, when free from stress, must be in simple proportion to the distance along the curve from the end at which the weight is attached, in order that when held by one end it may be straightened by the weight fixed at the other end.

The weight is about 2 per cent. heavier than that which would keep the spring straight when horizontal; and the fixed end of it is so held that the spring stands, not horizontal, but inclined at a slope of about 1 in 5, with the weighted end above the level of the fixed end. In this position the equilibrium is very nearly unstable. A definite sighted position has been chosen for the weight, relatively to a mark rigidly connected to the fixed end of the spring, fulfilling the condition that in this position the equilibrium is stable at all the temperatures for which it has hitherto been tested; while the position of unstable equilibrium is only a few millimetres above it for the highest temperature for which the instrument has been tested, which is about 16° C.

The fixed end is rigidly attached to one end of a brass tube, about 8 centimetres diameter, surrounding the spring and weight, and closed at the upper end of the incline by a glass plate through which the weight is viewed. The tube is fixed to the hypotenuse of a right-angled triangle of sheet brass, of which one leg, inclined to it at an angle of about 1/5 radian, is approximately horizontal, and is supported by a transverse trunnion resting on fixed V's under the lower end of the tube, with a micrometer screw under the short, approximately vertical, leg of the triangle.

The observation consists in finding the number of turns and parts of a turn of the micrometer screw, required to bring the instrument from the position at which the bubble of the spirit-level is between its proper marks, to the position which equilibrates the spring-borne weight, with a mark upon it exactly in line with a chosen divisional line on a little scale of 20 half-millimetres, fixed in this tube in the vertical plane perpendicular to its length.

The instrument is, as is to be expected, exceedingly sensitive to changes of temperature. An elevation of temperature of 1° C. diminishes the Young's modulus of the german silver so much that about a turn and a half of the micrometer screw (lowering the upper end of the tube at the rate of 2/3 millimetre per turn) produces the requisite change of adjustment for the balanced position of the movable weight. About $1\frac{1}{3}$ turn of the screw corresponds to a difference of 1/5000 in the force of gravity, and the sensibility of the instrument is amply valid for 1/40 of this amount; that is to say, for 1/200,000 difference in the force of gravity. Hence it is not want of sensibility in the instrument that can prevent its measuring differences of gravity to the 1/100,000; but to attain this degree of minuteness it will be necessary to know the temperature of the spring to within 1/20° C. I do not see that there can be any great difficulty in achieving the thermal adjustment by the aid of a water jacket and a delicate thermometer. To facilitate the requisite thermal adjustment I propose, in a new instrument of which I shall immediately commence the construction, to substitute for the brass tube a long double girder of copper (because of the high thermal conductivity of copper), by which sufficient uniformity of temperature along the spring throughout the mainly effective portion of its length, and up to near the sighted end, shall be secured. The water jacket will secure a slight enough variation of temperature to allow the absolute temperature to be indicated by the thermometer with, I believe, the required accuracy.

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16. *Comparison of the Harcourt and Methven Photometric Standards.*
By W. STEPNEY RAWSON, *M.A.*

The author of the paper explained the growing necessity for a reliable governmental standard of light, and showed two of the standards to which reference was made in the report of a committee appointed by the Board of Trade in 1881.

These were the Harcourt air-gas lamp and the Methven screen.

The improvements made in the former since the last meeting of the British Association consisted in an adjustable black background and screen for protecting the eye from the light of all but the upper point of the flame when regulating the height, and thereby enabling the exact height to be determined more accurately; also in a rack and pinion movement with a scale engraved in millimetres for setting the height of the platinum wire; and besides these an entirely new method of preserving an accurately even rate of drop of pentane for feeding the lamp in the portable form exhibited.

This device consists in producing a perfectly constant head by providing an overflow outlet from which the excess of pentane drops into a small bottle, which can be removed when necessary, and emptied into the main reservoir, which is on the top of the lamp, the bottle forming a stopper to the reservoir to prevent evaporation.

The rate of drop into the lamp is regulated with great delicacy by letting the pentane flow down a fine glass tube, in which there is a constricted passage, which can be more or less closed by a fine platinum wire which can be screwed in or out of it by means of a thread working in a cap at the top of the tube. This method is due to Mr. W. F. Donkin.

In other respects the lamp remains exactly as described by Mr. Vernon Harcourt at previous meetings of the Association.

The Methven screen was one of the form as now constructed, but differing from that upon which the committee on photometric standards reported in 1881. The author showed by a diagram the errors introduced by the alteration of form, amounting to fully 16 per cent. below its normal value.

He gave the result of observations made by Mr. W. F. Donkin and himself, and showed that the errors may be determined theoretically, and were practically coincident with the result of observations.

The value of the Methven varied from 1·687 at 65″ to 2·149 at 11″.

Observations also showed that the increased thickness of flame subtended by the disc as it approached the slot caused an increase in the value.

Allusion was made to experiments for determining the absorption of light by cylindrical glass chimneys, and it was stated that whereas frosted glass absorbs 30–40 per cent. of the light a glass cylinder frosted on the outside only absorbs from 7–15 per cent.

17. *Fuel Calorimetry.*[1] *By* B. H. THWAITE, *F.C.S.*

Although instruments for the precise estimation of most of the agents of our industries have long ago been introduced, the heating value of coal—the great natural source of power—is rarely tested calorimetrically, even by the largest consumers.

At present the different qualities of coals are known as *bests, seconds,* &c. whereas a calorific estimation might show that the *seconds,* or even inferior qualities, possessed a higher calorific efficiency than the *firsts.*

By the utilisation of fuel calorimetry a user of coal would be able to ascertain exactly the financial value of different fuels, and to compare the heat energy possessed by the fuel with that economically evolved.

Fuel calorimetry would prove a strong inducement to the adoption of more perfect combustion arrangements, and thus aid the laudable objects of the Smoke Abatement Society.

The disadvantage of Dulong's calorimeter, in which the fuel is consumed in a current of oxygen, is that the combustion occupies a considerable time, and consequently requires correction for re-cooling; moreover, unless the oxygen is applied by compression, the instability of carbon dioxide in the presence of carbon prevents

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[1] See *Engineering,* November 12, 1886, p. 507.

the entire oxidation of the carbon, and part of the gases escape as carbon monoxide (CO), with a consequent loss of heat energy, and the measurements are incorrect.

In the apparatus of Messrs. Favre and Silbermann the gases resulting from the combustion of fuel are deprived of the carbon dioxide and passed over cupric oxide, for the estimation of the weight of carbon monoxide, but even this modification does not enable an absolutely exact correction to be made.

Mr. Lewis Thompson designed some time ago an ingenious apparatus, in which he obtained the oxygen for fuel combustion from potassium chlorate and potassium nitrate intimately mixed with the fuel in a finely divided condition: the mixture is ignited with a fuse.

The dissociation of the potassium chlorate, however, generates heat, and heat is absorbed by the transition of the oxygen from a solid to a gaseous condition; the dissolution of the residual potassium chloride also absorbs heat, so that considerable corrections have to be made.

Berthelot mentions that in the hands of Stohmann the solid oxygen arrangement has been greatly improved and increased in accuracy. Berthelot and Vieille finally decided to confine themselves to the use of oxygen in a gaseous form as the oxidising agent in their calorimeter. By the use of gaseous oxygen a single difficulty only has to be overcome—the complete oxidation of the fuel without producing a trace of carbon monoxide or of hydrocarbon. This difficulty is successfully met by compressing oxygen to about seven atmospheres, and with a weight of combustible such that the proportion of oxygen consumed does not exceed 30 or 40 per cent. of its total quantity. The air is forced into the small and strongly formed mortar-shaped vessel by a force-pump.

The advantages obtained by this new arrangement are that the calorimetric measurement can be performed in from three to four minutes, whilst the actual combustion occupies only a few seconds. A very small quantity of water is required, so that a high temperature is obtained, thereby increasing the precision. The product is not found to contain any residual gases, judging from critical analyses.

The ignition is effected by passing an electric current through a platinum wire and cage (in which the fuel is placed).

With this instrument Berthelot and Vieille have established the calorific value of the most important pyrogenic hydrocarbon compounds. The results are given in the 'Comptes Rendus' for May 31, 1886.

The only disadvantage of this excellent instrument is its cost; it can be obtained from M. Golas, of Rue St. Jacques, Paris, who makes Berthelot's splendid instruments of precision.

Mr. W. Thomson, of Manchester, has lately improved the Lewis Thompson calorimeter, employing gaseous in preference to solid oxygen, in a very simple manner, and, as far as the author can judge, the instrument appears the most satisfactory for popular use: the combustion is likely to be slightly incomplete owing to the use of oxygen at atmospheric pressure, but for practical purposes the instrument is all that could be desired.

The author suggests that the standard marketable value of coal should be expressed in the weight of fuel in decimals of a pound required to raise one pound of water to 212° Fahr. or 100° Centigrade from an initial temperature of (say) 77° Fahr. or 25° Centigrade.

18. *On Secular Experiments in Glasgow on the Elasticity of Wires.*
By J. T. Bottomley, *M.A., F.R.S.E.*

The object of this paper is to put on record the state of the wires in the secular experiments on stretching of wires commenced under the British Association and with the aid of a money grant. A committee was appointed at the last Glasgow meeting for the purpose of inaugurating these experiments; and preparations having been made in the interval, the wires were set up in 1879. Several reports have been already made to the British Association, and observations are carried on from time to time on the condition of the wires, which are hung up in the Tower of the University Buildings of Glasgow.

There are pairs of wires of each of the metals platinum, gold, palladium. These are hung side by side from the *same* top support, and one of the wires in each pair carries a light load ($\frac{1}{10}$ of the breaking weight), the other a heavy load, about $\frac{3}{4}$ of the breaking weight. A comparison is made between the pulling out of the heavily loaded wire and the lightly loaded wire by means of apparatus described in former Reports.

The wires were set up on May 3, 1879. By May 6 they had all come to a fairly steady condition, though the heavily weighted wires were running down to an extent just perceptible from day to day.

From May 6, 1879, till August 7, 1880, the running down of the heavily loaded wire in comparison with the lightly loaded wire was in the case of platinum 1·15 mm., on a length of 1553·33 centimetres; in the case of the gold wire 1·45 mm. on 1552·98 centimetres.

From August 7, 1880, till March 3, 1886, a further running down has taken place, which amounts in the case of the platinum to 0·40 mm., and in the case of the gold to 0·80 mm.

MATHEMATICAL SUB-SECTION.

1. *Report of the Committee for Calculating Tables of the Fundamental Invariants of Algebraic Forms.*

2. *On the Rule for Contracting the Process of Finding the Square Root of a Number. By* Professor M. J. M. HILL.

The rule is this:—

See 'Todhunter's Algebra,' Art. 246.

When $n+1$ figures of a square root have been obtained by the ordinary method, n more may be obtained by division only, supposing $2n+1$ to be the whole number.

After giving the demonstration Todhunter says: 'The above demonstration implies that N (the number whose square is to be found) is an integer with an exact square root; but we may easily extend the result to other cases.'

He does not, however, give a general proof of his statement.

The object of this paper is to show that the result of the division may exceed by unity the remaining n figures of the square root, and then the rule fails.

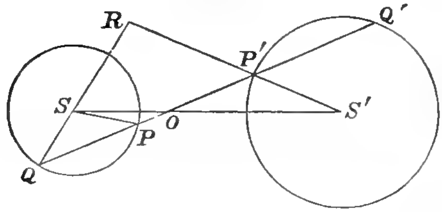
The proof given in text-books on algebra is applicable to the case when the square root can be exactly obtained as an integer, but not to all other cases.

3. *On the Explicit Form of the Complete Cubic Differential Resolvent. By the* Rev. R. HARLEY, *F.R.S.*—See Reports, p. 439.

4. *On a Geometrical Transformation. By* Professor R. W. GENESE, *M.A.*

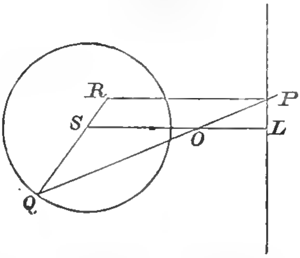
Let SP, S′P′ be parallel radii of two circles in opposite directions, then PP′ passes through a fixed point O on the line of centres SS′ (viz., O is the internal centre of similitude). Let PP′ meet the circles again at QQ′. Then the locus of the intersection of SQ, S′P′ is a conic of foci S, S′. For in fig. 1 SP = SQ ∴ RP′ = RQ ∴ S′R − SR = S′P′ + SQ = constant (if the circles cut, we find S′R + SR constant).

FIG. 1.



Now let the circle round S′ become a straight line, S′ passing to infinity. Then *any point* O on SL (the perpendicular to the straight line) may be regarded as the centre of similitude of the circle and straight line.

FIG. 2.



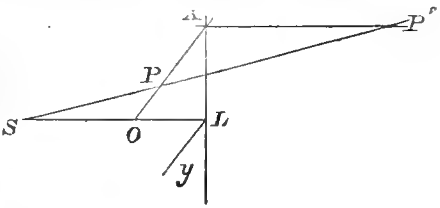
The changed construction is shown in fig. 2, where P'R is parallel to SO. We have

$$\begin{aligned} \mathrm{RQ} : \mathrm{RP'} &= \mathrm{SQ} : \mathrm{SO} = \text{constant} \\ &= \mathrm{SR} : \mathrm{RP'} - \mathrm{SO}. \end{aligned}$$

Thus R is on a conic, focus S, directrix parallel to LP'. The above suggests the following correspondence:

Let S, O be two fixed points, XLy a plane perpendicular to SO (though this restriction may easily be removed). Let P be any point in space, and let OP meet the plane in X; then a parallel XP' to SO meets SP in a point P' corresponding to P.

FIG. 3.



If P move over a plane, P' lies on another (intersecting the first on the plane XLy). Therefore if P describe a straight line, P' describes another.

If P lie on a surface, P' lies on another of the same degree.

The following theorem determines the analysis, viz.:—

$$\frac{\mathrm{SO}}{\mathrm{SP}} + \frac{\mathrm{OL}}{\mathrm{SP'}} = \operatorname{Cos} \mathrm{PSO};$$

or, if SL be axis of x; SO $= a$; OL $= b$; $\frac{a}{x} + \frac{b}{x'} = 1$.

Hence if x, y, z be co-ordinates of P; x, y', z', of P' (S being origin),

$$\frac{x}{x'} = \frac{y}{y'} = \frac{z}{z'} = \frac{x-a}{b} = \frac{a}{x'-b} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Thus, the plane

$$lx + my + nz = ka$$

is transformed into the plane

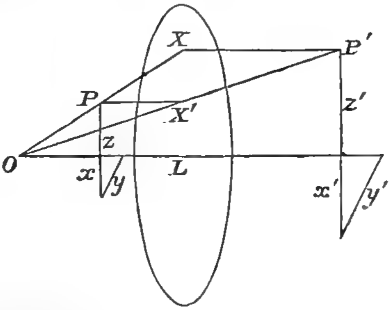
$$lx' + my' + nz' = k(x' - b),$$

and so on.

If we take SO = OL, the correspondence becomes involutional in character, *i.e.*, if P' correspond to P, then P will correspond to P'.

In that case the point S may be dropped, and we have the following construction:—

FIG. 4.



O is a fixed point, LXX' a fixed plane; P is any point in space, PX' perpendicular to plane LXX'; OX' meets a parallel through X to PX' in P'. Then P' corresponds to P.

Taking O as origin, and co-ordinates as before, we have

$$\frac{y}{y'} = \frac{z}{z'} = \frac{x}{d} = \frac{d}{x'} \quad . \quad . \quad . \quad . \quad (2)$$

Where $d = \mathrm{OL}$.

Thus

$$\begin{array}{lcl} y = mx + nd & \text{becomes} & y = nx + md; \\ y^2 + x^2 = d^2 & ,, & y^2 + d^2 = x^2; \\ y^2 + z^2 = x^2 & ,, & y^2 + z^2 = d^2; \end{array}$$

and so on.

Since PP' passes through a fixed point S in OL, we see that perspective projection is a particular case of the correspondence, and the formulæ (2) are probably the simplest obtainable for projection.

5. *On the Sum of the* n*th Powers of the Terms of an Arithmetical Progression. By* Professor R. W. GENESE, *M.A.*

We know that

$$1^n+2^n+3^n+\ \ldots\ +t^n=\frac{t^{n+1}}{n+1}+\text{ lower powers of } t$$
$$=\phi(t) \text{ say.}$$

Then $(t+1)^n+(t+2)^n+\ \ldots\ (t+r)^n=\phi(t+r)-\phi(t)$.

Now this statement is true for more than n values of t (viz., for *all* integral values).

Therefore it is an identity.

Putting $t=\frac{a}{d}$ we obtain

$$(a+d)^n+(a+2d)^n+\ \ldots\ +(a+rd)^n=d^n\left\{\phi\left(\frac{a}{d}+r\right)-\phi\left(\frac{a}{d}\right)\right\}$$

A number of interesting results can be obtained from the identity.

6. *On a Form of Quartic Surface with twelve Nodes.*
By Professor CAYLEY, *LL.D., F.R.S.*

Using throughout capital letters to denote homogeneous quadric functions of the co-ordinates (x, y, z, w), we have as a form of quartic surface with eight nodes $\Omega=(*\between U,V,W)^2=0$; viz., the nodes are here the octad of points, or eight points of intersection of the quadric surfaces $U=0$, $V=0$, $W=0$; the equation can be by a linear transformation on the functions U,V,W (that is, by substituting for the original functions U,V,W linear functions of these variables) reduced to the form $\Omega=U^2+V^2+W^2=0$.

Suppose now that the function Ω can be in a second manner expressed in the like form $\Omega=P^2+Q^2+R^2$ (where P, Q, R are not linear functions of U,V,W); that is, suppose that we have identically $U^2+V^2+W^2=P^2+Q^2+R^2$, this gives $U^2-P^2+V^2-Q^2+W^2-R^2=0$; or, writing $U+P$, $V+Q$, $W+R=A, B, C$, and $U-P$, $V-Q$, $W-R=F, G, H$, the identity becomes $AF+BG+CH=0$; and this identity being satisfied, the equation $\Omega=0$ of the quartic surface may be written in the two forms

$$\Omega=(A+F)^2+(B+G)^2+(C+H)^2=0, \quad \text{and}$$
$$\Omega=(A-F)^2+(B-G)^2+(C-H)^2=0;$$

viz. the quartic surface has the nodes which are the intersections of the three quadric surfaces $A+F=0$, $B+G=0$, $C+H=0$, and also the nodes which are the intersections of the three quadric surfaces $A-F=0$, $B-G=0$, $C-H=0$. We may of course also write the equation of the surface in the form

$$\Omega=A^2+B^2+C^2+F^2+G^2+H^2=0.$$

An easy way of satisfying the identity $AF+BG+CH=0$ is to assume $A, B, C, F, G, H=ayz, bzx, cxy, fxw, gyw, hzw$, where the constants a, b, c, f, g, h satisfy the condition $af+bg+ch=0$; this being so, the functions A, B, C, F, G, H, and consequently the functions $A+F$, $B+G$, $C+H$ and $A-F$, $B-G$, $C-H$ each of them vanish for the four points $(y=0, z=0, w=0)$, $(z=0, x=0, w=0)$, $(x=0, y=0, w=0)$, $(x=0, y=0, z=0)$, or say the points (1,0,0,0), (0,1,0,0), (0,0,1,0), (0,0,0,1); it hence appears that the quartic surface

$$\Omega=a^2y^2z^2+b^2z^2x^2+c^2x^2y^2+f^2x^2w^2+g^2y^2w^2+h^2z^2w^2=0$$

is a quartic surface with twelve nodes; viz. it has as nodes the last-mentioned four points, the remaining four points of intersection of the surfaces $ayz+fxw=0$, $bzx+gyw=0$, $cxy+hzw=0$, and the remaining four points of intersection of the surfaces $ayz-fxw=0$, $bzx-gyw=0$, $cxy-hzw=0$.

The above is the analytical theory of one of the two forms of quartic surface with twelve nodes recently established by Dr. K. Rohn in a paper in the 'Abhandlungen der K. Sächsische Gesellschaft zu Leipzig.'

7. *On the Jacobian Ellipsoid of Equilibrium of a rotating Mass of Fluid.* *By* Professor G. H. DARWIN, *F.R.S.*

8. *On the Dynamical Theory of the Tides of Long Period.* *By* Professor G. H. DARWIN, *F.R.S.*

9. *Note on Sir William Thomson's Correction of the Ordinary Equilibrium Theory of the Tides.* *By* Professor J. C. ADAMS, *LL.D., F.R.S.*

In Art. 806 of Thomson and Tait's 'Treatise on Natural Philosophy,' it is pointed out that if the earth's surface is supposed to be only partially covered by the ocean, the rise and fall of the water at any place, according to the equilibrium theory, would be falsely estimated if, as is usually done, it were taken to be the same as the rise and fall of the spheroidal surface that would bound the water were there no dry land.

In the articles which immediately follow the above, it is shown that in order to satisfy the condition that the volume of the water remains unchanged, the expression for the radius vector of the spheroid bounding the water must contain, in addition to the terms which would be sufficient if there were no land, a quantity (a) which depends on the positions of the sun and moon at the time considered, and which is the same for all points of the sea at the same time.

This quantity (a) contains five constant coefficients which depend merely on the configuration of land and water. The values of these coefficients in the case of the actual oceans of our globe have been carefully determined very recently by Mr. H. H. Turner, of Trinity College, in a joint paper by Professor G. H. Darwin and himself, which is published in vol. xl. of the 'Proceedings of the Royal Society.'

It should be remarked that every inland sea or detached sheet of water on the globe has in the same way a set of five constants, peculiar to itself, which enter into the expression of the height of the tide at any time in that sheet of water.

By taking such constants into account the formulæ which apply to the oceanic tides are rendered equally applicable to the tides of such a sea as the Caspian, which are thus theoretically shown to be very small, as they are known to be practically.

In the work above cited reference is made to a passage in a memoir by Sir William Thomson on the Rigidity of the Earth, published in the 'Philosophical Transactions' for 1862, as being the only one known to the writers in which any consciousness is shown that such a correction of the ordinary equilibrium theory as that above mentioned is required.

However just this remark may be in reference to modern writers on the equilibrium theory, it is only fair to Bernoulli, the originator of the equilibrium theory, to point out that in his prize essay on the tides he distinctly recognises the fact that when the sea is supposed to have only a limited extent the rise and fall of its surface cannot be the same as if the earth were entirely covered by it. In particular, he shows that the tides are so much the smaller as the sea has less extent in longitude, and thus explains why they are altogether insensible in the Caspian and in the Black Sea and very small in the Mediterranean, of which the communication with the ocean is almost entirely cut off at the Strait of Gibraltar (see Bernoulli, 'Traité sur le Flux et Reflux de la Mer,' Chapitre XI. section ii.

It may be as well to mention that this treatise of Bernoulli, as well as the dissertations of Maclaurin and Euler on the same subject, is published in the 3rd volume of the Jesuits' edition of Newton's 'Principia,' and also appears in the Glasgow reprint of that edition.

10. *On the Determination of the Radius Vector in the Absolute Orbit of the Planets.* *By* Professor GYLDEN.

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11. *Note on the Orbits of Satellites.* *By* Professor ASAPH HALL.

[PLATE XI.]

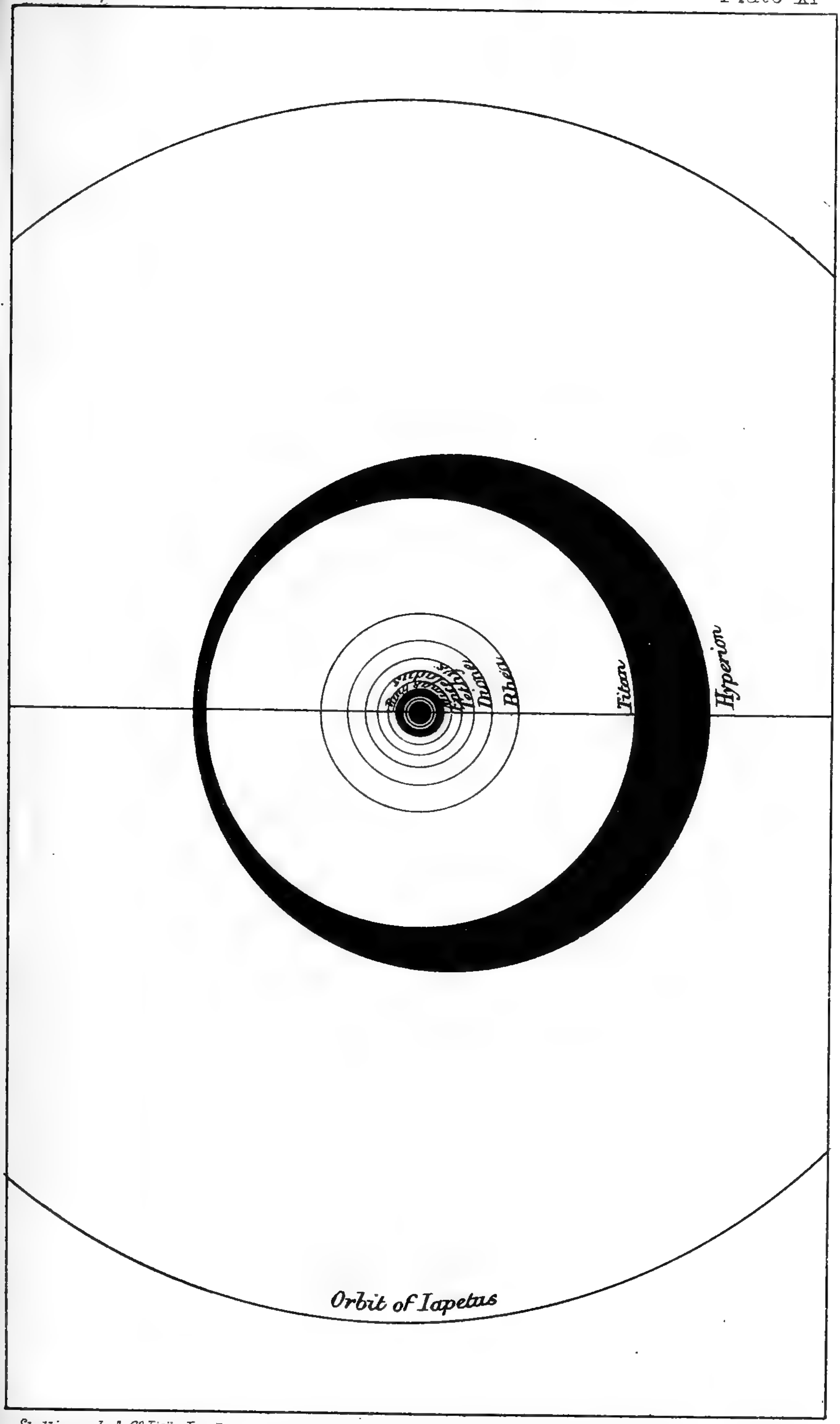
The observations of the five inner satellites of Saturn made at Washington since the mounting of the 26-inch refractor in 1873 have been reduced and discussed, and new orbits of these satellites have been determined. It is true that our observations of these satellites are not very numerous, and that further observation will be necessary in order to reach a definitive result. It should be stated also that the elliptical figure of this planet and the presence of its ring make it difficult to determine the position of a satellite by means of a filar micrometer in a manner that shall be wholly free from the suspicion of systematic errors. The probable error of one of our measurements is +0·27″; and I am inclined to think therefore that the Washington observations are as good as any that have been made. The result of our discussion is that the five inner satellites move in orbits whose planes very nearly coincide with the equator of the planet, and the plane of the ring; and also that these orbits are practically circles. The first result is what is generally assumed, but the fact that our observations can be satisfied within the limits of their probable errors by circular orbits seems to me a remarkable one. It would have been interesting of course to have found elliptical orbits, which would have given us the positions of the lines of apsides and their motions, and which would have led to a value of the mass of the ring; but the circular orbits exclude such results.

In the accompanying diagram the orbits of the satellites of Saturn are shown as they would be seen from the pole of the planet's equator, with the exception of the orbit of Iapetus, which is not correctly drawn, since this orbit is inclined to the plane of projection about 14°. A glance at the diagram will show the relations of the orbits. Thus, beginning at the centre of the planet, the distances to the edges of the ring and to the satellites increase regularly until we reach Rhea. From Rhea to Titan there is a large interval. The orbit of Titan is on the inner edge of the coloured surface, and that of Hyperion is on the outer edge of this surface. This small satellite is so connected with Titan that it may be looked upon as almost a companion of the large satellite. From Hyperion to Iapetus we have a very long interval. It is in these two intervals that one would naturally look for new satellites.

But what I wish now to call especial attention to is the fact of the circular orbits of the five inner satellites. In this connection we may notice that the orbit of the satellite of Neptune, those of the four satellites of Uranus, and also those of the three inner satellites of Jupiter are likewise all circular. The orbit of the outer satellite of Mars is very nearly circular. As for the orbit of the inner satellite of this planet, the discussion of my observations of 1877 gave an eccentricity 0·0321, which seemed real; but the recent discussion of my observations of 1879 has diminished this eccentricity, and indicates that this orbit also must be nearly circular. The observations of 1879 are better, I think, than those of 1877, since although the satellite was fainter in 1879, the disc of the planet was so much smaller that the measurements were not so liable to systematic errors which might produce a spurious eccentricity.

In the table on next page I have collected the distances and eccentricities of the satellites of our solar system. The distances are expressed in equatorial radii of the primary planets.

This table shows that Hyperion has the largest eccentricity, but this satellite is connected with Titan in such a manner that it may be considered an exceptional case. Generally it appears that the satellites with small distances have also very small eccentricities. To this it may be objected that such a result depends partly on the difficulty of determining for the small distances a good definite value of the eccentricity. There is some ground for such an objection, since in this case small



Spottiswoode & Co. Lith. London.

Illustrating Professor Asaph Hall's Note on the Orbits of Satellites.

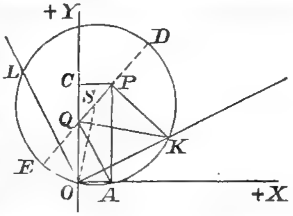
errors in the measurements would have a greater influence on the eccentricity; but in nearly every case the observations are now so numerous, and have been made by so many observers, that the results given in the table must be nearly correct.

Planet	Satellite	Distance	Eccentricity
Earth	Moon	60·253	0·0549
Mars	Phobos	2·756	0·0066
„	Deimos	6·885	0·0057
Jupiter . . .	I.	6·046	0·0000
„	II.	9·628	0·0000
„	III.	15·372	0·0013
„	IV.	27·023	0·0073
Saturn. . . .	Mimas	3·348	0·0000
„	Enceladus . . .	4·312	0·0000
„	Tethys	5·333	0·0000
„	Dione	6·837	0·0000
„	Rhea	9·560	0·0000
„	Titan	22·156	0·0284
„	Hyperion . . .	26·837	0·1000
„	Iapetus . . .	64·681	0·0278
Uranus . . .	Ariel	7·508	0·0000
„	Umbriel . . .	10·473	0·0000
„	Titania . . .	17·161	0·0000
„	Oberon . . .	22·902	0·0000
Neptune . . .	Satellite . . .	12·754	0·0000

It is my purpose to call attention to the relations between the distances of the satellites and the eccentricities of their orbits, because such relations may throw some light on the generation of these systems. Although we may gain but little, yet the facts acquired will serve to test and control the various hypotheses that are brought forward on this obscure but interesting question. I will venture but one suggestion. If we suppose the satellites with the smaller distances to have formerly moved in a resisting medium, and denote by t the time, e the eccentricity, and k a constant, there will be a secular term in the motion of a satellite of the form $-ket$. Such a term would tend to destroy the eccentricity of the orbit.

12. *Diagrammatic Representation of Moments of Inertia in a Plane Area.*
By ALFRED LODGE, *M.A.*[1]

The object of the paper is to give a simple construction for measuring the moments and products of inertia about any pair of rectangular axes through a point O of a plane section, and for finding the principal axes at the centre of area of the section, having been given the moments and product of inertia about any other pair of rectangular axes through the point O, and the position of the centre of area. Two alternative methods are given, the first dealing with the radii of gyration and with the product of inertia divided by the area of the section, the second dealing with the moments and products of inertia directly, either containing the area of the section as a factor or not, as most convenient.



I. Let OX, OY be the given axes about a point O in the section, PA the radius of gyration about OX, the area of the rectangle OAPC = the product of inertia (after division by the area of the section), and AQ the radius of gyration about OY. Bisect PQ in S, and with centre S and

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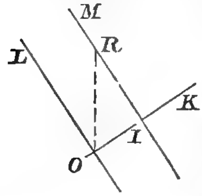
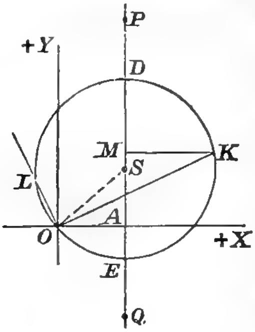
[1] See *Phil. Mag.* for November 1886.

radius SO describe the circle AKL, cutting in K, L any other pair of rectangular axes OK, OL which pass through O. Then PK, QK are the radii of gyration about OK, OL respectively, and twice the area of the triangle PKQ is the product of inertia about them. In particular, if PQ be produced to cut the circle in D and E, the principal axes at O are OD, OE.



If I is the centre of inertia, draw OK passing through I, and draw IM perpendicular to OI and parallel to OL. Then the product of inertia about IK, IM is equal to that about OK, OL, and is therefore known; the radius of gyration about OK is known, and that about IM is also known, as its square is less than that of the radius about OL by the square of OI. Hence the principal axes at I can be found by a fresh application of the above construction or by the construction given below.



II. OX, OY are the given axes, OA the product of inertia about them, AP the moment of inertia about OX, AQ that about OY, PAQ being in a line parallel to OY, and as drawn in the figure. Bisect PQ in S, with centre S and radius SO describe a circle. If OK, OL are another pair of rectangular axes, and K the point where OK cuts the circle, then if KM be drawn perpendicular to PQ, PM, QM are the moments of inertia about OK, OL respectively, and KM is the product of inertia about them. If PQ cuts the circle in D, E, the principal axes at O are OD, OE.

TUESDAY, SEPTEMBER 7.

The following Reports and Papers were read:—

1. *Report of the Committee for reducing and tabulating Tidal Observations in the English Channel, made with the Dover Tide-gauge, and for connecting them with Observations made on the French Coast.*—See Reports, p. 151.

2. *Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements.*—See Reports, p. 145.

3. *Report of the Committee on Electrolysis.*—See Reports, p. 308.

4. *On an Electric Motor Phenomenon.*[1] *By* W. M. Mordey.

When testing an electric motor in the works of the Anglo-American Brush Electric Light Corporation a phenomenon presented itself which the author at first found some difficulty in explaining. The motor was of the Schuckert-Mordey 'Victoria' type, series-wound, constructed to give 36 horse-power with a current of 20 ampères. It was supplied with power by a large Brush dynamo. On starting the generator on the occasion in question, the motor, being connected in the circuit, also started, but ran very slowly, and developed but little power. There being apparently some fault in the connections or elsewhere, the circuit was opened in order to stop the motor for the purpose of examination. On breaking the circuit the motor, which at the time was running slowly, stopped suddenly, and instantly started again, running backwards or oppositely to its usual direction, at a rate of

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[1] This paper was published *in extenso* in the *Electrical Review*, vol. xix. p. 259 (Sept. 10, 1886), and in other journals.

speed considerably greater than when it was connected in the circuit, slowly decreasing in speed until it stopped.

An examination showed that its fields had been inadvertently connected as a shunt on the armature instead of in series with it. On joining it up as a series motor it ran without exhibiting any unusual action. The cause of the unexpected reversal under the above-described circumstances will be understood from the following explanation:—

As the motor was series-wound, but improperly joined up as a shunt, it will be understood that a strong field was produced, the current through the field-magnet coils being large, the armature being traversed by only a small portion of the total current.

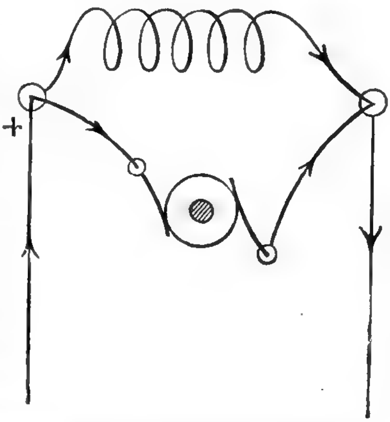
It will also be understood that on breaking the external circuit the momentum of the armature converts a shunt motor into a generator, the motion of the armature producing a strong current, circulating in the armature in the reverse direction to the previously received current, but in the fields in the same direction. In fact, a shunt motor under such conditions acts like a series generator with its terminals short-circuited. The intensity of this action in any motor depends to a great extent upon the form of the generating 'characteristic' of the machine. Properly constructed shunt motors, having fields wound to a comparatively high resistance, do not exhibit this action to any marked degree unless a suitable external circuit is provided for them, while shunt motors which are incapable of acting as shunt generators do not exhibit it at all. In the case in question, as the fields were of low resistance, the generation of current was considerable, and instantly stopped the motor.

A reference to the figures will show why, when it had stopped, the armature started again in the reverse direction.

Fig. 1 shows the connections and the course of the current when the motor was supplied with current from an external source, and when it was running in its proper 'forward' direction.

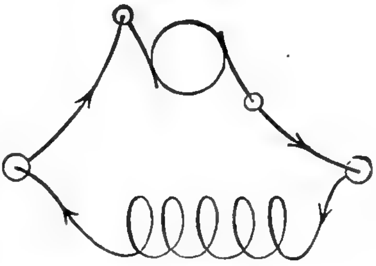
Fig. 2 shows the direction of current under the two conditions which successively occur when the external circuit is broken. In the first place the momentum of the armature causes a current to be generated which, it will be seen, is in the same direction in the field as before, but in the opposite direction in the armature. This at once stops the armature. Then the momentary induced ('extra') current follows in the same direction at the moment when motion has ceased, and causes the armature to start again in the reverse direction. This extra current is produced in both the armature and the field-magnet coils, but mainly in the latter, as in them the coefficient of self-induction is very considerable.

FIG. 1.



It may be added that the motor in question has for several months been working very successfully in New Zealand, where it is used to supply power to the machinery at the Phœnix Gold Mine. The current is transmitted to it from generators driven by water power at a considerable distance from the mine, the conductor consisting of three miles of copper wire, ·165 inch in diameter, supported on telegraph poles. The effective return is over 65 per cent.

FIG. 2.



Referring to the proposed utilisation of the braking power possessed by motors the author pointed out that sudden strains should be avoided, and that the power should rather be wasted in a brake-block, where it did no harm, than in heating the motor itself. The exceptions were those cases where accidents could be prevented, or the generated current could be actually used.

The author then proceeded to show that the extra current at breaking-circuit was much less in motors than in generators, on account of the opposing E.M.F. in motor armatures. He thought that M. Marcel Deprez had in his recent experiments taken needless precautions to avoid the effects of extra currents in his motors, and said that he had frequently opened the circuits of Brush generators giving 2,000 to 3,000 volts and 10 ampères without in any case doing any harm.

5. *On Electric Induction between Wires and Wires.*

By W. H. PREECE, *F.R.S.*

Along the Gray's Inn Road in London the Post Office has a line of iron pipes buried underground carrying many telegraph wires. The United Telephone Company has a line of open wires along the same route over the housetops situated eighty feet from the underground wires. Considerable disturbances were experienced on the telephone circuits, and even Morse signals were read which were said to be caused by the continuous and parallel telegraph circuits.

A very careful series of experiments, extending over some period, proved unmistakably that it was so, and that the well-known pattering disturbances due to induction are experienced at a much greater distance than was anticipated.

It became of importance to find out how far these effects could be detected.

Experiments conducted on the Newcastle town moor extended the area of the disturbance to a distance of 3,000 feet, while the effects were detected on parallel lines of telegraph between Durham and Darlington at a distance of $10\frac{1}{4}$ miles. But the greatest distance experimented upon was between the east and west coast of the Border, where two lines of wire 40 miles apart were affected, the one by the other, sounds produced at Newcastle on the Jedburgh line being distinctly heard at Gretna on a parallel line, though no wires connected the two places.

Very careful experiments have shown that these effects are independent of the earth, and are probably inductive effects through the air.

Distinct conversation has been held by telephone through the air, without any wire, through a distance of one quarter of a mile; and this distance can probably be much exceeded.

Effects are not confined to the air, for submarine cables, half a mile apart in the sea, disturb each other.

6. *On a Magnetic Experiment.* *By* W. H. PREECE, *F.R.S.*

A broken bit of needle was discovered in a hand by a strongly magnetised and delicately suspended needle when no indications were given by an induction-balance.

7. *On a new Scale for Tangent Galvanometer.* *By* W. H. PREECE, *F.R.S.*, *and* H. R. KEMPE.

The instrument is 'slewed' around, so that the plane of the coil makes an angle of 60° with the meridian, instead of coinciding with the meridian, and this point is taken as *zero*, whence a scale in tangent divisions is drawn, coincident with the old scale of tangent-divisions when the zero and the meridian agree. This renders the instrument far more sensitive to increments of current for high deflexions, while the divisions are still proportional to the current strength.

8. *On Stationary Waves in Flowing Water.*[1]

By Sir WILLIAM THOMSON, *LL.D.*, *F.R.S.*

The subject includes the beautiful wave-pattern produced by a steamer under way in smooth water. But the communication to the Section was limited to another interesting and well-known phenomenon, the rippling of the surface of a natural rivulet, or of the water flowing in a mill-stream, or through a conduit of any

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[1] For the full paper see the *Phil. Mag.* for October 1886 and the succeeding months.

kind. The dynamical theory of the steady motion observed in all such cases was explained to the Section.

9. *Artificial Production and Maintenance of a Standing Bore.*
By Sir WILLIAM THOMSON, *LL.D., F.R.S.*

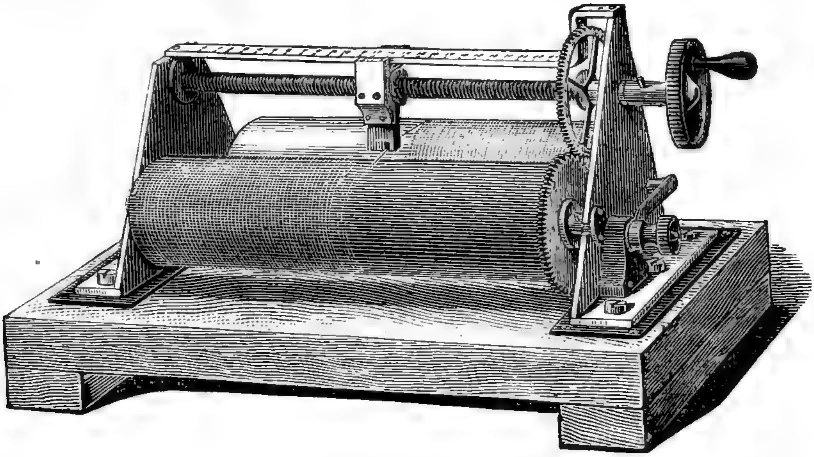
10. *Velocity of Advance of a Natural Bore.*
By Sir WILLIAM THOMSON, *LL.D., F.R.S.*

11. *Graphical Illustrations of Deep Sea Wave-groups.*
By Sir WILLIAM THOMSON, *LL.D., F.R.S.*

12. *Sir William Thomson's Improved Wheatstone's Rheostat.*
By J. T. BOTTOMLEY, *M.A., F.R.S.E.*

Wheatstone's rheostat was invented over forty years ago; but, though admirable in conception, and commonly shown on the lecture-table in explaining the nature of and illustrating electric resistance, it is scarcely if at all used in the laboratory. This is altogether owing to practical defects in the instruments as commonly constructed. The wire comes loose, the contacts are uncertain, and, the current being incessantly broken and made again, the galvanometer needle is perpetually swinging about, instead of showing, as it ought, a continuously increasing or diminishing deflection when the resistance is wound out of the circuit or wound into it.

Modifications of the original instrument have been made from time to time, and a very important improvement was recently introduced by Mr. Jolin, of Bristol. In Jolin's rheostat a toothed-wheel fixed on one of the two cylinders gears into a toothed wheel on a shaft carrying the other cylinder, and a spring fixed to this shaft acts on the last-named cylinder, which surrounds it, on the principle of the mainspring of a watch. By this arrangement the wire is kept tightly stretched, and the barrels can be turned both forwards and backwards by means of a handle attached to one of them. Thus the necessity of shifting the handle from one to the other when the motion is to be reversed is obviated.



In Sir William Thomson's improved rheostat the spiral groove in the non-conducting cylinder of previous instruments is dispensed with, and the wire is guided between the cylinders so as to be laid on them spirally by means of a travelling nut on a long screw. The screw is turned by the handle and carries a toothed-wheel which gears into two toothed-wheels, one of which turns one of the cylinders, and the other the axial shaft of the other cylinder containing the watch-spring. The guiding nut is also arranged to stop the motion of the screw-shaft at each end of the range, and so prevent the possibility of overwinding. It also carries an index which moves along a graduated scale and counts the turns of the wire on the insulating cylinder.

In Jolin's rheostat, as already described, the two cylinders are geared together directly, and turn in contrary directions, the wire passing from the upper side of one to the under side of the other. In Sir William Thomson's instrument, as is seen in the diagram, the toothed-wheels of the two cylinders are turned in the same direction by the wheel on the screw shaft, and the wire passes horizontally from the top of one cylinder to the top of the other.

The conducting cylinder and the wire are both of platinoid, a metallic alloy having properties which make it specially suitable for the purpose. It has very high electric resistance, very small temperature variation of resistance, and it remains with its surface almost or altogether untarnished in the air. On account of the last-named property the contact between the wire and the conducting cylinder is as perfect as can be desired; and continuity of action, which was a great difficulty in the old form of the instrument, is absolutely complete.

13. *Description of Experiments for determining the Electric Resistance of Metals at High Temperatures.* *By* J. T. Bottomley, *M.A., F.R.S.E.*

This paper gives an account of apparatus and experiments for the purpose of determining the electric resistance of certain platinum wires at temperatures varying from 0° C. up to the temperature of dull redness, or even a little higher. The wires experimented on were wires which have been used and are in use in an investigation on heat radiation at different temperatures in vacuum, and in air and other gases. The necessity for knowing with accuracy the rate of variation of electric resistance with temperature of the wires was explained in previous communications (1884 and 1885) to Section A of the British Association. The variation of electric resistance of platinum with temperature differs so much in different specimens that it is necessary to determine its value for each particular wire which is used in the investigation just referred to.

The principal apparatus described are an air-thermometer and a copper heating jacket; but a somewhat detailed account is also given of other heating apparatus employed, and of the electrical arrangements.

The air thermometer used is formed from a piece of thin glass tube from $\frac{3}{8}$ in. to $\frac{1}{2}$ in. in internal diameter. This is allowed to fall in before the blowpipe and drawn out to a capillary tube at each end; and one of the ends (a) is conveniently turned up along the side of the bulb. The length of the bulb is from 2 in. to $2\frac{1}{2}$ in. The thermometer is filled with perfectly dry pure air with the help of an aspirator, and the capillary tube a is closed by *drawing off* a small portion by means of a finely pointed blowpipe flame, care being taken that the blowpipe flame does not play on the open end, which might contaminate the air within. When a number of these bulbs are made and filled at one time, the end b is also closed, after the filling with pure air, and the thermometers are then ready for use.

When the thermometer is to be used it is placed in position, and very soon after the heating commences the end b of the capillary tube is opened with a file. When the bulb has taken the temperature which is to be measured, a hand blowpipe is brought and b is closed again. The thermometer having been removed from the hot space, it is allowed to cool, is carefully cleaned, if need be, and is then weighed. The weighing so obtained (after a small correction for air contained which it is usually unnecessary to apply) gives the weight of the glass. The thermometer is then immersed under mercury or water which has been boiled and cooled (water is preferred by the author for reasons stated), and the extremity of the capillary tube a is cut off with a glass-knife. The water entering fills the space with the exception of that occupied by the air which was left in the thermometer at the high temperature. A second weighing is then taken. Lastly the end b is opened and the thermometer is filled with water, and a third weighing taken. The small portions of glass cut off are of course weighed with the thermometer, and care is taken as to drying the outside of the thermometer for weighings 2 and 3. The barometer is also read at the closing and at the opening of the thermometer, and the temperature of the water used is noted. Also the observed barometric pressure at opening is corrected for vapour pressure when water is used, care being taken to ensure, as far as may be done, that the air left in the thermometer is saturated with moisture, though the experiment is carried through with tolerable quickness to avoid loss of air by absorption in the water.

Weighing No. 1 being subtracted from weighing No. 3, the whole volume of the thermometer (which must be corrected for expansion of the glass) is obtained. Weighing No. 2 being subtracted from weighing No. 3, the volume of the air at the high temperature is obtained. From the ratio of these two volumes the temperature is calculated by well-known formulas. For temperatures below redness the thermometers are made of German or somewhat hard English glass; for higher temperatures, of combustion-tubing.

A few words will suffice to describe the copper jacket. It consists of a considerable number (eight in the jacket exhibited) of sheet copper cylinders, each having a bottom, put one inside the other. These concentric cylinders fit each other very closely, there being only space for a lapping with a few turns of the thinnest asbestos thread to hold them together and keep an air space of perhaps $\frac{1}{32}$ of an inch.

The internal diameter of the innermost cylinder is about an inch. A stopper of woven asbestos closes the open end of the innermost cylinder and supports the air thermometer and the electrodes, of thick copper, to which the platinum wire to be tested is attached by silver soldering. The platinum wire is in the form of a spiral, with the turns well separated, wide enough in diameter to admit the bulb of the air thermometer. A very powerful Fletcher's 'solid flame' burner gives ample heat to raise the whole copper cylinder and its contents to redness.

Experiments described have shown that the temperature within the copper cylinder may be kept for any length of time so constant that there is no variation of electric resistance perceptible with exceedingly sensitive electric measuring apparatus.

Temperatures lower than 300° C. have generally been determined with the aid of the vapours of liquids of high boiling points. A very convenient series of organic liquids was proposed by Drs. Ramsay and Young two years ago.

The determination of the electric resistance of the wire was made by the potential method. An electric series is formed, consisting of a single gravity Daniell, the platinum coil to be tested, a known coil of platinoid on the outside of a large tin vessel filled with cold water (which contains a lump of slaked lime to prevent rusting of the tin vessel), and, lastly, a rheostat to regulate the series. The electrodes furnished with spring clips of a high resistance (10,000 ohms) galvanometer are clipped on alternately to the standard coil and the platinum wire under test.

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14. *On a new Standard Sine-Galvanometer.*[1]

By THOMAS GRAY, *B.Sc., F.R.S.E.*

The instrument proposed in this paper consists of a tube, the length of which is much greater than its diameter, covered with a single layer of wire, laid on uniformly all along its length. In the instrument proposed the tube is ten centimetres in diameter and one metre long. The advantages claimed for this arrangement are: the ease with which the constants can be obtained with sufficient accuracy; the great uniformity of the magnetic field produced at the centre of the coil by a current passing through it; the ease with which the various details of manufacture work out, and hence its comparative cheapness.

The coil is mounted on a vertical axis, the line of which passes through the centre of the axis of the tube, and turns above a horizontal table, to which is fixed a scale of degrees on which the angular position of the coil can be read. Arrangements are described by means of which the angular position of the suspended needle can be observed by means of a small telescope fixed in one end of the tube.

[1] Published in full in the *Phil. Mag.* for October 1886.

15. *On Magnetic Hysteresis.* *By* Professor G. FORBES, *M.A.*

Professor Ewing[1] has made a contribution to the science of magnetism, which has only lately come into the hands of scientific men, but which is certain to lead to an extension of our powers in dealing with applications as well as with the theory of magnetism. Lord Rayleigh has already drawn deductions from it in a paper communicated to the 'Philosophical Magazine' for August 1886.

The consequences which I wish to draw from it have reference partly to practical applications, and specially to secondary generators or transformers, and partly to Weber's molecular theory of magnetism.

If a coil of wire carrying an electric current encloses an iron core whose length is at least 400 times its diameter, or which is of a ring shape, the magnetic induction produced at the middle of the bar, or at any part of the ring, is due altogether to the direct action of the electric current, since there is no free magnetism. In this case the magnetic force is proportional to the electric current.

A curve may be drawn in which abscissæ denote electric current or magnetic force, and ordinates represent magnetic induction. As the magnetic force is increased a curve is traced; but this curve is not retraced as the magnetic force decreases. If the magnetic force reach alternately a positive and a negative maximum a closed curve is traced, the area of which indicates the work done upon the iron core in a cycle of these operations, just as the area of the curve traced by the steam engine indicator measures the work done by the engine in a complete cycle of the movements of the piston-rod.

The nature of this curve shows that we cannot express the magnetic induction in terms of the magnetic force alone. It is also a function of the history of the iron in the immediate past. This phenomenon is called magnetic hysteresis.

Fig. 1 (taken from Ewing) shows the increase of magnetic induction from zero to a maximum, with increase of magnetic force and the subsequent cycle produced. The arrows indicate the direction in which the curve is traced.

If the iron be subjected, during the process of magnetisation, to mechanical shocks, these peculiarities disappear, and the induction becomes a pure function of the magnetic force. It is generally supposed that the tremors of a dynamo machine prevent the effects of magnetic hysteresis from showing themselves. This may sometimes be the case. It is not always so. In the first model non-commutating dynamo constructed by me the electromotive force did not diminish ten per cent. after the exciting current was reduced to zero. That model consisted of a long cylindrical electromagnet, rotating about its axis, its poles being connected by a soft iron cylinder with closed ends. In secondary generators hysteresis must play an important part. In this case the magnetising force is due to the sum of the two currents in the primary and secondary coils. Now the maximum value of the current in the primary is reached earlier than the maximum of the sum of the two currents, and the maximum of the secondary current later. This fact introduces interesting modifications in the form of the magnetic indicator diagrams of the two circuits, to which I wish to draw attention. I will suppose that the maximum of magnetic induction is coincident in time with the maximum of the algebraical sum of the primary and secondary currents.

The phase of the primary current may precede, and the phase of the secondary current may follow, that of the magnetic induction by a value varying from O to $\frac{T}{4}$ when T is the period of a complete cycle. The currents are taken as harmonic functions of the time.

To transform Ewing's cyclic curve of hysteresis into the corresponding diagram for the primary or secondary circuit whose phase is $+a$ or $-a$ in advance of the phase of induction. Let the maximum abscissa represent the magnetic force due to the maximum current in that circuit, and describe a circle with this abscissa as radius, and the zero of co-ordinates O as centre. Take any point P on Ewing's curve; draw its ordinate PM. Let this line, produced if necessary, cut the circle in $Q\,Q_1$. This line cuts Ewing's curve in two points $P\,P_1$. If P be the

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[1] *Phil. Trans.* 1885, Part II.

higher of these points operate on Q, the highest of $Q\,Q_1$, and contrariwise. Draw OQ' inclined to OQ at an angle $+a$ or $-a$. Draw the ordinate $Q'\,M'$, and cut off $P'M' = PM$. P' is a point on the new curve corresponding to P on Ewing's curve.

In this manner figures have been drawn for the primary and secondary circuits of a secondary generator for cases where the acceleration and retardation of phase are $\frac{T}{8}$ and $\frac{T}{4}$.

In all these curves work is done in a complete cycle by the electric circuit on the iron when the curve is traced in a direction contrary to the motion of the hands of a watch, and contrariwise. We can now notice several facts:—

(1) In all diagrams for the primary circuit the curves are described in the same direction as Ewing's curve, showing that it does work on the iron.

(2) In both diagrams for the secondary circuit the curve is described in the opposite direction to Ewing's curve, showing that work is done by the iron on the circuit.

(3) When the acceleration of the primary is $\frac{T}{4}$ no work is done by the iron on the primary circuit at any part of the cycle.

(4) When the retardation of the secondary is $\frac{T}{4}$ no work is done by the circuit upon the iron at any part of the cycle.

(5) In the diagram for the secondary circuit, if the retardation be the angle corresponding to the abscissa OA, the curve passes through the origin, and the work done in a cycle is zero (A being the point where Ewing's curve cuts the axis of abscissæ).

(6) If the retardation be less than this, work is done in the cycle by the secondary circuit on the iron core.

(7) It follows from this that, owing to magnetic hysteresis, the retardation of the secondary current cannot be less than the angle corresponding to the abscissa OA except in so far as it derives energy by direct induction from the primary.

In most early attempts to make secondary generators the mutual induction of the primary and secondary coils was very slight, and here the retardation must be at least equal to the angle indicated.

These remarks hardly apply to the secondary generator of Gautard & Gibbs, who made it a commercial success mainly by causing the direct mutual induction of the circuits to be a maximum.

Lord Rayleigh has pointed out that since the hysteresial dissipation of energy per unit volume of iron is the same whether the magnetic circuit be open or closed, while the total work done on or by the electric circuits is greater with an open magnetic circuit, therefore the most efficient secondary generator is one with an open magnetic circuit. This is true only when hysteresial dissipation is the only cause of the loss of efficiency. It has appeared, however, that in actual secondary generators hysteresial dissipation is but a portion of the cause of loss of efficiency. Resistance of the generator itself is a principal cause, and the loss from this cause varies as the square of the current, and would be much greater with the high currents proposed by Lord Rayleigh for his elongated elliptical iron core than in a secondary generator with a closed iron magnetic circuit. The efficiency which Lord Rayleigh proposes to gain in hysteresial dissipation is proportional to the current. The loss due to resistance is proportional to the square of the current.

Throughout this investigation I have assumed that magnetic induction does not lag behind the magnetic force.

The second part of this paper has relation to the molecular hypothesis. This hypothesis as developed by Weber and Maxwell gives no account of hysteresis. Ewing has proposed a further assumption—that a molecule has a friction (not a viscous friction, but what Whewell called stiction) which prevents it from turning until the turning force exceeds a constant value ζ.

It seems to me that the fewer assumptions we make the more near to the truth are we likely to be. Weber has made the assumption that a constant force tends to restore the molecule to its original position. The simpler assumption seems to be that in ideally soft iron the molecules take up positions depending upon the influence of the others. I suppose that when there is no magnetisation the molecules naturally group themselves in pairs with poles of opposite name in juxtaposition, and that the value of the resolved part of the magnetic force required to separate them must reach a certain value K before any deflection takes place, and then the deflected molecule sets itself in the direction of the magnetic force. This seems to be a very likely hypothesis for iron of ideal softness. If H be the magnetic force and θ the inclination of the axis of a pair of molecules to the magnetic force, the molecules acted upon and set with their axis parallel to the direction of the force are those for which $\sin\theta$ is greater than $\frac{K}{H}$. The number of these varies as the magnetisation. Calling the magnetisation I, we have

$$I = \int_{\sin^{-1}\frac{K}{H}}^{\frac{\pi}{2}} a \sin\theta d\theta = \frac{a}{H}\sqrt{H^2 - K^2}$$

for magnetising forces less than H = K, I = O, for other values we have

$H = K$	$I = O$
$= 1{\cdot}2K$	$= {\cdot}55$
$= 1{\cdot}5K$	$= {\cdot}74$
$= 2{\cdot}0K$	$= {\cdot}86$
$= 5{\cdot}0K$	$= {\cdot}98$
$= 10{\cdot}0K$	$= {\cdot}995$

The curve deduced from this has the characteristics of extremely soft annealed iron. The only want of resemblance is the suddenness in the rise of the curve after H has reached the value K. This would doubtless be smoothed by any want of perfect mobility of the molecules such as is involved in Maxwell's addition to Weber's hypothesis, which must be taken into account in explaining the behaviour of steel which has no connection with the cause of hysteresis.

After a certain magnetisation is attained the magnetisation of the iron (if there be no demagnetising influence of ends) must retain each molecule in its axial direction, and the demagnetisation cannot commence until a reverse magnetic force is applied.

The effects deduced from this hypothesis are the same in character as those deduced from Ewing's friction hypothesis, but it seems to me that perfect mobility rather than friction is more likely to be the explanation of a property specially possessed by the softest kinds of iron, and I have thought that the hypothesis is at least worthy of consideration.

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16. *On a new System of Electrical Control for Uniform-motion Clocks.*

By HOWARD GRUBB, *F.R.S.*

The two systems of electrically controlled clocks in use for driving astronomical telescopes possess in common some disadvantages.

1. At best they can only correct the rate of the clock itself, and have no power to correct any error in the train of wheels between the clock and the endless screw which drives the instrument.

2. The checking apparatus acts on the clock governor itself, altering its rate; and as that portion of the instrument has a considerable *vis inertiæ* there is a liability to a slight oscillation in rate after a correction is made.

In the new system the author has endeavoured to avoid these disadvantages.

The 'detector' portion of the apparatus is attached directly, or almost so, to the screw spindle itself, and the acceleration or retardation is effected by the temporary introduction of a differential gearing into the train of wheels between the clock and the screw spindle.

17. *Design for working the Equatorial and Dome of 'Lick' Observatory, California, by Hydraulic Power. By* HOWARD GRUBB, *F.R.S.*

In the case of very large astronomical telescopes it is desirable to relieve the observer as much as possible from the great physical exertion required to work the instrument, dome, observing chair, &c.

The author has worked out a system of hydraulic machinery which effects all the necessary operations and at the same time brings them under the complete control of one individual.

This was illustrated by a working model in which the hydraulic apparatus was represented by clockwork governed, as in the case of the actual apparatus, by electricity.

WEDNESDAY, SEPTEMBER 8.

The following Papers were read :—

1. *The Advantages to the Science of Terrestrial Magnetism to be obtained from an expedition to the region within the Antarctic Circle. By* Staff Commander ETTRICK W. CREAK, *R.N., F.R.S.*—See p. 98.

2. *On Lithanode. By* DESMOND G. FITZ-GERALD.

It is claimed for this substance that it is the negative element *par excellence* for voltaic batteries, primary or secondary, and also a perfect anode for the electrolytic separation of the most electro-negative elements, *e.g.*, chlorine. No other substance fulfils all the *desiderata* for a negative voltaic element, and no other substance that can be generally employed as an anode in electrolysis is unattackable by chlorine. Lithanode is peroxide of lead in a dense, coherent, and highly conductive form. It constitutes a step in the series of inventions, initiated by Planté and continued by Faure, Volckmar, and others, by which the secondary battery has been perfected. By this step local action in the negative element, a defect of all secondary batteries excepting those constructed with lithanode, is entirely precluded. Lithanode is obtained by moulding a plastic mass of oxide of lead with the solution of a salt, such as ammonic sulphate, which is gradually decomposed by the oxide of lead. The effect of the gradual chemical action is to cause the substance to 'set,' and to acquire a high degree of cohesion and hardness. The mass is then electrolytically converted into a peroxide of lead differing from other forms of this substance, and withstands perfectly the processes of 'charging' and 'discharging,' however rapidly these may be effected. The advantages attending the use of lithanode in secondary batteries are—1, a permanent negative element; 2, economy of power; and 3, diminished weight. The advantage in commercial processes of electrolysis is that lithanode constitutes a cheap electrode, and the only one not attackable by chlorine.

3. *Draper Memorial Photographs of Stellar Spectra exhibiting Bright Lines. By* Professor EDWARD C. PICKERING.

The spectra of ordinary stars, whether examined directly by the eye or indirectly by means of photography, present little variety. The comparatively few cases of deviation from the usual type are therefore particularly interesting, and the occurrence of bright lines in a stellar spectrum constitutes perhaps the most singular exception to the general rule. The brightness of the F line in the spectra of γ Cassiopeiæ and β Lyræ was noticed by Secchi. Rayet afterwards found three rather faint stars in Cygnus, the light of which was largely concentrated in bright lines or bands. The adoption at Harvard College Observatory of a system of sweeping, with a direct-vision prism attached to the eyepiece of the equatorial telescope, resulted in the discovery by the present writer of several additional objects of the same class. Still more recently Dr. Copeland, during a journey to the Andes, has extended the list by the discovery of some similar stars in the southern heavens.

Among the photographic observations which have been undertaken at Harvard College Observatory, as a memorial to the late Professor Henry Draper, is included a series of photographs of the spectra of all moderately bright stars visible in the latitude of the observatory. A recent photograph of the region in Cygnus previously known to contain four spectra exhibiting bright lines has served to bring to our knowledge four other spectra of the same kind. One of these is that of the comparatively bright star P. Cygni, in which bright lines, apparently due to hydrogen, are distinctly visible. This phenomenon recalls the circumstances of the outburst of light in the star T. Coronæ, especially when the former history of P. Cygni is considered. According to Schönfeld it first attracted attention as an apparently new star in 1600, and fluctuated greatly during the seventeenth century, finally becoming a star of the fifth magnitude, and so continuing to the present time. It has recently been repeatedly observed at Harvard College Observatory with the meridian photometer, and does not appear to be undergoing any variation at present.

Another of the stars shown by the photograph to have bright lines is D.M. + 37° 3821, where the lines are unmistakably evident, and can readily be seen by direct observation with the prism. The star has been overlooked, however, in several previous examinations of the region, which illustrates the value of photography in the detection of objects of this kind.

The other two stars first shown by the photograph to have spectra containing bright lines are relatively inconspicuous. The following list contains the designations, according to the Durchmusterung, of all eight stars, the first four being those previously known: 35° 4001, 35° 4013, 36° 3956, 36° 3987, 37° 3821, 38° 4010, 37° 3871, 35° 3952 or 3953. Of these 37° 3871 is P. Cygni, and 37° 3821 is the star in the spectrum of which the bright lines are most distinct.

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4. *An Apparatus for determining the Hardness of Metals.*

By Thomas Turner, *A.R.S.M.*

Hitherto there have been but few attempts to quantitatively determine the relative hardness of metals. The method adopted by the United States Government in 1856 consisted in the punching of a hole by a tool in the form of a pyramid and under a constant pressure. The indentation was carefully measured, its capacity calculated, and in this way relative hardness was expressed. But it has been shown that the results obtained really depended in part upon tenacity, and so were not accurate representations of hardness. In 1859 Calvert and Johnson employed a modification of the same method, which was further improved by Bottone in 1873.

The apparatus recommended by the author is an adoption of the method which has already been employed in determinations of the hardness of minerals, namely, by scratching the surface with a weighted diamond. The diamond is attached to a graduated beam arranged so as to allow of motion in both a horizontal and a vertical plane. By means of a sliding weight, sufficient pressure is applied to cause a distinct scratch on drawing the diamond over a smooth surface of the metal to be tested. The weight is then moved until the diamond just ceases to produce a visible scratch, when the position of the weight on the scale is observed. Some experience is necessary in observing the scratch, but when this has been obtained the apparatus gives uniform results.

The author's experiments with cast iron have shown the common idea that hardness and tenacity necessarily accompany each other to be erroneous. Very soft cast iron can be obtained with a high tensile strength, while hard cast-iron has very often a low tensile strength. When metal has to be worked, unnecessary hardness leads to useless expenditure of power and tools, and in such circumstances a soft metal is much to be desired.

The apparatus is intended to be used in connection with tensile tests of the metal, and in this way affords valuable information as to the mechanical properties of the material.

5. *On Star Photography.*

By ISAAC ROBERTS, *F.R.A.S., F.G.S.*

During the past eighteen months I have been at work taking photographic negatives with a twenty-inch silver on glass reflector for the purpose of mapping the stars in the northern hemisphere, between the pole and the equator, and up to the present time about four hundred plates, each covering four square degrees of sky, inclusive of overlap, have been secured between the pole and declination fifty-seven degrees. The extent of the work done would have been much greater if the weather had permitted.

The negatives are exposed for fifteen minutes, which is sufficient time to show very faint stars, the magnitudes of which have not yet been determined. Stars of the ninth magnitude are photographed faintly in one second.

Recently I received from Admiral Mouchez, the Director of the Paris Observatory, four magnificent enlarged photographs of stars in the constellation Cygnus taken with the 13-inch refractor made by MM. Henry. The negatives were taken one in June and three in August last year, and I deemed it desirable to direct my 20-inch reflector on to the same sky spaces, and take negatives at the corresponding time this year, with similar duration of exposures, namely, sixty minutes each, so as to enable comparisons to be made between the results obtained with two instruments constructed on different principles and with unequal apertures.

The five photographs which were exhibited are the result. Those marked Nos. 1 and 2 have Æ $21^{h}\ 2^{m}$, and Declination + 38° 12′, one being exposed for thirty-four minutes, and the other for sixty minutes. No. 3 has Æ $19^{h}\ 45^{m}$, and Declination + 35° 30′. No. 4 has Æ $19^{h}\ 55^{m}$, and Declination + 37° 45′. No. 5 has Æ $20^{h}\ 4^{m}$, and Declination + 35° 30′.

The enlargements have been made to correspond very nearly with MM. Henry's photographs, and on comparing them with these it will at once be observed that the appearance of the star discs differs. In the Henry photographs the discs are round, with perfectly sharp circumferences, whilst the reflector shows them round, but with circumferences somewhat undefined, and presenting more the diffraction appearances which always accompany telescopic eye-observations of stars.

Another very striking difference is the equal brightness of the Henry star discs. Fifteenth or sixteenth magnitude stars seem as bright as those of first magnitude, and differ from them only in the diameter of discs, whereas the reflector shows gradations between the brightest and faintest stars that will severely tax the powers of classification. They diminish till they are lost in the colour of the film on the paper, and on the negatives they can be traced to still fainter degrees, and the imagination finds no difficulty in following the diminution till space from our point of view appears to be filled with stars.

The reflector also seems to have the advantage over the refractor in the number of stars photographed in a given time; for instance, if I select at random any square inch of surface upon one of the Henry's plates, and count the stars in it, they number, say, fifty-nine; but in the same space on my plate they number 109, being in the ratio of nearly two to one. Of course this is a rough mode of making the comparison, but it is the readiest method available at present.

The plates which I now submit are not to be considered exceptional or picked, but as average samples of those I can produce on any moderately clear night with the mirror film in an average state of polish.

If the photographs numbered 1 and 2 be compared with each other the relative number of the stars which were imprinted on the films with thirty-four and sixty minutes respective exposures may be counted.

A photograph of my duplex telescope and observatory at Maghull was also exhibited.

6. *Exhibition and Description of Miller's portable Torsion Magnetic Meter.*
By Professor JAMES BLYTH.

The armature is formed of five small bars of soft iron, 5 mm. long, and weighing 1 gramme.

The index wheel has its rim divided into $\frac{1}{100}$ths, and carries the outer end of a flat spiral spring, the inner end of which is firmly fixed to the long axis which carries the small armature bars. A fixed pointer projects from the ends of the case across the edge of the disc, and another pointer is fixed to the armature axis. In the normal position the pointers both point to the zero of the scale.

When the armatures are placed in a magnetic field they are turned round and are brought back to their zero position by coiling the spring through a definite angle depending upon the strength of the field. A constant is determined for the instrument by experiments in a field of known strength, or if necessary it can be empirically graduated.

It is hoped that the instrument will be found of service to makers of dynamos for finding the strength of the field in various parts, and also for finding the best forms of pole pieces.

There was also exhibited a form of small attraction magnetometer.

7. *On the Protection of Life and Property from Lightning.*[1]
By W. McGREGOR.

The paper proposes the formation of a committee with the following aims and objects:—

(*a*) To travel, and by means of illustrated lectures or papers to awaken general interest in this vital subject.

(*b*) In a plain journal to publish details of any serious disasters, with professional opinion in language to be easily understood by the public.

(*c*) To provide scientific advice and co-operation.

(*d*) To bring about *esprit de corps* amongst architects, engineers, builders, and manufacturers of lightning conductors.

(*e*) To advise and encourage authorities whose duty it is to protect life and property to employ the means provided by science.

(*f*) To encourage and support insurance companies to insist on employment of these means, and to frame a clause in the policy to enforce proper inspection and testing.

(*g*) To insist upon architects showing the arrangements of metal in buildings, the nature and position of the means adopted for protection against lightning.

(*h*) To investigate (if not already known) the cause why in a general assembly it occurs that men are more frequently killed or injured than women, and why certain localities are more specially selected by lightning.

(*i*) Finally to enable the society, branch, or committee to illustrate to the public the practicability of securing perfect safety at a minimum cost, and to have the lightning conductors or system of conductors as easily governed and tested as the gas-pipes, and the tests read off as simply and inexpensively as the reading of the meter, which can be accomplished by observing the following rules:—

(1) Employ none but qualified persons.

(2) Avoid extra expense and trouble by having testing-wires fixed at once.

(3) Do not grudge an extra length of conductor if required by the nature of the soil near the building. When you are selecting land for cultivation, or soil for certain plants, some trouble is involved; let the same interest be taken in the spot where the earth terminal is to be laid.

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[1] See also pamphlets by same author on *Protection of Life and Property from Lightning* and *Loss of Life and Property by Lightning*, and paper contributed by him to the Bengal Asiatic Society.

8. *An improved Form of Clinometer.* *By* JOHN HOPKINSON, *F.L.S., F.G.S.*

A 'day-and-night' compass-card is set to true N. over the compass-needle which necessarily points to magnetic N. The diameter of the card is less than the length of the needle, the points of the needle therefore projecting beyond the card, so that the correction made is seen and can be adjusted when required. The same result would be attained by placing the card below the needle. The clinometer 'dip' is as usual below the magnetic needle, and can be easily seen outside the compass-card. The advantage of being able to take the amount and direction of the dip of strata with a single instrument without loss of time and liability to error in making the correction for magnetic deviation, and at the same time having the points of the compass exposed for more minute observation, must be obvious.

SECTION B.—CHEMICAL SCIENCE.

PRESIDENT OF THE SECTION—WILLIAM CROOKES, F.R.S., V.P.C.S.

THURSDAY, SEPTEMBER 2.

The PRESIDENT delivered the following Address:—

A GLANCE over the Presidential Addresses delivered before this Section on former occasions will show that the occupiers of this chair have ranged over a fairly wide field. Some of my predecessors have given a general survey of the progress of chemical science during the past year; some, taking up a technological aspect of the subject, have discussed the bearings of chemistry upon our national industries; others, again, have passed in review the various institutions in this country for teaching chemistry; and in yet other cases the speaker has had the opportunity of bringing before the scientific world, for the first time, an account of some important original researches.

On this occasion I venture to ask your attention to a few thoughts on the very foundations of chemistry as a science—on the nature and the probable, or at least possible, origin of the so-called elements. If the views to which I have been led may at first glance appear heretical, I must remind you that in some respects they are shared more or less, as I shall subsequently show, by not a few of the most eminent authorities, and notably by one of my predecessors in this chair, Dr. J. H. Gladstone, F.R.S., to whose brilliant address, delivered in 1883, I must beg to refer you.

Should it not sometimes strike us, chemists of the present day, that after all we are in a position unpleasantly akin to that of our forerunners, the alchemists of the Middle Ages? These necromancers of a time long past did not, indeed, draw so sharp a line as do we between bodies simple and compound; yet their life-task was devoted to the formation of new combinations, and to the attempt to transmute bodies which we commonly consider as simple and ultimate—that is, the metals. In the department of synthesis they achieved very considerable successes; in the transmutation of metals their failure is a matter of history.

But what are we of this so-called Nineteenth Century doing in our laboratories and our libraries? Too many of us are content to acquire simply what others have already observed and discovered, with an eye directed mainly to medals, certificates, diplomas, and other honours recognised as the fruits of 'passing.' Others are seeking to turn the determined facts of chemistry to useful purposes; whilst a third class, sometimes not easily distinguished from the second, are daily educing novel organic compounds, or are racking their ingenuity to prepare artificially some product which Nature has hitherto furnished us through the instrumentality of plants and animals. The practical importance of such investigations, and their bearing on the industrial arts and on the purposes and needs of daily life, have been signally manifested during the last half-century.

Still a fourth class of inquirers, working at the very confines of our knowledge, find themselves occasionally at least face to face with a barrier which has hitherto proved impassable, but which must be overthrown, surmounted, or turned, if chemical science is ever to develop into a definite, an organised unity. This barrier is nothing less than the chemical elements commonly so called, the bodies as yet undecomposed into anything simpler than themselves. There they extend before us, as stretched the wide Atlantic before the gaze of Columbus, mocking, taunting, and murmuring strange riddles, which no man yet has been able to solve.

The first riddle, then, which we encounter in chemistry is, 'What are the elements?' Of the attempts hitherto made to define or explain an element none satisfy the demands of the human intellect. The text-books tell us that an element is 'a body which has not been decomposed'; that it is 'a something to which we can add, but from which we can take away nothing,' or 'a body which increases in weight with every chemical change.' Such definitions are doubly unsatisfactory: they are provisional, and may cease to-morrow to be applicable in any given case. They take their stand, not on any attribute of the things to be defined, but on the limitations of human power; they are confessions of intellectual impotence.

Just as to Columbus long philosophic meditation led him to the fixed belief of the existence of a yet untrodden world beyond that waste of Atlantic waters, so to our most keen-eyed chemists, physicists, and philosophers a variety of phenomena suggest the conviction that the elements of ordinary assumption are not the ultimate boundary in this direction of the knowledge which man may hope to attain. Well do I remember, soon after I had obtained evidence of the distinct nature of thallium, that Faraday said to me, 'To discover a new element is a very fine thing, but if you could decompose an element and tell us what it is made of—that would be a discovery indeed worth making.' And this was no new speculation of Faraday's, for in one of his early lectures he remarked, 'At present we begin to feel impatient, and to wish for a new state of chemical elements. For a time the desire was to add to the metals, now we wish to diminish their number. . . . To decompose the metals, then, to reform them, to change them from one to another, and to realise the once absurd notion of transmutation are the problems now given to the chemist for solution.'

Mr. Herbert Spencer, in his hypothesis of the constitution of matter, says:—'All material substances are divisible into so-called elementary substances composed of molecular particles of the same nature as themselves; but these molecular particles are complicated structures consisting of congregations of truly elementary atoms, identical in nature and differing only in position, arrangement, motion, &c., and the molecules or chemical atoms are produced from the true or physical atoms by processes of evolution under conditions which chemistry has not yet been able to reproduce.'

Mr. Norman Lockyer has shown, I think on good evidence, that, in the heavenly bodies of the highest temperature, a large number of our reputed elements are dissociated, or, as it would perhaps be better to say, have never been formed. Mr. Lockyer holds that 'the temperature of the sun and the electric arc is high enough to dissociate some of the so-called chemical elements, and give us a glimpse of the spectra of their bases'; and he likewise says that 'a terrestrial element is an exceedingly complicated thing that is broken up into simpler things at the temperature of the sun, and some of these things exist in some sun-spots, while other constituents exist in others.'

The late Sir Benjamin Brodie, in a lecture on Ideal Chemistry delivered before the Chemical Society in 1867, goes even further than this. He says:—'We may conceive that, in remote time or in remote space, there did exist formerly, or possibly do exist now, certain simpler forms of matter than we find on the surface of our globe—α, χ, ξ, ν, and so on. . . . We may consider that in remote ages the temperature of matter was much higher than it is now, and that these other things existed then in the state of perfect gases—separate existences—uncombined. . . . We may then conceive that the temperature began to fall, and these things to combine with one another and to enter into new forms of existence, appropriate to the circumstances in which they were placed. . . . We may further consider that, as the temperature went on falling, certain forms of matter became more permanent and more stable, to the exclusion of other forms. . . . We may conceive of this process of the lowering of the temperature going on, so that these substances, when once formed, could never be decomposed—in fact, that the resolution of these bodies into their component elements could never occur again. You would then have something of our present system of things. . . .

'Now this is not purely an imagination, for when we look upon the surface of our globe we have actual evidence of similar changes in Nature. . . . When we look at some of the facts which have been revealed to us by the extraordinary analyses which have been made of the matter of distant worlds and nebulæ, by means of the spectroscope, it does not seem incredible to me that there may even be evidence, some day, of the independent existence of such things as χ and ν.'

In his Burnett Lectures 'On Light as a Means of Investigation,' Professor Stokes, speaking of a line in the spectrum of the nebulæ, says:—'It may possibly indicate some form of matter more elementary than any we know on earth. There seems no *à priori* improbability in such a supposition so great as to lead us at once to reject it. Chemists have long speculated on the so-called elements, or many of them, being merely very stable compounds of elements of a higher order, or even perhaps of a single kind of matter.'

In 1868 Graham wrote of Sir W. Thomson's vortex-ring theory, as enlivening 'matter into an individual existence and constituting it a distinct substance or element.'

From these passages, which might easily be multiplied, it plainly appears that the notion—not necessarily of the decomposability, but at any rate of the complexity of our supposed elements—is, so to speak, in the air of science, waiting to take a further and more definite development. It is important to keep before men's minds the idea of the genesis of the elements; this gives some form to our conceptions, and accustoms the mind to look for some physical production of atoms. It is still more important, too, to keep in view the great probability that there exist in Nature laboratories where atoms are formed and laboratories where atoms cease to be. We are on the track and are not daunted, and fain would we enter the mysterious region which ignorance tickets 'Unknown.' It is for us to strive to unravel the secret composition even of the so-called elements—to undauntedly persevere—and 'still bear up right onward.'

If we adopt the easy-going assumption that the elements, whether self-existent or created, are absolutely and primordially distinct; that they existed as we now find them prior to the origin of stars and their attendant planets, constituting, in fact, the primal 'fire-mist,' we are little, if any, the wiser. We look at their number and at their distinctive properties, and we ask, Are all these points accidental or determinate? In other words, might there as well have been only 7, or 700, or 7,000 absolutely distinct elements as the 70 (in round numbers) which we now commonly recognise? The number of the elements does not, indeed, commend itself to our reason from any *à priori* or extraneous considerations. Might their properties have conceivably differed from those which we actually observe? Are they formed by a 'fortuitous concatenation,' or do they constitute together a definite whole, in which each has its proper part to play, and from which none could be extruded without leaving a recognisable deficiency?

If their peculiarities were accidental it would scarcely be possible for the elements to display those mutual relations which we find brought into such prominent light and order in the periodic classification of Newlands, Mendeleeff, and Meyer. Has not the relation between the atomic weights of the three halogens, chlorine, bromine, and iodine, and their serially varying properties, physical and chemical, been worn nearly threadbare? And the same with the calcium and the sulphur groups? Surely the probability of such relations existing among some 70 bodies which had come into fortuitous existence would prove to be vanishingly small!

We ask whether these elements may not have been evolved from some few antecedent forms of matter—or possibly from only one such—just as it is now held that all the innumerable variations of plants and animals have been developed from fewer and earlier forms of organic life? As Dr. Gladstone well puts it, they 'have been built up one from another, according to some general plan.' This building up, or evolution, is above all things not fortuitous: the variation and development which we recognise in the universe run along certain fixed lines which have been preconceived and foreordained. To the careless and hasty eye design and evolution seem antagonistic; the more careful inquirer sees that evolution, steadily proceeding along an ascending scale of excellence, is the strongest argument in favour of a preconceived plan.

The array of the elements cannot fail to remind us of the general aspect of the organic world. In both cases we see certain groups well filled up, even crowded, with forms having among themselves but little specific difference. On the other hand, in both, other forms stand widely isolated. Both display species that are common and species that are rare; both have groups widely distributed—it might be said cosmopolitan—and other groups of very restricted occurrence. Among animals I may mention as instances the Monotremata of Australia and New Guinea, and among the elements the metals of the so-called rare earths.

Now, as these facts in the distribution of organic forms are generally considered by biological experts to rank among the weightiest evidences in favour of the origin of species by a process of evolution, it seems natural, in this case as in the other, to view existing elements not as primordial but as the gradual outcome of a process of development, possibly even of a 'struggle for existence.' Bodies not in harmony with the present general conditions have disappeared, or perhaps have never existed. Others—the asteroids among the elements—have come into being, and have survived, but only on a limited scale; whilst a third class are abundant because surrounding conditions have been favourable to their formation and preservation.

The analogy here suggested between elements and organisms is, indeed, not the closest, and must not be pushed too far. From the nature of the case there cannot occur in the elements a difference corresponding to the difference between living and fossil organic forms. The 'great stone book' can tell us nothing of extinct elements. Nor would I for a moment suggest that any one of our present elements, however rare, is like a rare animal or plant in process of extinction; that any new element is in the course of formation, or that the properties of existing elements are gradually undergoing modification. All such changes must have been confined to that period so remote as not to be grasped by the imagination, when our Earth, or rather the matter of which it consists, was in a state very different from its present condition. The epoch of elemental development is decidedly over, and I may observe that in the opinion of not a few biologists the epoch of organic development is verging upon its close.

Making, however, every allowance for these distinctions, if evolution be a cosmic law, manifest in heavenly bodies, in organic individuals, and in organic species, we shall in all probability recognise it, though under especial aspects, in those elements of which stars and organisms are in the last resort composed.

Is there, then, in the first place, any direct evidence of the transmutation of any supposed 'element' of our existing list into another, or of its resolution into anything simpler?

To this question I am obliged to reply in the negative.

I doubt whether any chemist here present could suggest a process which would hold out a reasonable prospect of dissociating any of our accepted simple bodies. The highest temperatures and the most powerful electric currents at our disposal have been tried, and tried in vain. At one time there seemed a possibility at least that the interesting researches of Prof. Victor Meyer might show the two higher members of the halogen group, bromine and iodine, as entering upon the path of dissociation. These hopes have not been fulfilled. It may be said, in the general opinion of the most eminent and judicious chemists, that none of the phenomena thus elicited prove that even an approach has been made to the object in view.

Even if we leave our artificial laboratories and seek an escape from the difficulty by observing the processes of the great laboratories of Nature, we feel no sufficiently firm ground.

We find ourselves thus driven to indirect evidence—to that which we may glean from the mutual relations of the elementary bodies. Such evidence of great value is by no means lacking, and to this I now beg to direct attention. First, we may consider the conclusion arrived at by Herschel, and pursued by Clerk-Maxwell, that atoms bear the impress of manufactured articles. Let us look a little more closely at this view. A manufactured article may well be supposed to involve a manufacturer. But it does something more: it implies certainly a raw material, and probably, though not certainly, the existence of by-products, residues, paraleipomena. What or where is here the raw material? Can we detect any form of matter which bears to the chemical elements a relation like that of a raw material to the finished product—like that, say, of coal-tar to alizarin? Or can we recognise any elementary bodies which seem like waste or refuse? Or are all the elements, according to the common view coequals? To these questions no direct answer is as yet forthcoming.

And this leads us up to a hypothesis which, if capable of full demonstration, would show us that the accepted elements are not coequal, but have been formed by a process of expansion or evolution. I refer to the well-known hypothesis of Prout, which regards the atomic weights of the elements as multiples, by a series of whole numbers, of unity = the atomic weight of hydrogen. Everyone is aware that the recent more accurate determinations of the atomic weights of different elements do not by any means bring them into close harmony with the values which Prout's law would require. Still in no small number of cases the actual atomic weights approach so closely to those which the hypothesis demands that we can scarcely regard the coincidence as accidental. Accordingly, not a few chemists of admitted eminence consider that we have here an expression of the truth, masked by some residual or collateral phenomena which we have not yet succeeded in eliminating.

The original calculations on which the most accurate numbers for the atomic weights are founded have recently been recalculated by Mr. F. W. Clarke. In his concluding remarks, speaking of Prout's law, Mr. Clarke says that 'none of the seeming exceptions are inexplicable. In short, admitting half-multiples as legitimate, it is more probable that the few apparent exceptions are due to undetected constant errors than that the great number of close agreements should be merely accidental. I began this recalculation of the atomic weights with a strong prejudice against Prout's hypothesis, but the facts as they came before me have forced me to give it a very respectful consideration.'

But if the evidence in favour of Prout's hypothesis in its original guise is deemed insufficient, may not Mr. Clarke's suggestion of half-multiples place it upon an entirely new basis? Suppose that the unit of the scale, the body whose atomic weight, if multiplied by a series of whole numbers, gives the atomic weights of the remaining elements, is not hydrogen, but some element of still lower atomic weight? We are here at once reminded of helium—an element purely hypothetical as far as our Earth is concerned, but supposed by many authorities, on the faith of spectroscopic observations, to exist in the sun and in other stellar bodies. Most solar eruptions present merely the characteristic lines of hydrogen C, F, and H, and along with them one particular line which at first was classed in the sodium group, but which is a little more refrangible, and is designated by the symbol D_3. According to Mr. Norman Lockyer and the late Father Secchi, this ray undergoes modifications not comparable to those affecting other rays of the chromosphere. In the corresponding region of the spectrum no dark ray has been observed. That the accompanying lines C, F, and H pertain to hydrogen is evident; and as D_3 has never been obtained in any other spectrum, it is supposed to belong to a body foreign to our Earth, though existing in abundance in the chromosphere of the sun. To this hypothetical body the name helium is assigned.

In an able memoir on this subject, read before the Academy of Brussels, the Abbé E. Spée shows that, if helium exists, it enjoys two very remarkable properties. Its spectrum consists of a single ray, and its vapour possesses no absorbent power. The simple single ray, though I believe unexampled, is by no means an impossible phenomenon, and indicates a remarkable simplicity of molecular constitution. The non-absorbent property of its vapour seems to be a serious objection to a general physical law. Professor Tyndall has demonstrated that the absorptive power increases with the complexity of molecular structure, and hence he draws the conclusion that the simpler the molecule the feebler the absorption. This conclusion the Abbé Spée regards as perfectly legitimate; but it neither explains nor even necessitates the absence of *all* absorptive power.

Granting that helium exists, all analogy points to its atomic weight being below that of hydrogen. Here, then, we may have the very element, with atomic weight half that of hydrogen, required by Mr. Clarke as the basis of Prout's law.

But a more important piece of evidence for the compound nature of the chemical elements has yet to be considered. Many chemists must have been struck with certain peculiarities in the occurrence of the elements in the Earth's crust; it is a stale remark that we do not find them evenly distributed throughout the globe. Nor are they associated in accordance with their specific gravities; the lighter elements placed on or near the surface, and the heavier ones following serially deeper and deeper. Neither can we trace any distinct relation between local climate and mineral distribution. And by no means can we say that elements are always or chiefly associated in nature in the order of their so-called chemical affinities; those which have a strong tendency to form with each other definite chemical combinations being found together, whilst those which have little or no such tendency exist apart. We certainly find calcium as carbonate and sulphate, sodium as chloride, silver and lead as sulphides; but why do we find certain groups of elements with little affinity for each other yet existing in juxtaposition or commixture? The members of some of these groups are far from plentiful, not generally or widely diffused, and certainly they are not easy to separate.

As instances of such grouping we may mention—

1. Nickel and cobalt, of which it may be said that had their compounds been colourless they would have been long regarded as identical, and possibly even yet would not have been separated.
2. The two groups of platinum metals.
3. The so-called 'rare earths,' occurring in gadolinite, samarskite, &c. and evidently becoming more numerous the more closely they are examined.

Certain questions here suggest themselves:—Is the series of these elements like a staircase or like an inclined plane? Will they, the more closely they are scrutinised, be found to fade away the more gradually the one into the other? Further, will a mixture hitherto held to be simple, like (*e.g.*) didymium, be capable of being split up in one direction only, or in several? I have been led to ask this last question because I have separated from didymium bodies which seem to agree neither with the praseodymium and neodymium of Dr. Auer von Welsbach, nor with the components detected by M. de Boisbaudran and M. Demarçay.

Why, then, are these respective elements so closely associated? What agency has brought them together?

An eminent physicist evades the difficulty by suggesting that their joint occurrence is simply an instance of the working of the familiar principle 'Birds of a feather flock together.' In their chemical and physical attributes these rare earths are so closely similar that they may be regarded as substantially identical in all the circumstances of solution and precipitation to which they may have been exposed during geological ages.

But do we, in point of fact, recognise any such agency at work in Nature? Is there any power which regularly and systematically sorts out the different kinds of matter from promiscuous heaps, conveying like to like and separating unlike from unlike? I must confess that I fail to trace any such distributive agency, nor, indeed, do I feel able to form any distinct conception of its nature.

I must here remark that coral worms in some cases do effect a separation of certain kinds of matter. Thus a *Gorgonia* of the species *Melithæa*, and *Mussa sinuosa*, undoubtedly eliminate from sea-water not merely lime, but even yttria; and other recent corals, *Pocillopora damicornis*, and a *Symphyllia* close to the yttria-secreting *Mussa*, separate samaria from sea-water. Sea-weeds and aquatic mollusks contain a larger proportion of iodine and bromine than the waters which they inhabit, and may thus be said to separate out these elements from the chlorine with which they are mingled.

But if we examine these cases of elimination we see that they are limited in their scope. They extend only to substances existing in solution, of which there is a fresh supply always at hand, and which are capable of entering into the animal or vegetable economy. Again, the elimination of iodine and bromine, effected as just described, is of a very imperfect character, and, when such water-plants and animals die and decay, their constituents will be again distributed in the water.

We cannot well consider that nickel and cobalt have been deposited in admixture by organic agency, nor yet the groups iridium, osmium, and platinum—ruthenium, rhodium, and palladium.

Since the earthy metals to which I have referred—such as yttrium, samarium, holmium, erbium, thulium, ytterbium, &c.—are very rare, the probability of their ever having been brought together in some few uncommmon minerals discovered only in a few localities must be regarded as trifling indeed, if we suppose that these metals had at any time been widely diffused in a state of great dilution with other matter. The features which we have just recognised in these earths seem to point to their formation severally from some common material placed in conditions in each case nearly identical. The case is strengthened by a consideration of the other groups of elements, also similar in properties, having little affinity for each other and occurring in admixture; either all or at least some of the elements concerned being moreover decidedly rare. Thus we have nickel and cobalt not plentiful or widely distributed; cobalt, perhaps, never found absolutely free from nickel, and *vice versâ*. We have also the two platinum groups, where very similar features prevail.

A weighty argument in favour of the compound nature of the elements is that drawn from a consideration of the compound radicles, or, as they might be called, pseudo-elements. Their similarity with the accepted elements is perfectly familiar to all chemists. If, for example, we suppose that in some age or in some country men of science were cognisant of the existence and of the behaviour of cyanogen, but had not succeeded in resolving it into its constituents, nothing, surely, would prevent their viewing it as an element, and assigning it a place with the halogens. It may fairly be held that if a body which we know to be compound can be found playing the part of an element, this fact lends a certain plausibility to the supposition that the elements also are not absolutely simple. This line of thought, or at least one closely approximating to it, was worked out by Dr. Carnelley in a paper read before this Association at its last meeting. From a comparison of the physical properties of inorganic with those of organic compounds, Dr. Carnelley concludes that '*the elements, as a whole, are analogous to the hydrocarbon radicles.*' This conclusion, if true, he adds, should lead to the further inference that the so-called elements are not truly elementary, being made up of at least two absolute elements, named provisionally A and B. Hence, he argues, it should be possible to build up a series of compounds of these two primary elements which would correspond to what we now call elements. Such an arrangement, to be admissible, would have to fulfil certain conditions:—The secondary elements thus generated from A and B must exhibit the phenomena of periodicity, and the series would have to form octaves; the entire system is bound to display some feature corresponding to the 'odd and even series' of Mendeleeff's classification; the atomic weights must increase across the system from the first to the seventh group; that is, from the positive to the negative end of each series; the atomicity would have to increase from the first to the middle group, and then either increase or decrease to the seventh group; some feature should appear corresponding to the eighth group; and, lastly, the atomic weights in such a system ought to agree with the atomic weights as experimentally determined.

This last condition Dr. Carnelley rightly regards as the most crucial, and he finds his arrangement gives atomic weights which in a majority of instances coincide approximately with the actual atomic weights. Thus out of a total of sixty-one elements whose atomic weights have been determined with at least approximate accuracy, and whose places in the periodic system are not disputed, twenty-seven agree almost exactly with the actual numbers, whilst nineteen others are not more than one unit astray.

For a detailed consideration of the conclusions which follow from Dr. Carnelley's views I must refer to his paper as read at our last meeting. Two points bear more especially upon the subject now under consideration—that is, if this speculation on the genesis of the elements is well founded. First, the existence of elements of identical atomic weights, isomeric with each other, would be possible; as such Dr. Carnelley mentions respectively nickel and cobalt (now found to have slightly different atomic weights), rhodium and ruthenium, osmium and iridium, and the metals of some of the rare earths. Secondly, in Dr. Carnelley's scheme all the chemical elements save hydrogen are supposed to be composed of two simpler elements, $A = 12$ and $B = -2$. Of these he regards A as a tetrad identical with carbon, and B as a monad of negative weight—perhaps the ethereal fluid of space.

Dr. Carnelley's three primary elements therefore are carbon, hydrogen, and the ether.

Starting from the supposition that pristine matter was once in an intensely heated condition, and that it has reached its present state by a process of free cooling, Dr. E. J. Mills suggests that the elements as we now have them are the result of successive polymerisations. Dr. Mills reminds us that chemical substances in the process of cooling naturally increase in density, and, if such increase be measured as a function of time or of temperature, we sometimes observe that there are critical points corresponding to the formation of new and well-defined substances. In this manner, ordinary phosphorus is converted into the red variety, I is transformed into I_2, S_2 becomes S_6, and NO_2 N_2O_4. Among organic bodies styrol, in like manner, according to Dr. Mills, is converted into metastyrol, aldehyd into paraldehyd, the cyanates into cyanurates, and turpentine into metaterebenthene. At the critical points above referred to heat is liberated in especial abundance, and the bodies thus formed are known as polymers. If we could gradually cool down substances through a vast range of temperature, we should then probably discover a much greater number of such critical points, or points of multiple proportion, than we have been able to discover experimentally.

The heat given out in the act of polymerisation naturally reverses to some extent the polymerisation itself, and so causes a partial return to the previous condition of things. This forward and backward movement, several times repeated, constitutes 'periodicity.' Dr. Mills regards variable stars as instances, now in evidence, of the genesis of elementary bodies.

From a study of the classification of the elements, Dr. Mills is of opinion that the only known polymers of the primitive matter are arsenic, antimony, and perhaps erbium and osmium; whilst zirconium, ruthenium, samarium, and platinum approximate to the positions of other polymers. Hence, from this genetic view, these elements may be described as products of successive polymerisations.

I must now call attention to a method of illustrating the periodic law, proposed by my friend Professor Emerson Reynolds, of the University of Dublin, which will here assist us. Professor Reynolds points out that in each period the general properties of the elements vary from one to another with approximate regularity until we reach the seventh member, which is in more or less striking contrast with the first element of the same period, as well as with the first of the next. Thus chlorine, the seventh member of Mendeleeff's third period, contrasts sharply both with sodium, the first member of the same series, and with potassium, the first member of the next series; whilst, on the other hand, sodium and potassium are closely analogous. The six elements whose atomic weights intervene between sodium and potassium vary in properties, step by step, until chlorine, the contrast to sodium, is reached. But from chlorine to potassium, the analogue of sodium, there is a change in properties *per saltum*. Further, such alternations of gradual and abrupt transitions are observed as the atomic weights increase. If we thus recognise a contrast in properties—more or less decided—

between the first and the last members of each series, we can scarcely help admitting the existence of a point of mean variation within each system. In general, the *fourth* element of each series possesses the properties we might expect a transition-element to exhibit. If we examine a particular period—for instance, that one whose meso-element is silicon, we note:—*First*, that the three elements of lower atomic weight than silicon, viz. sodium, magnesium, and aluminium, are distinctly *electro-positive* in character, while those of higher atomic weight, viz., phosphorus, sulphur, and chlorine, are as distinctly *electro-negative*. Throughout the best known periods this remarkable subdivision is observable, although, as might be anticipated, the differences become less strongly marked as the atomic weights increase. *Secondly*, that the members above and below the meso-element fall into pairs of elements, which, while exhibiting certain analogies, are generally in more or less direct chemical contrast. Thus, in the silicon period we have—

Si^{iv}

$+ Al'''$	$P''' -$
$+ Mg''$	$S'' -$
$+ Na'$	$Cl' -$

This division also happens, in many cases, to coincide with some characteristic valence of the contrasted elements. It is noteworthy, however, that the members on the electro-negative side exhibit the most marked tendency to variation in atom-fixing power, so that valence alone is an untrustworthy guide to the probable position of an element in a period.

Thus for the purpose of graphic translation Professor Reynolds considers that the fourth member of a period—silicon, for example—may be placed at the apex of a symmetrical curve, which shall represent, for that particular period, the direction in which the properties of the series of elements vary with rising atomic weights.

In the drawing before you (fig. 1) I have modified Professor Reynolds's diagram in one or two points. I have turned it the reverse way, as it is more convenient to start from the top and proceed downwards. I have represented the pendulous swing as gradually declining in amplitude according to a mathematical law, and I have introduced another half-swing of the pendulum between cerium and lead, which not only renders the oscillations more symmetrical, but brings gold, mercury, thallium, lead, and bismuth on the side where they are in complete harmony with members of foregoing groups, instead of being out of harmony with them. This modification has another advantage, inasmuch as it leaves many gaps to be hereafter filled in with new elements just when the development of research is beginning to demand room for such expansion.

I do not, however, wish to infer that the gaps in Mendeleeff's table, and in this graphic representation of it, necessarily mean that there are elements actually existing to fill up the gaps; these gaps may only mean that at the birth of the elements there was an easy potentiality of the formation of an element which would fit into the place.

Following the curve from hydrogen downwards we find that the elements forming Mendeleeff's eighth group are to be found near three of the ten nodal points. These bodies are 'interperiodic,' both because their atomic weights exclude them from the small periods into which the other elements fall, and because their chemical relations with certain members of the adjacent periods show that they are probably interperiodic in the sense of being transitional.

This eighth group is divided into the three triplets—iron, nickel, and cobalt; rhodium, ruthenium, and palladium; iridium, osmium, and platinum. The members of each triplet have often been regarded as modifications of one single form of matter.

Notice how accurately the series of like bodies fits into this scheme. Beginning at the top, run the eye down analogous positions in each oscillation, taking either the electro-positive or electro-negative swings:—

N	Be	Li	Na	Mg	Al	Si	P	S	Cl	C
V	Ca	K	Cu	Zn	Ga	Ge	As	Se	Br	Ti
Nb	Sr	Rb	Ag	Cd	In	Sn	Sb	Te	I	Zr
—	Ba	Cs	—	—	—	—	—	—	—	—
Ta			Au	Hg	Tl	Pb	Bi			

Notice, also, how orderly the metals discovered by spectrum analysis fit in their places—gallium, indium, and thallium.

The symmetry of nearly all this series proclaims at once that we are working in

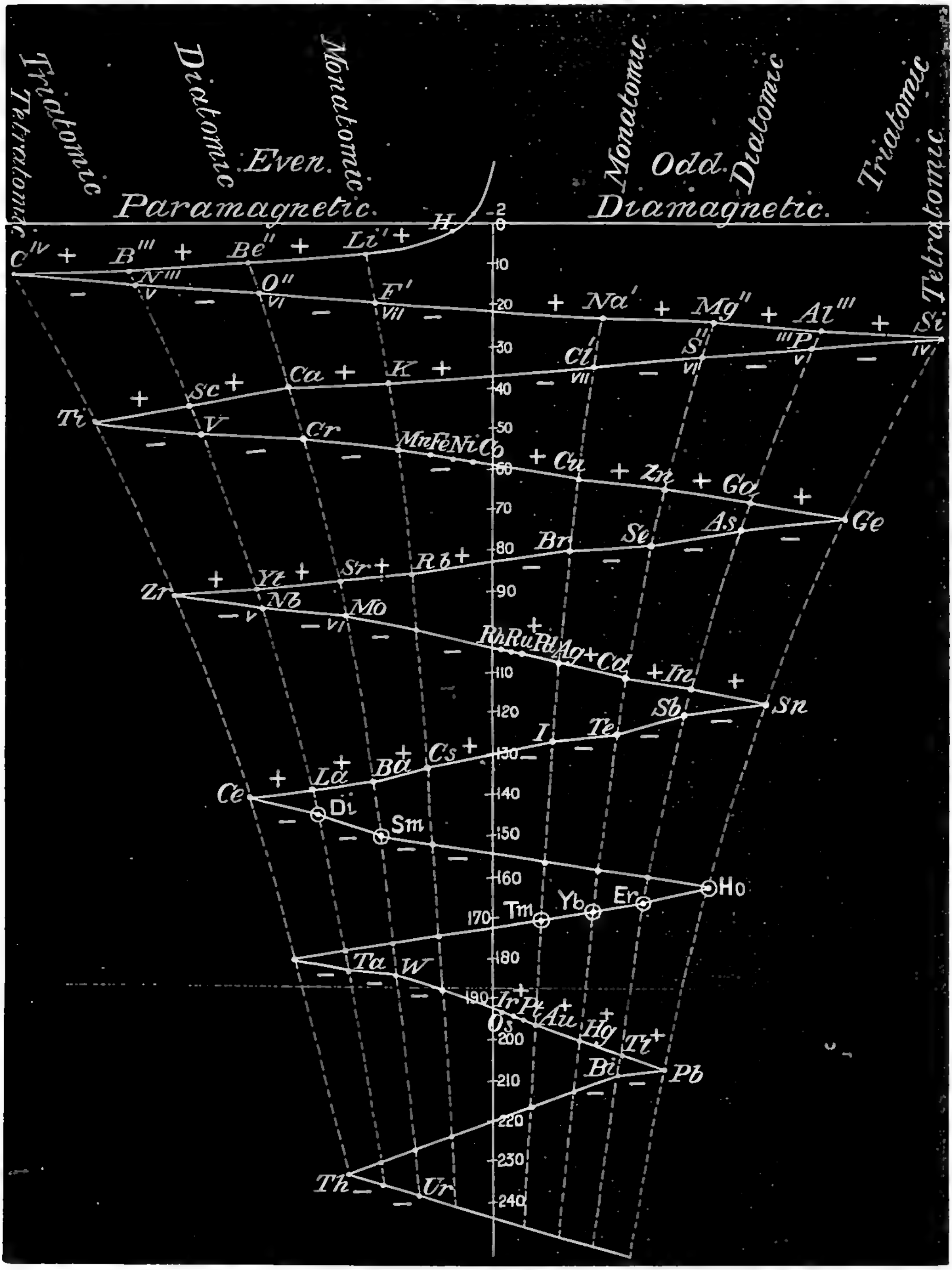

FIG. 1.

the right direction. We can also learn much from the anomalies here visible. Look at the places marked with a circle; didymium, samarium, holmium, erbium, ytterbium, and thulium. Didymium cannot follow in order after the triad nitrogen, vanadium, columbium; nor erbium follow phosphorus, arsenic, antimony; nor thulium follow chlorine, bromine, iodine; nor ytterbium follow potassium, rubidium, cæsium. The inference to be drawn is that these bodies are out of place, owing to their atomic weights not having been correctly determined—an inference which is strengthened by the knowledge that the elementary character of some of these bodies is more than doubtful, whilst the chemical attributes of most of them are unknown.

The more I study the arrangement of this zigzag curve the more I am convinced that he who grasps the key will be permitted to unlock some of the deepest mysteries of creation. Let us imagine if it is possible to get a glimpse of a few of the secrets here hidden. Let us picture the very beginnings of time, before geological ages, before the earth was thrown off from the central nucleus of molten fluid, before even the sun himself had consolidated from the original *protyle*.[1] Let us still imagine that at this primal stage all was in an ultragaseous state, at a temperature inconceivably hotter[2] than anything now existing in the visible universe; so high, indeed, that the chemical atoms could not yet have been formed, being still far above their dissociation-point. In so far as *protyle* is capable of radiating or reflecting light, this vast sea of incandescent mist, to an astronomer in a distant star, might have appeared as a nebula, showing in the spectroscope a few isolated lines, forecasts of hydrogen, carbon, and nitrogen spectra.

But in course of time some process akin to cooling, probably internal, reduces the temperature of the cosmic *protyle* to a point at which the first step in granulation takes place; matter, as we know it, comes into existence, and atoms are formed. As soon as an atom is formed out of *protyle* it is a store of energy, potential (from its tendency to coalesce with other atoms by gravitation or chemically) and kinetic (from its internal motions). To obtain this energy the neighbouring *protyle* must be refrigerated by it,[3] and thereby the subsequent formation of other atoms will be accelerated. But with atomic matter the various forms of energy which require matter to render them evident begin to act; and, amongst others, that form of energy which has for one of its factors what we now call *atomic weight*. Let us assume that the elementary *protyle* contains within itself the potentiality of every possible combining proportion or atomic weight. Let it be granted that the whole of our known elements were not at this epoch simultaneously created. The easiest formed element, the one most nearly allied to the *protyle* in simplicity, is first born. Hydrogen—or shall we say helium?—of all the known elements the one of simplest structure and lowest atomic weight, is the first to come into being. For some time hydrogen would be the only form of matter (as we now know it) in existence, and between hydrogen and the next formed element there would be a considerable gap in time, during the latter part of which the element next in order of simplicity would be slowly approaching its birth-point: pending this period we may suppose that the evolutionary process which soon was to determine the birth of a new element would also determine its atomic weight, its affinities, and its chemical position.

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[1] We require a word, analogous to protoplasm, to express the idea of the original primal matter existing before the evolution of the chemical elements. The word I have ventured to use for this purpose is compounded of πρό (*earlier than*) and ὕλη (*the stuff of which things are made*). The word is scarcely a new coinage, for 600 years ago Roger Bacon wrote in his *De Arte Chymiæ*, 'The elements are made out of ὕλη, and every element is converted into the nature of another element.'

[2] I am constrained to use words expressive of high temperature; but I confess I am unable clearly to associate with *protyle* the idea of hot or cold. *Temperature*, *radiation*, and *free cooling* seem to require the periodic motions that take place in the chemical atoms; and the introduction of centres of periodic motion into protyle would constitute its being so far changed into chemical atoms.

[3] I am indebted to my friend G. Johnstone Stoney, F.R.S., for the idea here put forward, as well as for other valuable suggestions and criticisms on some of the theoretical questions here treated of.

In the original genesis the longer the time occupied in that portion of the cooling down during which the hardening of the *protyle* into atoms took place, the more sharply defined would be the resulting elements; and, on the other hand, with more irregularity in the original cooling, we should have a nearer approach to the state of the elemental family such as we know it at present.

In this way it is conceivable that the succession of events which gave us such groups as platinum, osmium, and iridium—palladium, ruthenium, and rhodium—iron, nickel, and cobalt, if the operation of genesis had been greatly more prolonged, would have resulted in the birth of only one element of these groups. It is also probable that by a much more rapid rate of cooling, elements would originate even more closely related than are nickel and cobalt, and thus we should have formed the nearly allied elements of the cerium, yttrium, and similar groups; in fact the minerals of the class of samarskite and gadolinite may be regarded as the cosmical lumber-room where the elements in a state of arrested development—the unconnected missing links of inorganic Darwinism—are finally aggregated.

I have said that the original *protyle* contained within itself the potentiality of all possible atomic weights. It may well be questioned whether there is an absolute uniformity in the mass of every ultimate atom of the same chemical element. Probably our atomic weights merely represent a mean value around which the actual atomic weights of the atoms vary within certain narrow limits.

Each well-defined element represents a platform of stability connected by ladders of unstable bodies. In the first accreting together of the primitive stuff the smallest atoms would form, then these would join together to form larger groups, the gulf across from one stage to another would be gradually bridged over, and the stable element appropriate to that stage would absorb, as it were, the unstable rungs of the ladder which led up to it. I conceive, therefore, that when we say the atomic weight of, for instance, calcium is 40, we really express the fact that, while the majority of calcium atoms have an actual atomic weight of 40, there are not a few which are represented by 39 or 41, a less number by 38 or 42, and so on. We are here reminded of Newton's 'old worn particles.'

Is it not possible, or even feasible, that these heavier and lighter atoms may have been in some cases subsequently sorted out by a process resembling chemical fractionation? This sorting out may have taken place in part while atomic matter was condensing from the primal state of intense ignition, but also it may have been partly effected in geological ages by successive solutions and reprecipitations of the various earths.

This may seem an audacious speculation, but I do not think it is beyond the power of chemistry to test its feasibility. An investigation on which I have been occupied for several years has yielded results which to me appear apposite to the question, and I therefore beg permission here to allude briefly to some of the results, reserving details to a subsequent communication to the Section.

My work has been with the earths present in samarskite and gadolinite, separating them by systematic fractionation. Chemical fractionation, on which I hope to say more on another occasion, is very similar to the formation of a spectrum with a wide slit and a succession of shallow prisms. The centre portion remains unchanged for a long time, and the only approach to purity at first is at the two ends, while a considerable series of operations is needed to produce an appreciable change in the centre. The groups of didymium and yttrium earths are those which have chiefly occupied my attention. On comparing these rare earths we are at once struck with the close mutual similarity, verging almost into identity, of the members of the same group.

The phosphorescent spectra of these earths when their anhydrous sulphates are submitted to the induction discharge *in vacuo* are extremely complicated, and change in their details in a puzzling manner. For many years I have been persistently groping on in almost hopeless endeavour to get a clue to the meaning I felt convinced was locked up in these systems of bands and lines. It was impossible to divest myself of the conviction that I was looking at a series of autograph inscriptions from the molecular world, evidently of intense interest, but written in a strange and baffling tongue. All attempts to decipher the mysterious signs were, however, for a long time fruitless. I required a Rosetta stone.

Down to a date comparatively recent nothing was more firmly fixed in my mind than the notion that yttria was the oxide of a simple body, and that its phosphorescent spectrum gave a definite system of coloured bands, such as you see in the drawing before you (fig. 2). Broadly speaking, there is a deep red band, a red band, a very luminous citron-coloured band, a pair of greenish-blue bands, and a blue band. It is true these bands varied slightly in relative intensities and in sharpness with almost every sample of yttria I examined; but the general character of the spectrum remained unchanged, and I had got into the way of looking upon this spectrum as characteristic of yttria: all the bands being visible when the earth was present in quantity, whilst only the strongest band of all—the citron band—was visible when traces, such as millionths, were present. But that the whole system of bands spelled yttria, and nothing but yttria, I was firmly convinced.

During the later fractionations of the yttria earths, and the continued observations of their spectra, certain suspicions which had troubled me for some time assumed consistent form. The bands which hitherto I had thought belonged to yttria began to vary in intensity among themselves, and continued fractionation increased the differences first observed. Whilst I was in this state of doubt and uncertainty, and only beginning to see my way towards arranging into a consistent whole the facts daily coming to light, help came from an unexpected quarter. M. de Marignac, with whom I had been for some time in correspondence, kindly sent me a small specimen of the earth which he had discovered and provisionally named Y*a* (now Gadolinia). In the radiant-matter tube this earth gave a bright spectrum, like the one in the diagram before you (fig. 3). The spectrum above it (fig. 2) is that ascribed to yttria. Look at the two. Omitting minor details, Y*a* is yttria with the chief characteristic band—the citron band—left out, and with the double green band of samaria added to it. Now look at fig. 4, which represents the spectrum of a mixture of sixty-one parts of yttria and thirty-nine parts of samaria. It is identical almost to its minutest detail with the spectrum of Y*a*,

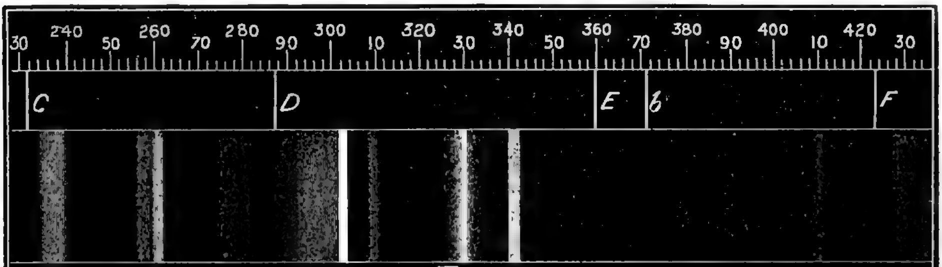

Fig. 2. Yttria

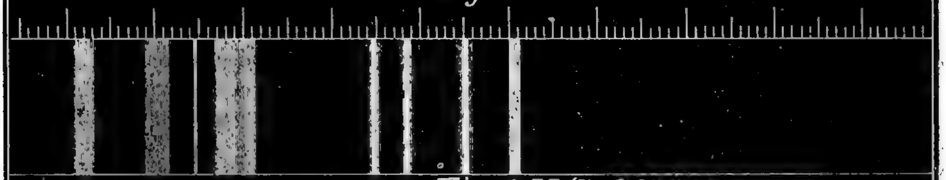

Fig. 3. Ya (Gadolinia)

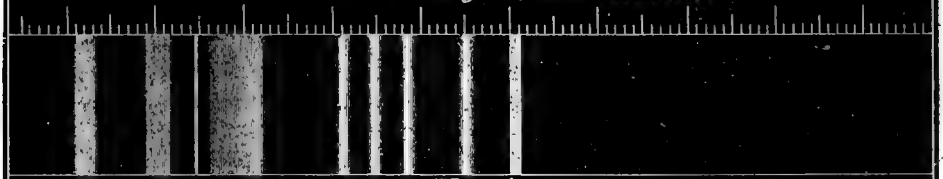

Fig. 4. Yttria 61 Samaria 39.

with this not unimportant difference—the citron band is as prominent as any other line. Y*a* consists, therefore, of samaria with the greenish blue of yttria and some of the other yttria bands added to it.

I may aptly call the Y*a* spectrum my Rosetta stone. It threw a flood of light on all the obscurities and contradictions I had found so plentiful, and showed me that a much wider law than the one I had been working upon was the true law governing the occurrence of these obscure phenomena. For what does the spectrum of Y*a* show? It proves that what I had hitherto thought was one of the chief bands in the yttria spectrum—the citron band—could be entirely removed, whilst another characteristic group—the double green of yttria—could also be separated from the citron.

It would exceed legitimate limits were I to enter into details respecting the chemical and physical reasons which led me to these definite conclusions. To settle one single point more than 2,000 fractionations have been performed.

The meaning of the strongly marked symbolic lines had first to be ascertained. For a long time I had to be content with roughly translating one group of coloured symbols as 'yttrium' and another group as 'samarium,' disregarding the fainter lines, shadows, and wings frequently common to both. Constant practice in the decipherment has now given me fuller insight into what I may call the grammar of these hieroglyphic inscriptions. Every line and shadow of a line, each faint wing attached to a strong band, and every variation in intensity of the shadows and wings among themselves, now has a definite meaning which can be translated into the common symbolism of chemistry.

In a mineral containing the rarer earths those most widely separated in chemical properties are most easily obtained in a state of comparative purity by simple chemical means. For instance, in separating didymium from lanthanum, or samarium from yttrium, a few simple chemical reactions and a little waste will give these bodies in a state of purity; but when it comes to splitting up yttrium into its components ordinary chemical separation is useless, and fractionation must be pushed to the utmost limit, many thousand operations and enormous waste of material being necessary to effect even a partial separation.

Returning, therefore, after this explanatory digression, to the idea of heavy and light atoms, we see how well this hypothesis accords with the new facts here brought to light. From every chemical point of view the stable molecular group, yttrium, behaves as an element. Excessive and systematic fractionation has acted the part of a chemical 'sorting Demon,' distributing the atoms of yttrium into several groups, with certainly different phosphorescent spectra, and presumably different atomic weights, though all these groups behave alike from the usual chemical point of view. Here, then, is one of the elements the spectrum of which does not emanate equally from all its atoms, but some atoms furnish some, other atoms others, of the lines and bands of the compound spectrum of the element. And as this is the case with one element, it is probably so in a greater or less degree with all. Hence the atoms of this element differ probably in weight, certainly in the internal motions they undergo.

Another important inference which may be drawn from the facts is that the atoms of which yttrium consists, though differing, do not differ continuously, but *per saltum*. We have evidence of this in the fact that the spectroscopic bands characteristic of each group are distinct from those of the other groups, and do not pass gradually into them. We must accordingly expect, in the present state of science, that this is probably the case with the other elements. And the atoms of a chemical element being known to differ in one respect may differ in other respects, and presumably do somewhat differ in mass.

Restricted by limited time and means, even a partial separation of these atomic groupings is possible to me only with enormous difficulty. Have we any evidence that Nature has effected such a separation? The following facts I think supply this evidence.

The earth yttria occurs in several minerals, all extremely rare. These minerals are of very diverse chemical composition, and occur in localities widely separated geographically. Does the pure yttria (*pure* in respect to every other known element) from these different sources behave differently to the radiant-matter test? To the chemist hitherto the earth yttria has been the same thing and has possessed the same properties, whatever its source; but armed with this new power of seeing into the atomic groupings which go to make up yttrium, we find evidence of differentiation between one yttrium and another.

Thus when the samarskite yttrium was formed all the constituent atoms—deep red, red, orange, citron, greenish-blue, and blue[1]—condensed together in fair proportion, the deep red being faintest. In gadolinite yttrium the citron and greenish-blue constituents are plentiful, the red is very deficient, the orange is absent, and the others occur in moderate quantities. In the yttrium from xenotime the citron is most plentiful, the greenish-blue occurs in smaller proportion, the red is all but absent, and the orange is quite absent. Yttrium from monazite contains the greenish-blue and citron, with a fair proportion of the other constituents; the greenish-blue is plentiful, and the red is good. Yttrium from fluocerite is very similar to that from monazite, but the blue is weaker. Yttrium from hielmite is very rich in citron, has a fair quantity of blue and greenish-blue, less of red, no orange, and only a very faint trace of deep red. Yttria from euxenite is almost identical with that from hielmite. Yttria from cerite contains most red and citron, a fair amount of orange, less greenish-blue and blue, and only a trace of deep red.

This is unlikely to be an isolated case. The principle is very probably of general application to all the elements. In some, possibly in all elements, the whole spectrum does not emanate from all its atoms, but different spectral rays may come from different atoms, and in the spectrum as we see it all these partial spectra are present together. This being interpreted means that there are definite differences in the internal motions which go on in the several groups of which the atoms of a chemical element consist. For example, we must now be prepared for some such events as that the seven series of bands in the absorption-spectrum of iodine may prove not all to emanate from every molecule, but that some of these molecules emit some of these series, others others, and in the jumble of all these kinds of molecules, to which is given the name 'iodine vapour,' the whole seven series are contributors.

To me it appears the theory I have here ventured to formulate, taken in conjunction with the diagram in fig. 1, may aid the scientific imagination to proceed a step or two further in the order of elemental evolution. In the undulating curve may be seen the action of two forces, one acting in the direction of the vertical line, and the other pulsating backwards and forwards like a pendulum. Assume the vertical line to represent temperature slowly sinking through an unknown number of degrees, from the dissociation-point of the first-formed element down to the dissociation-point of those last shown on the scale. But what form of energy is represented by the oscillating line? Swinging to and fro like a mighty pendulum to points equidistant from a neutral centre; the divergence from neutrality conferring atomicity of one, two, three, and four degrees as the distance from the centre is one, two, three, or four divisions; and the approach to, or retreat from, the neutral line deciding the electro-negative or electro-positive character of the element—all on the retreating half of the swing being positive and all on the approaching half negative—this oscillating force must be intimately connected with the imponderable matter, essence, or source of energy we call electricity.

Let us examine this a little more closely. Let us start at the moment when the first element came into existence. Before this time matter, as we know it, was not. It is equally impossible to conceive of matter without energy, as of energy without matter; from one point of view the two are convertible terms. Before the birth of atoms all those forms of energy which become evident when matter acts upon matter could not have existed—they were locked up in the *protyle* as latent potentialities only. Coincident with the creation of atoms all those attributes and properties which form the means of discriminating one chemical element from another start into existence fully endowed with energy.

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[1] For brevity I call them by their dominant spectrum band.

The pendulum begins its swing from the electro-positive side; lithium, next to hydrogen in simplicity of atomic weight, is now formed: then glucinum, boron, and carbon. Definite quantities of electricity are bestowed on each element at the moment of birth, on these quantities its atomicity depends,[1] and the types of monatomic, diatomic, triatomic, and tetratomic elements are fixed. The electro-negative part of the swing now commences; nitrogen appears, and notice how curiously position governs the mean dominant atomicity. Nitrogen occupies the position below boron, a triatomic element, therefore nitrogen is triatomic. But nitrogen also follows carbon, a tetratomic body, and occupies the fifth position counting from the place of origin. How beautifully these opposing tendencies are harmonised by the endowment of nitrogen with at least a double atomicity, and making its atom capable of acting as tri- and pentatomic. With oxygen (di- and hexatomic) and fluorine (mon- and heptatomic) the same law holds, and one-half oscillation of the pendulum is completed. Again passing the neutral line the electro-positive elements sodium (monatomic), magnesium (diatomic), aluminium (triatomic), and silicon (tetratomic) are successively formed, and the first complete oscillation of the pendulum is finished by the birth of the electro-negative elements, phosphorus, sulphur, and chlorine; these three—like the corresponding elements formed on the opposite homeward swing—having each at least a double atomicity depending on position.

Let us pause at the end of the first complete vibration and examine the result. We have already formed the elements of water, ammonia, carbonic acid, the atmosphere, plant and animal life, phosphorus for the brain, salt for the sea, clay for the solid earth, two alkalies, an alkaline earth, an earth, together with their carbonates, borates, nitrates, fluorides, chlorides, sulphates, phosphates, and silicates, sufficient for a world and inhabitants not so very different from what we enjoy at the present day. True, the human inhabitants would have to live in a state of more than Arcadian simplicity, and the absence of calcic phosphate would be awkward as far as bone is concerned. But what a happy world it would be! No silver or gold coinage, no iron for machinery, no platinum for chemists, no copper wire for telegraphy, no zinc for batteries, no mercury for pumps, and, alas! no rare earths to be separated.

The pendulum does not, however, stop at the end of the first complete vibration; it crosses the neutral point, and now the forces at work are in the same position as they were at the beginning. Had everything been as it was at first, the next element again would have been lithium, and the original cycle would have recurred, repeating for ever the same elements. But the conditions are not quite the same; the form of energy represented by the vertical line has declined a little—the temperature has sunk—and not lithium, but the one next allied to it in the series comes into existence—potassium, which may be regarded as the lineal descendant of lithium, with the same hereditary tendencies, but with less molecular mobility and higher atomic weight.

Pass we rapidly along the to and fro curve, and in nearly every case the same law is seen to hold good. The last element of the first complete vibration is chlorine. In the corresponding place in the second vibration we do not have an exact repetition of chlorine, but the very similar body bromine; and when for a third time the position recurs we see iodine. I need not multiply examples.

In this far-reaching evolutionary scheme it could not come to pass that the

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[1] 'Nature presents us with a single definite quantity of electricity. . . . For each chemical bond which is ruptured within an electrolyte a certain quantity of electricity traverses the electrolyte, which is the same in all cases.'—G. Johnstone Stoney, 'On the Physical Units of Nature.' *British Association Meeting*, 1874, Section A. *Phil. Mag.*, May 1881.

'The same definite quantity of either positive or negative electricity moves always with each univalent ion, or with every unit of affinity of a multivalent ion.'—Helmholtz, Faraday Lecture, 1881.

'Every monad atom has associated with it a certain definite quantity of electricity; every dyad has twice this quantity associated with it; every triad three times as much, and so on.'—O. Lodge, 'Or Electrolysis,' *British Association Report*, 1885.

potential elements would all be equal to one another. Some would be unable to resist the slightest disturbance of the unstable equilibrium in which they took their rise; others would endure longer, but would ultimately break down as temperature and pressure varied. Many degrees of stability would be here represented; not all the chemical elements are equally stable, and if we look with scrutinising eyes we shall still see our old friend the missing link, coarse enough to be detected by ordinary chemical processes, associated in the groups containing such elements as iron, nickel, and cobalt; palladium, ruthenium, and rhodium; iridium, osmium, and platinum. Whilst in their more subtile form these missing links present themselves as the representatives of the differences which I have detected and described between the atoms of the same chemical element.

Dr. Carnelley has pointed out that 'those elements belonging to the even series of Mendeleeff's classification are always paramagnetic, whereas the elements belonging to the odd series are always diamagnetic.' On this curve the even series to the left, as far as can be ascertained, are paramagnetic, and, with a few exceptions, all to the right are diamagnetic. The very powerful magnetic metals, iron, nickel, cobalt, and manganese, occur close together on the proper side. The interperiodic groups of which palladium and platinum are examples are said to be feebly magnetic, and if so they form the exceptions. Oxygen, which, weight for weight, is more magnetic than iron, comes near the beginning of the curve, while the powerfully diamagnetic metals, bismuth and thallium, are at the opposite end of the curve.

On the odd, or diamagnetic half of the swing, the energy appears to have considerable regularity, whilst it is very irregular on the opposite side of the curve. Thus, between the extreme odd elements, silicon (28), germanium (73), tin (118), the missing element (163), and lead (208), there is a difference of exactly 45 units, conferring remarkable symmetry on one half of the curve. The differences on the even side are 36, 42, 51, 39, and 53 (giving the missing element between cerium and thorium an atomic weight of 180); these at first sight appear conformable to no law, but they become of great interest when it is seen that the mean difference of these figures is almost exactly the same as that on the other side of the curve —viz. 44·2.

This uniformity of difference—actual on the one side and average on the other—brings out the important inference that, whilst on the odd side there has been little or no variation in the vertical force, minor irregularities have been the rule on the even side. That is to say, the fall of temperature has been very uniform on the odd side—where every element formed during this half of the vibration is the representative of a strongly marked group—sodium, magnesium, aluminium, silicium, phosphorus, sulphur, and chlorine; whilst on the even side of the swing the temperature has sunk with considerable fluctuations, which have prevented the formation here of any well-marked groups of elements, with the exception of those of which lithium and glucinum are the types.

If we can thus trace irregularities in the fall of temperature can we also detect any variation in the force represented by the pendulous movement? I have assumed that this represents chemical energy. In the early formed elements we have those in which chemical energy is at its maximum intensity, while, as we descend, affinities for oxygen are getting less and the chemism is becoming more and more sluggish. Part may be due to the lower temperature of generation not permitting such molecular mobility in the elements, but there can be little doubt that the chemism-forming energy, like the fires of the cosmical furnace, is itself dying out. I have endeavoured to represent this gradual fading out by a diminution of amplitude, the curve being traced from a photographic record of the diminution of the arc of vibration of a body swinging in a resisting medium.

When we look on a curve of this kind there is a tendency to ask, what is there above and below the portion which is seen? At the lower end of our curve what is there to be noted? We see a great hiatus between barium (137) and iridium (192·5), which it seems likely will be filled up by the so-called rare elements. Judging from my own researches, it is probable that many of these earthy elements will be found included in one or more interperiodic groups, whilst the higher members of the calcium, the potassium, the chlorine, and the sulphur groups, together with the elements between silver and gold, cadmium and mercury, indium and thallium, and antimony and bismuth, are still waiting to be discovered. We now come to an oasis in the desert of blanks. Platinum, gold, mercury, thallium, lead, and bismuth, all familiar friends, form a close little group by themselves, and then after another desert space the list is closed with thorium (233) and uranium (240).

This oasis and the blanks which precede and follow it may be referred with much probability to the particular way in which our Earth developed into a member of our solar system. If this be so it may be that on our Earth only these blanks occur, and not generally throughout the universe.

What comes after uranium? I should consider that there is little prospect of the existence of an element much lower than this. Look at the vertical line of temperature slowly sinking from the upper to the lower part of the curve; the figures representing the scale of atomic weights may be also supposed to represent, inversely, the scale of a gigantic pyrometer dipping into the cauldron where suns and worlds are in process of formation. Our thermometer shows us that the heat has been sinking gradually, and, *pari passu*, the elements formed have increased in density and atomic weight. This cannot go on for an indefinite extent. Below the uranium point the temperature may be so reduced that some of the earlier formed elements which have the strongest affinities are able to enter into combination among themselves, and the result of the next fall in temperature will then be—instead of elements lower in the scale than uranium—the combination of oxygen with hydrogen, and the formation of those known compounds the dissociation of which is not beyond the powers of our terrestrial sources of heat.

Let us now turn to the upper portion of the scheme. With hydrogen of atomic weight = 1, there is little room for other elements, save perhaps for hypothetical helium. But what if we get 'through the looking-glass,' and cross the zero-line in search of new principles—what shall we find the other side of zero? Dr. Carnelley asks for an element of negative atomic weight; here is ample room and verge enough for a shadow series of such unsubstantialities. Helmholtz says that electricity is probably as atomic as matter;[1] is electricity one of the negative elements? and the luminiferous ether another? Matter, as we now know it, does not here exist; the forms of energy which are apparent in the motions of matter are as yet only latent possibilities. A substance of negative weight is not inconceivable.[2] But can we form a clear conception of a body which combines with other bodies in proportions expressible by negative quantities?

A genesis of the elements such as is here sketched out would not be confined to our little solar system, but would probably follow the same general sequence of events in every centre of energy now visible as a star.

Before the birth of atoms to gravitate towards one another, no pressure could be exercised; but at the outskirts of the fire-mist sphere, within which all is protyle—at the shell on which the tremendous forces involved in the birth of a chemical element exert full sway—the fierce heat would be accompanied by gravitation sufficient to keep the newly-born elements from flying off into space. As temperature increases expansion and molecular motion increase, molecules tend to fly asunder, and their chemical affinities become deadened; but the enormous pressure of the gravitation of the mass of atomic matter outside what I may for brevity call the birth-shell would counteract this action of heat.

Beyond this birth-shell would be a space in which no chemical action could take place, owing to the temperature there being above what is called the dissociation-point for compounds. In this space the lion and the lamb would lie down

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[1] 'If we accept the hypothesis that the elementary substances are composed of atoms, we cannot avoid concluding that electricity also, positive as well as negative, is divided into definite elementary portions, which behave like atoms of electricity.'—Helmholtz, Faraday Lecture, 1881.

[2] 'I can easily conceive that there are plenty of bodies about us not subject to this intermutual action, and therefore not subject to the law of gravitation.'—Sir George Airy. *Faraday's Life and Letters*, vol. ii. p. 354.

together; phosphorus and oxygen would mix without union; hydrogen and chlorine would show no tendency to closer bonds; and even fluorine, that energetic gas which chemists have only isolated within the last month or two, would float about free and uncombined.

Outside this space of free atomic matter would be another shell, in which the formed chemical elements would have cooled down to the combination-point, and the sequence of events so graphically described by Mr. Mattieu Williams in 'The Fuel of the Sun' would now take place, culminating in the solid earth and the commencement of geological time.

And now I must draw to a close, having exhausted not indeed my subject, but the time I may reasonably occupy. We have glanced at the difficulty of defining an element; we have noticed, too, the revolt of many leading physicists and chemists against the ordinary acceptation of the term element. We have weighed the improbability of their eternal self-existence or their origination by chance. As a remaining alternative we have suggested their origin by a process of evolution like that of the heavenly bodies according to Laplace, and the plants and animals of our globe according to Lamarck, Darwin, and Wallace. In the general array of the elements, as known to us, we have seen a striking approximation to that of the organic world. In lack of direct evidence of the decomposition of any element, we have sought and found indirect evidence. We have taken into consideration the light thrown on this subject by Prout's law, and by the researches of Mr. Lockyer in solar spectroscopy. We have reviewed the very important evidence drawn from the distribution and collocation of the elements in the crust of our earth. We have studied Dr. Carnelley's weighty argument in favour of the compound nature of the so-called elements from their analogy to the compound radicles. We have next glanced at the view of the genesis of the elements; and, lastly, we have reviewed a scheme of their origin suggested by Professor Reynolds's method of illustrating the periodic classification.

Summing up all the above considerations we cannot, indeed, venture to assert positively that our so-called elements have been evolved from one primordial matter; but we may contend that the balance of evidence, I think, fairly weighs in favour of this speculation.

This, then, is the intricate question which I have striven to unfold before you, a question which I especially commend to the young generation of chemists, not only as the most interesting but the most profoundly important in the entire compass of our science.

I say deliberately and advisedly the *most interesting*. The doctrine of evolution, as you well know, has thrown a new light upon and given a new impetus to every department of biology, leading us, may we not hope, to anticipate a corresponding wakening light in the domain of chemistry?

I would ask investigators not necessarily either to accept or to reject the hypothesis of chemical evolution, but to treat it as a provisional hypothesis; to keep it in view in their researches, to inquire how far it lends itself to the interpretation of the phenomena observed, and to test experimentally every line of thought which points in this direction. Of the difficulties of this investigation none can be more fully aware than myself. I sincerely hope that this, my imperfect attempt, may lead some minds to enter upon the study of this fundamental chemical question, and to examine closely and in detail what I, as if amidst the clouds and mists of a far distance, have striven to point out.

The following Papers were read:—

1. *On the Absorption Spectra of Uranium Salts.*
By W. J. Russell, *F.R.S., and* W. Lapraik, *F.C.S.*

Well-marked absorption bands are produced in the visible spectrum by the different salts of this metal. The salts are divided into two very distinct classes, uranous and uranic salts, and each class gives an entirely different absorption spectrum;

both consist of three distinct bands or groups of bands: those produced by the uranous salts are at the red end of the spectrum, and those produced by the uranic salts at the blue end, the one set of bands beginning where the other set ends, so that when both salts are together in solution there are a series of bands visible which are distributed with tolerable regularity over the whole visible spectrum. Nine uranic salts, some organic some inorganic, have been examined, and it has been found that all give the same spectrum, that is, the spectrum is unaffected by the acid radicle. With other metals, such as cobalt for instance, this is not the case, different radicles producing different spectra. This spectrum, common apparently to all uranic salts, is however slightly altered by the addition of free acid, the acid causing a diminution of intensity in the least refrangible bands, and causing an apparent slight shift in others. Crystals of the uranic nitrate give an absorption spectrum similar to that produced by an aqueous solution of this salt.

The uranous salts give also in all cases examined a common spectrum, and one in which all the bands are less refrangible than those belonging to the uranic salts. The authors have also examined a few of the uranous salts in the solid state, and find that these salts have then a far more complicated spectrum than when in solution.

2. *The Air of Dwellings and Schools, and its relation to Disease.* *By* Professor T. Carnelley, *D.Sc.*

3. *On some probable new Elements.* *By* Alexander Pringle.

4. *On the Action of Bromine on the Trichloride of Phosphorus.*[1] *By* A. L. Stern.

After a short historical introduction experiments were described in which phosphorus trichloride and bromine were mixed in various proportions; in all cases a considerable quantity of heat was evolved, and when sufficient bromine was present crystals were deposited on cooling; on analysing these it was found that the amount of bromine present at any given temperature was proportional to the amount of bromine present in the mixtures, also that those crystals which contained the most bromine were the least stable; at a temperature of 10° C. it was possible to obtain a compound containing ten atoms of halogen, while at 35° C. the compound PCl_3Br_2 was decomposed (Michaelis).

It was also found that bromine replaces part of the chlorine of the trichloride, but not much more than half even when such a large excess was present as twelve atoms of bromine to one of the trichloride; Gladstone, however, found that in the presence of a small quantity of iodine all the chlorine of the trichloride may be replaced by bromine and the penta-bromide formed.

The constitution of these compounds was then discussed and it was suggested that they are merely compounds of phosphorus with varying proportions of halogen, and not molecular compounds; the number of atoms of halogen with which one atom of phosphorus can combine being an inverse function of the temperature.

5. *Dissociation and Contact-action.*[2] *By the* Rev. A. Irving, *B.Sc., B.A.*

The author refers to a letter of his which appeared in 'Nature' on March 25 last, in which he suggested that the true explanation of the many instances known of contact-action of solid bodies in facilitating combination of gases, which under ordinary conditions and in the free state are chemically inert to one another, was to be found in the transformation of a portion of the energy of translation of the molecules into intramolecular work, producing (or tending to produce) dissociation as a preliminary to chemical change.

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[1] Printed in full in *Journ. Chem. Soc.*, 815, 1886.

[2] Published *in extenso*, *Chemical News*, October 8, 1886.

In this paper such explanations as have been offered from time to time are criticised and rejected as inapplicable to all the phenomena, and an attempt is made to reason out a *general* explanation on purely thermo-dynamical principles. The initial-temperature of dissociation is referred to the inequality of the atom-temperatures (absolute) of the molecules, there being (from a variety of causes) a number of molecules in every mass of gas in a state of greater thermal activity (both as regards translational and internal vibrational energy) than that which corresponds to the mean condition which is indicated by the thermometer. For such molecules a smaller addition of heat is required to bring about dissociation, while the enormous increase in the extent of solid surface presented by the introduction of a porous or finely divided solid, increases proportionately the number of instances of impact in a given period of time, and a corresponding increase in the amount of intra-molecular work done in promoting the vibrational energy of the atoms.

The term 'quasi-nascent state' is used to indicate such a degree of tension, thus brought about within some of the molecules, that atoms of opposite electro-chemical energies can, under the influence of their mutual attraction, escape from the molecules in which they were previously held, and enter into new combinations.

Collateral evidence of the truth of the theoretical view here propounded is brought forward, (1) from a purely dynamical example given by Sir W. Thomson in a discussion in Section A last year; (2) from the action of Mr. Crookes' radiometer; (3) from a lecture on dissociation given by Mr. Frederick Siemens in May last at the Royal Institution.

The general application of the theory is pointed out as claiming more consideration than the more empirical explanations hitherto offered, each of which only applies to a few instances of the kind. It also enables us to refer the contact influence of chemically inert solid bodies, and the action of such purely physical agencies as heat, electricity, and light, in promoting combination, to the same general principles, while it seems to extend our idea of the action of atoms in the *nascent* state.

FRIDAY, SEPTEMBER 3.

The following Reports and Papers were read:—

1. *Second Report of the Committee on Vapour Pressures and Refractive Indices of Salt Solutions.*—See Reports, p. 204.
2. *Second Report of the Committee on certain Physical Constants of Solution, especially the Expansion of Saline Solutions.*—See Reports, p. 207.

3. *On the Phenomena and Theories of Solution.*
By Professor W. A. TILDEN, *F.R.S.*—See Reports, p. 444.

4. *Water of Crystallisation.*[1] *By* Dr. NICOL.

The author examines the evidence for and against the existence of water of crystallisation in solution, derivable from thermo-chemical and other data. He shows that there is no relation between heat of hydration of the solid salt and the number of water molecules in the hydrated salt; that it is not sufficient to deduct the heat of change of state of the water to obtain the true heat of solution of a dehydrated salt; and that the heat of neutralisation of a dissolved base by a dissolved acid is conclusive against the existence of water of crystallisation in aqueous solution, for with the seven soluble bases this is a constant for H_2SO_4, and

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[1] Since published in the *Chemical News*, p. 191, 1886.

another constant for 2HCl and $2HNO_3$, while the sulphates and other salts formed possess in the solid state most varied amounts of water of crystallisation, and if this exists in solution it would be necessary to assume that the constancy of the neutralisation results is a coincidence, an assumption directly opposed to the probabilities of the case.

5. *On the Magnetic Rotation of Mixtures of Water, and some of the Acids of the Fatty Series with Alcohol and with Sulphuric Acid, and Observations on Water of Crystallisation.*[1] *By* W. H. PERKIN, *Ph.D., F.R.S.*

The author first pointed out that the magnetic rotation of water was higher than that of a sum of the value of H_2+O, as deduced from other compounds, and that therefore the magnetic rotation of a body containing these elements would show whether they existed as water or were otherwise combined. Formic, acetic, and propionic acid were then each mixed with water in the proportions of one molecule of acid to one of water, and examined as to their molecular rotation. This was of special interest because acids so diluted were believed to form trihydric alcohols. Alcohol diluted in a similar manner was also examined at the same time for the sake of comparison, because it could not form a compound with water. The result of the numbers obtained from the magnetic rotation showed that these diluted compounds consist simply of the acids + water, the diluted alcohol giving similar confirmatory numbers.

Sulphuric acid was then examined in a similar manner, both concentrated and hydrated by the addition of water in the proportion of one, two, and three molecules to one of acid.

From the results obtained the author concludes that sulphuric acid forms with water the compound $(HO)_4SO$ only.

The study of these hydrated compounds having caused the author to consider the subject of water of crystallisation, he first draws attention to the want of consistency as to the presence or absence of water of crystallisation in the simple salts of metals belonging to the same class, and to the same thing shown in the existence of hydrated methyl-bromide, &c., and concludes that its relation to a salt or other body has not any connection with chemical combination, but that it is purely physical, and is present as a necessity of the crystalline form, and that it is present only when it is conducive to the production of that form which is most readily produced under the circumstances existing at the time, in support of which he brings forward the case of the alums and other isomorphous compounds, and shows that if this be the function of water of crystallisation salts containing it when dissolved will no longer remain in union with it, which is now believed to be the case by so many who have studied the subject of the solution of salts.

6. *On the Nature of Liquids.*
By WILLIAM RAMSAY, *Ph.D., and* SYDNEY YOUNG, *D.Sc.*

The subject of this paper may well be included in a discussion on the nature of solution, for it is impossible to devise a completely satisfactory theory of solution without a knowledge of the molecular structure of the solvent. During the last few years we have made determinations of the vapour pressures, densities of the saturated and unsaturated vapour, specific gravities, and, in some cases, compressibilities of methyl and ethyl alcohol, ether, and acetic acid under various conditions of pressure and temperature. By means of the thermo-dynamical equation

$$L=(S_1-S_2)\frac{dp}{dt}\cdot\frac{t}{J}$$

the heats of vaporisation have also been calculated.

The data which bear most strongly on the subject under discussion are the

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[1] For full paper see *Jour. Chem. Soc.*, vol. xlix. p. 777.

densities of the saturated vapour, that of hydrogen under similar conditions of temperature and pressure being taken as unity. At low temperatures the saturated vapours of the alcohols and ether follow Boyle's and Gay Lussac's laws; but if the temperature is raised the density of the saturated vapour is found to increase, slowly at first, but more and more rapidly, until the critical point is reached, when the specific gravity of the liquid is equal to that of its saturated vapour, and the deviation from Boyle's law is very great. Thus with ethyl alcohol the density of the saturated vapour is normal at about 40°, and it remains normal at lower temperatures. With acetic acid very different results are obtained. The constants for this body have not been determined up to the critical point, the temperature being too high for the method adopted. From about 140° to 280°, however, the density of the saturated vapour is found to increase, and there can be no doubt that this increase would go on up to the critical point. When the temperature is reduced below 140° the density of the saturated vapour (which at this point is about 50, the normal density being 30) does not continue to decrease but becomes nearly constant, and at still lower temperatures rises again more and more rapidly until at 50° it is nearly 60. There is then a marked difference between such substances as ethyl alcohol, in which no dissociation of any kind is known to occur, and acetic acid, the vapour of which is believed by many chemists to consist, in part, of molecules of the formula $n(C_2H_4O_2)$, n being generally supposed equal to 2. It is very improbable that the increase of the density of the saturated vapour with rise of temperature, which appears to be common to all bodies, is due to the union of simple gaseous molecules to form complex groups, for dissociation is always increased by rise of temperature; on the other hand, owing to the high pressure, the molecules are brought into close proximity, and the abnormality may be caused by a general attraction of the molecules for each other. At low temperatures, at which the pressure is small, the molecules are far apart, and such a general attraction is out of the question. The deviation in the case of acetic acid at low temperatures is therefore probably due to the combination of the simple gaseous molecules to form complex groups of the formula $n(C_2H_4O_2)$. This is borne out by the fact that with nitric peroxide, the vapour of which is known to dissociate according to the equation $N_2O_4 = 2NO_2$, a similar increase of the density of the saturated vapour takes place. The densities of the unsaturated vapour at various constant temperatures have been determined by the Natansons ('Wied. Ann.' July 1886) and the vapour pressures by ourselves ('Phil. Trans.' 1885). The junction of the isothermals showing the relation of pressure to vapour density with the horizontal lines indicating vapour pressures gives points on the curve representing the relation of the densities of the saturated vapour to pressure; and it is thus found that the density of the saturated vapour increases with fall of temperature and pressure.

It is extremely improbable that the increase of the density of the saturated vapour of acetic acid at both high and low temperatures can be due to the same cause, the conditions being so totally different; and it may fairly be concluded that at high temperatures the abnormality of this and of all other bodies is due to a physical rather than a chemical attraction. The existence of complex molecular groups in the vapours of normal substances, such as alcohol, is therefore very unlikely, and it can hardly be supposed that they are formed at the moment of condensation; hence, in all probability, the molecules of ordinary liquids are simple gaseous molecules in close proximity.

Other facts observed in the course of this research lead to the same conclusion. We shall discuss their bearing on the question in the 'Philosophical Magazine.'

We have attempted to study the solubility of eosin in alcohol at temperatures above the critical point, but the experimental difficulties are so great that no very definite conclusions have been arrived at. It appears, however, most probable that at temperatures but slightly higher than the critical point, the eosin remains in solution for some time (as shown by its fluorescence), but that it is gradually deposited.

7. *On the Nature of Solution.*[1] *By* Professor SPENCER U. PICKERING.

Although various special experiments seem to render it incontestable that hydrates of a salt do exist in solution in some cases, the strength of the hydrate theory should be derived from more general considerations as to the nature of the solvent and substance dissolved, and from the thermal results of dissolution. At the same time, however, equally general considerations render this theory inadequate to explain all the facts observed, though to such special lines of argument, such as those which Dr. Nicol derives from the specific volumes, no weight whatever can be attached, for they would lead to the conclusion that the radicles composing the salt itself are no more united than is the salt with its water. The explanation of this conflicting evidence may be explained by the recognition of the real complexity of the units of matter; a great number of our so-called molecules unite to form aggregates which bear the stamp of true chemical compounds in most respects, but are so greatly influenced by physical conditions that their composition, to our imperfect means of investigation, appears indefinite. The existence of such compounds alone can explain the peculiarities of minerals, artificial crystals of isomorphous salts, alloys, basic salts, &c. Dissolution is a result not of the formation of definite hydrates only, but also of (apparently) indefinite hydrates. The formation of these hydrates would always be accompanied by an evolution of heat, but at the same time the aggregates of a solid being more complex than those of a liquid, an act of decomposition absorbing heat would also be a no less invariable accompaniment. The coexistence of two such counteracting actions can alone explain all the thermal effects of dissolution.

SATURDAY, SEPTEMBER 4.

The following Papers were read:—

1. *On the Fading of Water-colours.* *By* Professor W. N. HARTLEY, *F.R.S.*

Referring to the article Light and Water-colours, written by Mr. J. C. Robinson, in the 'Nineteenth Century,' Professor Hartley pointed out that colours consist of mineral substances, for the most part of a stable character and organic substances consisting of stable colours and unstable changeable colours. With the exception of ultramarine, bodies of the former class may be generally considered as unalterable unless they contain lead or mercury; those of the second class may be considered alterable under certain conditions. The action of light, according to the researches of Chastaing, on these two classes of substances when it is capable of affecting them is different: on mineral substances the red rays cause oxidation; the oxidising power decreases as the rays tend more towards the yellow; the yellowish-green rays are without action and form a neutral region; the blue rays reverse the action of the red—for they promote reduction—and this action increases in intensity in the violet and ultra-violet rays.

On organic substances the action of light is an oxidising one throughout, continuously increasing in power as the rays extend through the red and yellow into the violet end of the spectrum. There is, however, a modification in the green, the rays having a diminished oxidising power. The action of light on organic substances is not confined to oxidation, for bodies of a complex and unstable character may be changed in composition, and, being resolved into more stable compounds, changed in colour or rendered colourless.

Experiment on colours showed that this was apparently the case with crimson lake, gamboge, bistre, and to a less extent with brown madder and sepia. Indigo is permament. Ultramarine is bleached by acids, but not by light.

In order to preserve water-colour drawings in which yellow and delicate red tints

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[1] *Chemical News*, 54, p. 215.

are largely used, as, for instance, Turner's sun-light pictures, they should be kept in a very subdued light, preferably of a yellow tint, such as is obtained by blinds of unbleached linen. For artificial illumination the arc-light is unsuitable, but incandescence lamps are preferable to gas, as yielding no products of combustion, which in the case of gas are capable of causing injury. The action of the violet rays is two to three times as powerful as the red or yellow; and there is a great difference between the action of diffused daylight sufficiently strong to view pictures, and direct sunlight. Without exact measurements it is difficult to appreciate its magnitude, but the latter may be safely set down as on an average forty times, and in summer even probably four hundred times as great as the former; hence a picture which would fade in ten years in sun-light might be preserved for several hundred years in a subdued yellow light. The author has not observed any destructive action of light on grey tints made from mixtures of indigo and light red, even in sketches painted as long as sixty years ago, by his father, and since exposed to subdued daylight. The acidity in drawing paper should be corrected by a wash of a dilute solution of borax, and in no case ought any paste or glue to be placed at the back of a drawing for the purpose of mounting it.

2. *On the Distribution of the Nitrifying Organism in the Soil.*
By R. Warington, *F.R.S.*

Previous experiments, conducted at Rothamsted on this subject (' Trans. Chem. Soc. ' 1884, p. 645) had led to the conclusion that the nitrifying organism is always to be met with down to 9 inches from the surface, and that at 18 inches it is sometimes present; but experiments with soil 2 to 8 feet from the surface failed to yield evidence of the presence of the organism.

Further experiments have been made in 1885, and during the present year, both in the field with the stiff clay subsoil previously worked on, and in another field having a loamy subsoil; in all sixty-nine new experiments have been made. The soil in the previous experiments was removed, with suitable precautions, from a freshly cut surface, and placed in sterilised solutions consisting of diluted urine (0·4 per cent.) It having since been found that the facility with which urine nitrifies is greatly increased by the presence of gypsum ('Trans. Chem. Soc.' 1885, p. 758), an addition of a small quantity of gypsum was made to the solutions employed in all the recent experiments; rather larger quantities of soil were also employed. The results may be summarised as follows:—

Depth of Soil	Number of Experiments	Number of Solutions Nitrifying	Number Nitrifying out of 10 Trials
Less than 2 feet	17	17	10·0
2 feet	11	11	10·0
3 „	11	10	9·1
4 „	11	7	6·4
5 „	2	1	5·0
6 „	9	4	4·4
7 „	2	0	0·0
8 „	6	0	0·0

Six of the above experiments were made with chalk, which underlies the Rothamsted subsoil; the chalk was from depths of 5, 6, 7, and 8 feet. None of the samples of chalk produced nitrification.

The new results show a far deeper distribution of the nitrifying organism than was concluded from the earlier experiments. The power of producing nitrification is now found to exist generally down to 3 feet from the surface. Below this point the occurrence of the organism becomes less frequent, though at 5 and 6 feet about half the trials resulted in nitrification. With soil from 7 and 8 feet no nitrification was obtained. The considerable difference between the earlier and later results is to be attributed to the employment of gypsum in the later solutions. The nitrifying organism in the subsoil is indeed less abundant, and probably much more feeble than in the surface soil, and is apparently unable to start nitrification in the decidedly alkaline solution which urine produces in the absence of gypsum.

Although it appears that the nitrifying organism may exist at considerable depths, nitrification is practically confined to the surface soil. The quantity of nitrogen as nitric acid annually obtained in the drainage water from soils of different depths in the drain gauges at Rothamsted is on an average of nine years:—

Soil 20 inches deep	40.2 lbs. per acre
Soil 40 " "	35·0 " "
Soil 60 " "	38·8 " "

There is no evidence here of a greater production of nitrates when the subsoil is included in the experiment.

Nitrates are always found most abundantly in the surface soil unless heavy rain has occurred to wash them downwards. Two fallow soils at Rothamsted were found to contain the following quantities of nitrogen as nitrates in lbs. per acre:—

1st 9 inches	28·5	40·1
2nd "	5·2	14·3
3rd "	—	5·5
Total .	33·7	59·9

3. *On the Action of Drinking-water on Lead.* *By* Dr. C. Meymott Tidy.

4. *Micro-Organisms in Drinking-water.* *By* Professor Odling, *F.R.S.*

MONDAY, SEPTEMBER 6.

The following Report and Papers were read:—

1. *Report of the Committee appointed to investigate the Influence of the Silent Discharge of Electricity on Oxygen and other Gases.*—See Reports, p. 213.

2. *On the Preservation of Gases over Mercury.*[1]
By Harold B. Dixon, *M.A., F.R.S.*

The author has found that different gases (hydrogen, electrolytic gas, cyanogen, and sulphurous acid) could be preserved over dry mercury for several years without any sensible alteration. This result is contrary to the conclusion arrived at by Faraday, that it was impossible to preserve gases over dry mercury, but agrees with the experiments of Sir Humphry Davy, recorded in the Laboratory Notebook of the Royal Institution. The author collected the gases in *hot* tubes over pure *hot* mercury.

3. *On the Methods of Chemical Fractionation.*[2]
By William Crookes, *F.R.S., V.P.C.S.*

Broadly speaking, the operation of chemical fractionation consists in fixing

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[1] Printed *in extenso* in the *Chem. News*, 54, p. 227.

[2] The original paper was published *in extenso* in the *Chemical News* for September 10, 1886.

upon some chemical reaction in which there is the most likelihood of a difference in the behaviour of the elements under treatment, and performing it in an incomplete manner, so that only a certain fraction of the total bases present is separated, the object being to get part of the material in the insoluble, and the rest in the soluble, state. The operation must take place slowly, so as to allow the affinities —which, by the nature of the case, are almost equally balanced—time to have free play. Let us suppose that two earths are present, almost identical in chemical properties, but differing by an almost imperceptible variation in basicity. Add to the very dilute solution dilute ammonia in such amount that it can only precipitate half the bases present. The dilution must be such that a considerable time elapses before the liquid begins to show turbidity, and several hours will have to elapse before the full effect of the ammonia is complete. On filtering we have the earths divided into two parts, and we can easily imagine that now there is a slight difference in the basic value of the two portions of earth; that in solution being, by an almost imperceptible amount, more basic than that which the ammonia has precipitated. This minute difference is made to accumulate by a systematic process until it becomes perceptible by a chemical or physical test.

In most methods of fractionation a rough sort of balance of affinities is arrived at before long, beyond which further separation by the same method is difficult. I have long noticed this action when fractionating with ammonia, with oxalic acid and nitric and with formic acid. One valuable point which renders this fact noteworthy is that the balance of affinities revealed by fractionation is not the same with each method. It was in consequence of the experience gained in these different methods of fractionation that in my paper read before the Royal Society, June 10 last ('Chemical News,' vol. liv. p. 13), after stating that I had not been able to separate didymium into Dr. Auer's two earths, I said, 'Probably didymium will be found to split up in more than one direction according to the method adopted.'

The process adopted must vary according to the bodies under treatment. Fractional crystallisation has yielded new results with didymium in the hands of Dr. Auer von Welsbach; and precipitation with formic acid, with ammonia, with ammonium oxalate, crystallisation of the oxalates from strong nitric acid, and fusing the nitrates and chlorides have all given me good results.

Working with the samarskite earths, fractional precipitation with oxalic acid separates first erbia, holmia, and thulia, then terbia, and lastly yttria. This is the only method which is applicable for the separation of small quantities of terbia from yttria.

Fusing the nitrates separates ytterbia, erbia, holmia, and thulia from yttria. It is not so applicable when terbia is present, and is most useful in purifying the gadolinite earths. This process is the only one known for separating ytterbia from yttria.

The formic acid process is best for separating terbia, as terbic formate is difficultly soluble in water, the other formates being easily soluble.

Selection must be made of these methods according to the mixture of earths under treatment, changing the method as one earth or the other becomes concentrated on one side or thrown out on the other. Each operation must be repeated very many times before even approximate purity is attained. The operations are more analogous to the separation of members of homologous series of hydrocarbons by fractional distillation than to the separations in mineral chemistry as ordinarily adopted in the laboratory.

When the balance of affinities, of which I spoke above, seems to be established, the earths appear in the same proportion in the precipitate and the solution; they are thrown down by ammonia, and the precipitated earths are worked up by some other process so as to alter the ratio between them, when the previous operation can be again employed.

Fractional precipitation by ammonia is the process generally adopted, for although in some cases it is not so powerful as other processes it is more generally applicable.

The best plan is to add half the equivalent amount of precipitant to the liquid, and, after complete settlement, filter. Starting with, say, 1000 grms. in the zero bottle, transfer the filtrate to bottle −1 and the precipitate to bottle +1. Then add another 1000 grms. to the 0 bottle, and repeat the operations as in the following table:—

NUMBERS OF THE BOTTLES.

	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6
							1000						
A.						500	1000	500					
B.					250	500	500	500	250				
C.				125	250	375	500	375	250	125			
D.			63	125	250	375	375	375	250	125	63		
E.		31	63	156	250	312	375	312	250	156	63	31	
F.	15	31	94	156	234	312	312	312	234	156	94	31	15

After the sixth fractionation the 2000 grms. of earth are spread out amongst 13 bottles in the proportions represented in the bottom line.

The separation of *two* earths by this plan is comparatively easy. The precipitation by ammonia depends not directly on the affinities of the earths for the acid, but rather on the excess of affinity of the precipitating ammonia. For if the affinities of the two earths are represented by 100 and 101, and that of ammonia by 150, the affinities on which the precipitation depends would be represented by $150-100=50$, and $150-101=49$, the difference of which is 2 per cent. of the larger.

Now if a precipitant of which the affinity for the acid was only 110 were used, the affinities in question would be $110-100=10$, and $110-101=9$, and the difference, $10-9=1$, is 10 per cent. of the larger instead of only 2 per cent. Therefore if an alkali of which the affinity of the acid was only a little greater than that of earths were used for precipitation, it is likely that the differences between the two earths would come out more strongly, and the labour of fractional precipitation might be much reduced. Professor Stokes has suggested that some of the compound ammonias might prove useful as precipitants instead of ammonia. I have not, however, tested the suggestion.

The amount of earths present has to be determined before each precipitation, so as to know how much ammonia is to be added to get half precipitated. This is done by standard solutions, and when everything is in good order it does not occupy much time. Filtration is always the lion's share of the trouble.

The above calculations have been based on the assumption that only two earths are present. If more than two are present, the process fails in any reasonable time to yield practically pure specimens of more than two out of a group of closely allied earths. Thus, if there are as many as three earths, say A, B, and C, whose positions in reference to the chemical process employed are in the order of sequence in which they are written, we may get a specimen of A as nearly as we please free from B and C, and a specimen of C as nearly as we please free from A and B, but we cannot get a specimen of B practically free from A and C. The law seems to be that *to obtain practically pure specimens of three closely allied earths, it is essential to have recourse to at least two different chemical processes.* The mere continued repetition of the same process will not do, unless indeed the operations are repeated such a vast number of times as to make the approximate expressions no longer applicable, even though the substances are chemically very close.

With a greater number of earths the same law holds good; thus with n earths closely allied, to be separated we must have recourse to $n-1$ different chemical processes.

The acid in which the earths are dissolved is not a matter of indifference. There is an objection to sulphuric acid on the ground of its disposition to form double salts, so that of the sulphates in solution a good portion might be double sulphates, in which the two molecules of base combined with one of acid consisted one of one base and one of the other; and the two molecules thus intimately associated might tend to remain together, whether as precipitate or as filtrate. On the whole, I prefer nitric acid, as having little tendency to form double salts, and being easily got rid of.

It is occasionally necessary to completely precipitate the whole contents of the bottles with ammonium oxalate, and after ignition to redissolve the earths in acid and proceed as before. If this precaution is not adopted the accumulation of ammonium nitrate in the solution dissolves an appreciable amount of the earths.

In the ordinary operations of separating distinct entities, such as the known gadolinite or samarskite earths, it is not difficult, as I have already pointed out, to find different chemical processes, which may be successively employed. When, however, the separations attempted are those of the constituents of yttrium, the simple straightforward fractionation, continued steadily month after month and year after year, is the only plan I know of.

The operation may be somewhat hastened by removing from the main series certain bottles in which one particular constituent is concentrated and subfractioning these by themselves. Also to avoid the spreading out sideways to too great an extent after a certain distance has been proceeded from the centre, say to bottles −20 and +20; the earths are allowed to accumulate in the last bottle at each end. They will after a time be in sufficient amount to subfractionate on their own account, and, being at the end of the series, they offer a good chance of getting the extreme constituents pretty pure.

It will be seen from the above description that there is little hope of success in fractionation unless the supply of crude earths is very large. In my laboratory I have, either worked up or ready for working, over 50 kilos. of samarskite containing about 10 per cent. of yttria, and about 20 kilos. of gadolinite containing 48 per cent. of yttria, besides a considerable quantity of other rare yttria minerals, giving a total yield of about 15 kilos. of yttria.

4. *On the Fractionation of Yttria.*[1]

By WILLIAM CROOKES, *F.R.S., V.P.C.S.*

Having already explained the methods of chemical fractionation, it is necessary now to describe some of the results yielded by an extended perseverance in these operations.

I must, in the first place, explain that my work has been confined to a limited and very rare group of bodies—the earthy bases contained in such minerals as samarskite, gadolinite, &c. These have been repeatedly put through the fractionation mill by other chemists, but the results have been most unsatisfactory and contradictory, no sufficiently good test being known whereby the singleness of any earth got out by fractionation could be decided, except the somewhat untrustworthy one of the atomic weight. I say *untrustworthy* because it is now known that fractionation, unless it is pushed far beyond the point to which some Continental chemists have even carried it, is quite as liable to give *mixtures* which refuse to split up under further treatment of the same kind, as it is to yield a chemically simple body.

It is well known that a limited group of these rare earths, when phosphoresced *in vacuo*, yield discontinuous spectra. The method adopted to bring out the spectra is to treat the substance under examination with strong sulphuric acid, drive off excess of acid by heat, and finally to raise the temperature to dull redness. It is then put into a radiant-matter tube, of the form shown in fig. 1, and the induction spark is passed through it after the exhaustion has been pushed to the required degree. The phosphorescence occurs beneath the negative pole. Bodies like yttrium sulphate, &c., under the stimulus phosphoresce, emitting light whose waves tend to collect round definite centres of length. The phosphorescent light which the discharge evokes is best seen in a spectroscope of low dispersion, and with not too

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[1] The original paper was published *in extenso* in the *Chemical News* for September 24, 1886.

narrow a slit. In appearance the bands are more analogous to the absorption bands seen in solutions of didymium than to the lines given by spark spectra. Examined with a high magnifying power all appearance of sharpness generally disappears; the scale measurements must therefore be looked upon as approximate only; the centre of each band may be taken as accurately determined within the unavoidable errors of experiment, but it is impossible to define their edges with much precision.

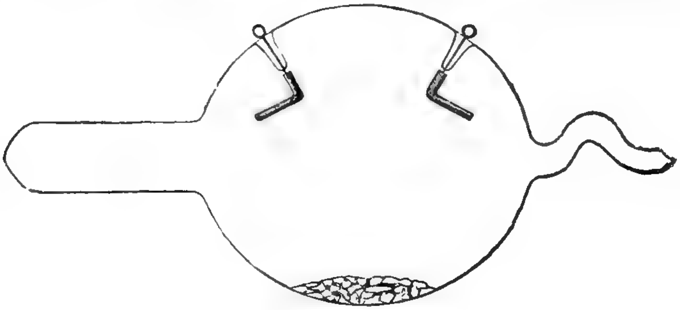

FIG. 1.

As a general rule, the purer the earth the sharper the band, and when impurities are removed to the utmost extent, the sharpness is such as to deserve the name of a line.

To this rule one exception occurs. The body which I have named Sδ, or 609, is remarkable for the great sharpness of its phosphorescent line, and I have noticed scarcely any variation in its sharpness, however large the bulk of extraneous earth associated with it. This line, however, is sharper and brighter when the current is first turned on than it is after phosphorescing for a minute or so.

In the Bakerian lecture on yttrium delivered before the Royal Society,[1] I described the phosphorescent spectrum given by this element, and in the address which I have had the honour of delivering before this Section I gave a drawing of the spectrum of yttrium, together with a sketch of the train of reasoning by which I had been led to the opinion that excessive and systematic fractionation had split up this stable molecular group into its components, distributing its atoms into several groups, with different phosphorescent spectra.

No longer than twelve months ago the name yttria conveyed a perfectly definite meaning to all chemists. It meant the oxide of the elementary body yttrium. I have in my possession specimens of yttria from M. de Marignac (considered by him to be purer than any chemist had hitherto obtained), from M. Clève (called by him 'purissimum'), from M. de Boisbaudran (a sample of which is described by this eminent chemist as 'scarcely soiled by traces of other earths'), and also many specimens prepared by myself at different times, and purified up to the highest degree known at the time of preparation. Practically these earths are all the same thing, and up to a year ago every living chemist would have described them as identical, *i.e.*, as the oxide of the element yttrium. They are almost indistinguishable one from the other, both physically and chemically, and they give the phosphorescent spectra *in vacuo* with extraordinary brilliancy. This is what I formerly called yttria, and have more recently called *old* yttria. Now these constituents of old yttrium are not *impurities* in yttrium any more than praseodymium and neodymium (assuming them really to be elementary) would be impurities in didymium. They constitute a veritable splitting up of the yttrium molecule into its constituents.

The plan adopted in the fractionation of yttria does not differ in principle from the methods described in my paper 'On the Methods of Chemical Fractionation.' Dilute ammonia is added to a very dilute solution of the earth in only sufficient quantity to precipitate one half. After standing for several hours the precipitate

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[1] *Phil. Trans.*, Part III. 1883.

is filtered. After each fractionation the filtrate is passed to the left and the precipitate to the right, and the operations are continued many thousand times.

The diagram (fig. 2) shows the scheme clearly, with the direction the precipitates and solutions travel. Limited space, even on a large diagram, prevents me from giving more than a few operations, but they will be sufficient to satisfy you that enormous patience, a large amount of material, and a not insignificant number of bottles, are requisites for successful fractionation.

After a certain time, on examining the series of earths in the lowest line of bottles, their phosphorescent spectra are found to alter in the relative intensities of some of the lines, and ultimately different portions of the fractionated earths show spectra, such as I have endeavoured to illustrate at the foot of the diagram (fig. 2), in which I have given the spectra of five components of yttrium.

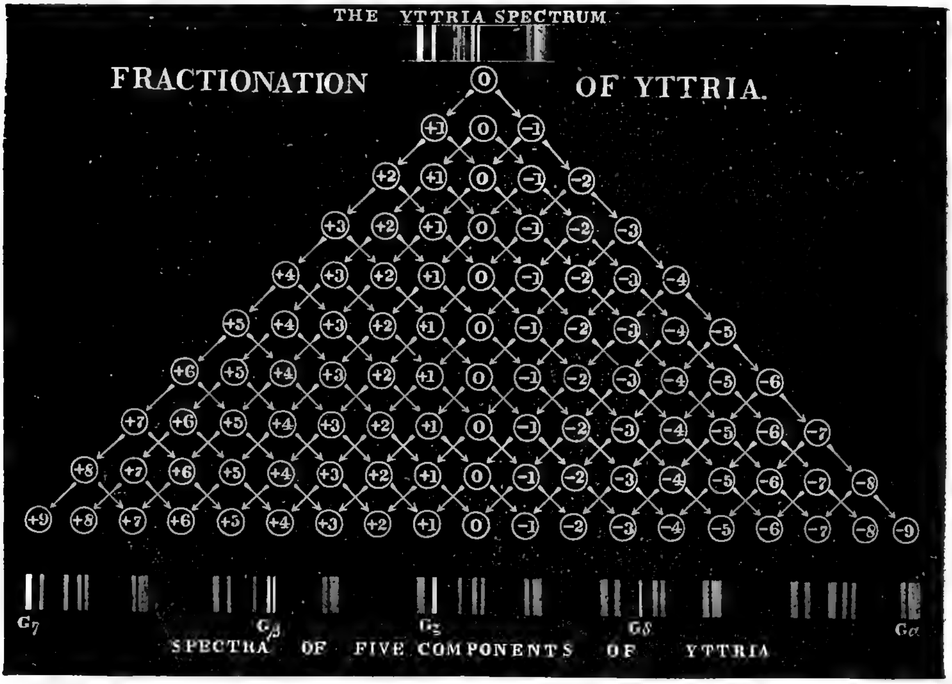

Fig. 2.

The final result to which I have come is that there are certainly five, and probably eight, constituents into which yttrium may be split. Taking the constituents in order of approximate basicity (the chemical analogue of refrangibility) the lowest earthy constituent gives a deep blue band Gα (λ 482); then there is a strong citron band Gδ (λ 574), which has increased in sharpness till it deserves to be called a line; then come a close pair of greenish blue lines, Gβ (λ 549 and λ 541, mean 545); then a red band, Gζ (λ 619), then a deep red band, Gη (λ 647), next a yellow band, Gε (λ 597), then another green band, Gγ (λ 564); this (in samarskite and cerite yttria) is followed by the orange line Sδ (λ 609). The samarium bands remain at the highest part of the series. These, I am satisfied, are also separable, although for the present I have scarcely touched them, having my hands fully occupied with the more easily resolvable earths. The yellow band, Gε, and green band, Gγ, may in fact be due to a splitting up of samarium.

Until we know more about these bodies I refrain from naming them, but will designate them provisionally by the mean wave-length of the dominant band. If, however, for the sake of easier discussion among chemists a definite name is thought to be more convenient, I will follow the plan frequently adopted in such cases, and provisionally name these bodies as shown in the following table:—

Position of lines in the spectrum	Scale of spectroscope	Mean wave-length of line or band	$\frac{1}{\lambda^2}$	Provisional name	Probability
Bright lines in—					
Deep blue	8·931	482	4304	Gα	New.
Greenish blue (mean of a close pair)	9·650	545	3367	Gβ	New, or the Zβ of M. de Boisbaudran.
Green	9·812	564	3144	Gγ	New.
Citron	9·890	574	3035	Gδ	New, or the Zα of M. de Boisbaudran.
Yellow	10·050	597	2806	Gε	New.
Orange	10·129	609	2693	Sδ	New.
Red	10·185	619	2611	Gζ	New.
Deep red	10·338	647	2389	Gη	New.

The initial letters S and G recall the origin of the earths respectively from samarskite and gadolinite.

Not only has yttrium been split up by subjection to fractionation, but samarium, as I have hinted above, is likely to prove equally unable to resist this operation. In the phosphorescent spectrum of samarium sulphate the line Sδ (609) is one of the constituents. When yttria is added to samaria this line is developed in greater intensity, as yttria has the power of deadening the other bands of samarium, while it does not seem to affect the line Sδ. Several circumstances, however, tend to show that although line Sδ accompanies samarium with the utmost pertinacity it is not so integral a part of its spectrum as the other red, green, and orange lines. For instance, the chemical as well as physical behaviour of these line-forming bodies is different. On closely comparing the spectra of specimens of samaria from different sources, line Sδ varies much in intensity, in some cases being strong and in others almost absent; the addition of yttria is found greatly to deaden the red, orange, and green lines of samarium, while yttria has little or no effect on the line Sδ; again, a little lime entirely suppresses line Sδ, while it brings out the samarium lines with increased vigour. Finally, attempts to separate line Sδ from samarium and those portions of the samarskite earths in which it chiefly concentrates has resulted in sufficient success to show me that, given time enough and an almost inexhaustible supply of material, a separation would not be difficult. These facts, together with the peculiar behaviour of the lines Gε and Gγ, strengthen my suspicion as to the resolvability of samarium.

Samaria giving the line Sδ has been prepared from cerite and samarskite. Many observations have led me to think that the proportion of band-forming constituents varies slightly in the same earth from different minerals. Amongst others, gadolinite showed indications of such a differentiation, and therefore I continued the work on this mineral. Very few fractionations were necessary to show that the body giving line Sδ was not present in the gadolinite earths, no admixtures of yttria and samaria from this source giving a trace of it. It follows therefore that the body whose phosphorescent spectrum gives line Sδ occurs in samarskite and cerite, but not in gadolinite.

It now became an interesting enquiry whether all these constituents of yttrium were united together in exactly the same proportion in every case. A glance at the diagram before you will show that yttrias from different sources, although they may be alike as far as our coarser chemical tests are concerned, are not built up exactly in the same manner. Thus, when the samarskite yttrium was forming, all the constituent molecules—which I have provisionally named Gα, Gβ, Gγ, Gδ, Gε, Gζ, Gη, and Sδ—condensed together in fair proportion. In gadolinite yttrium the constituents Gβ and Gδ are plentiful, Gζ is very deficient, Sδ is absent, and the others occur in moderate quantities. In the yttrium from xenotime Gδ is most plentiful, Gβ occurs in smaller proportion, Gζ is all but absent, and Sδ is quite absent. Yttrium from monazite contains Gβ and Gδ, with a fair proportion of the other constituents, Gβ is plentiful and the red is good. Yttrium from fluocerite is very similar to that from monazite, but Gα is weaker. Yttrium from hielmite is very rich in Gδ, has a fair quantity of Gα and Gβ, less of Gγ, no Sδ, and only a very faint trace of Gη. Yttrium from euxenite is almost identical with that from hielmite. Yttrium from cerite contains most Gζ and Gδ, less Gα and Gβ, only a trace of Gη, and a fair proportion of Sδ.

Referring to the diagram it is seen that Yα (gadolinium) is composed of the following band-forming bodies:—Gβ, Sδ, Gζ, together with a little samarium. Calling the samarium an impurity, it is thus seen that gadolinium is composed of at least three simpler bodies.

You have probably anticipated in your minds a question which is likely to occur at this point of the enquiry. If such results have been obtained by submitting yttrium to this novel method of analysis, what will be the result of fractionating some other reputed element?

Yttrium, as I have explained, is an exceedingly stable molecular group, capable of acting as an element, just as calcium, for instance, acts as an element: to split up yttrium requires not only enormous time and material, but the existence of a test by means of which the constituents of yttrium are capable of recognition. Had we tests as delicate for the constituent molecular groups of calcium, this also might be resolved into simpler groupings. It is one thing, however, to find out means of separating bodies which we know to be distinct and have colour or spectrum reactions to guide at every step; it is quite another thing to separate colourless bodies which are almost identical both in chemical reaction and atomic weight, especially if we have no suspicion that the body we are dealing with is a mixture.

One of the chief difficulties in the successful carrying out of an investigation in radiant-matter spectroscopy is the extraordinary delicacy of the test. This extreme sensitiveness is a drawback rather than a help. To the inexperienced eye one part of yttrium in ten thousand gives as good an indication as one part in ten, and by far the greater part of the chemical work undertaken in my hunt for spectrum-forming elements was performed upon material which later knowledge shows did not contain sufficient to respond to any known chemical test. It is as if the element sodium were to occur in ponderable quantity only in a few rare minerals seldom seen out of the collector's cabinet. With only the yellow line to guide, and seeing the brilliancy with which an imponderable trace of sodium in a mineral declares its presence in the spectrum, I venture to think that a chemist would have about as stiff a hunt before he caught his yellow line as I have had to bring my orange and citron bands to earth.

Chemistry, except in a few instances, such as water-analysis and the detection of poisons, where necessity has stimulated minute research, takes little account of 'traces,' and when an analysis adds up to 99·999, the odd 0·001 per cent. is conveniently put down to 'impurities,' 'loss,' or 'errors of analysis.' When, however, the 99·999 per cent. constitutes the impurity and this exiguous 0·001 is the precious material to be extracted, and when, moreover, its chemistry is absolutely unknown, the difficulties of the problem become enormously enhanced. Insolubility as ordinarily understood is a fiction, and separation by precipitants is nearly impossible. A new chemistry has to be slowly built up, taking for data uncertain and deceptive indications, marred by the interfering power of mass in withdrawing soluble salts from a solution, and the solubility of nearly all precipitates when present in traces in water or in ammoniacal salts. What is here meant by 'traces' will be better understood if I give an instance. After fifteen months' work I obtained the earth yttria in a state which most chemists would call absolutely pure, for it contained not more than one part of impurity (samaria) in two hundred and fifty thousand parts of yttria. But this one part in a quarter of a million profoundly altered the character of yttria from a radiant-matter-spectroscopic point of view, and the persistence of this very minute quantity of interfering impurity entailed another ten months' extra labour to eliminate these final 'traces' and to ascertain the real reaction of the earth called yttria.

5. *On the Colour of the Oxides of Cerium and its Atomic Weight.*[1] *By* H. Robinson, *M.A.*

This paper was principally a criticism of Wolf's paper on the atomic weight of cerium, published in the 'American Journal of Science and Art,' 1868. Great prominence is given to this work in Clarke's 'Constants of Nature.' Wolf's ceric oxide was white, and the atomic weight of the metal was 137·, or, as recalculated by Clarke, 138·. The writer of the present paper contended that Wolf's method of separation was wrong—that it would not give ceric but lanthanum oxide, which is white, and which contains a metal with an atomic weight lower than that of cerium. Wolf's method of separation was repeated fractionation of impure cerous sulphate by gentle evaporation. Robinson made similar experiments and found the proportion of Ce_2O_3 to La_2O_3 decreased from 4 to 1 to 2 to 1 by making the same number of crystallisations Wolf had done. He also found that at the temperature of the evaporation, 65°, 100· cc. of water held in solution 10·296 grains of Ce_23SO_4, while under the same conditions only 2·106 grains of La_23SO_4 remained in solution in the same quantity of water. He maintained the colour of ceric oxide is not white, as is sometimes supposed, but a pale sulphur yellow, and that the atomic weight of cerium is 140·2, as found by himself and also by Branner.

6. *On the Determination of the Constitution of Carbon Compounds from Thermo-chemical Data.* *By* Professor Armstrong, *F.R.S.*

7. *On the relative Stability of the Camphene Hydrochlorides $C_{10}H_{17}Cl$ obtained from Turpentine and Camphene respectively.* *By* Ernest F. Ehrhardt.[2]

Riban has shown that the former of these bodies is less easily decomposed by water; the author shows that it is also more stable under the influence of heat. Tilden has shown that at a low red heat turpentine breaks up more completely than camphene; the author extends this observation to lower temperatures, by observing the vapour densities in a bath containing melted lead.

The paradoxical result that the hydrochloride from the stable hydrocarbon is less stable than that from the unstable one is held to prove that this is a 'molecular' compound, the chlorine in it remaining associated with the hydrogen of the acid, while at the same time being attached to the hydrocarbon.

8. *On Derivatives of Tolidin and the Azotolidin Dyes.* *By* R. F. Ruttan, *B.A., M.D.*

Tolidin and its older homologue benzidin have only quite recently become prominent, owing to the discovery of the so-called azo-colours.

Benzidin was first prepared by Zinin, in 1845,[3] and its mode of formation from hydrazobenzene described by Hafman[4] Schultz[5] established the now accepted formula for this base, and investigated many of its reactions. Tolidin was prepared in an analogous way to benzidin, but its reactions were not studied. Petriew,[6] who was the first to obtain orthotolidin, only in small quantity, however, gives the melting-point 112°. This is too low; the proper melting-point is 127–128°. Generally this base resembles benzidin very closely in its behaviour, but differs considerably from toluidine.

It forms with mineral acids two series of salts, the acid salts being the more insoluble. It gives a play of colours from green to blue, finally scarlet, on dropping

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[1] Published *in extenso* in the *Chemical News*, vol. liv. p. 229.

[2] *Chemical News*, November 13, 1886.

[3] *Journal für practische Chemie*, xxxvi. p. 93.

[4] *Jahresberichte*, 1863, p. 424.

[5] Luby's *Annalen*, p. 174.

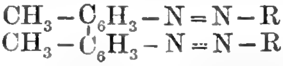
[6] *Berichte*, vi. p. 557.

a dilute aqueous solution of bromine in an alcoholic solution of the base. It forms a soluble monacetyl and an insoluble diacetyl derivative in form of silky needles. The hydrogen of the amidogen groups may be replaced by two or four methyl groups forming secondary bases resembling tolidin, and melting at 69° and 81° respectively. Further union with methyl iodide gives the ammonium salt, crystallising in red needles, from which the hydrate may be obtained by silver oxide.

With chloroform by no experiment could even traces of an isocyanide be obtained.

Carbon disulphide forms a thiourea but yields no isosulphocyanide. The base unites directly with cyanogen to form a dicyanogen compound of red colour and very insoluble. With urea it unites directly, evolving ammonia, forming a compound urea. The same substance can be obtained with phosgene gas, hydrochlorate of tolidin being simultaneously formed. The dinitrodiacetyl crystallises in yellow needles, soluble in hot nitrobenzol. Strong caustic potash forms from this the nitrotolidin in red plates soluble in alcohol.

Nitrous acid gives a tetrazoditolyl from which all the azotolidin colours are derived. Their general formula may be represented by



$$\begin{array}{l} \mathrm{CH_3-C_6H_3-N=N-R} \\ \qquad\quad\ | \\ \mathrm{CH_3-C_6H_3-N=N-R} \end{array}$$

where R represents more or less complex aromatic acids or their sodium salts. Thus in Congo red, R is the sodium salt of naphthylaminesulphonic acid; in chrysarine yellow it is sodium salicylate; in azo blue B-naphtholsulphonic acid. These colours are peculiar, in that they alone of all the artificial dyes are capable of dyeing cotton and wood fibre directly, *i.e.*, without the intervention of a mordant. Cotton fibre boiled in tolidin hydrochlorate, washed, dried, and dipped first in dilute nitrous acid, and then in some of the above acids is permanently coloured of particular dye formed by that acid, thus showing that the tolidin probably unites with the oxycellulon of the cotton, and so acts as a mordant. This is rendered further probable, as when once dyed by one of these colours cotton fibre will form mixed colours directly with such basic dyes as fucsin, methyl blue, &c.

TUESDAY, SEPTEMBER 7.

The following Papers were read:—

1. *On the Treatment of Phosphoric Crude Iron in Open-hearth Furnaces.* *By* J. W. Wailes.

The great importance of a process dealing with phosphoric iron must be measured by the extent of the deposits of ore yielding phosphoric pig. These deposits in Europe exceed by ten or twelve to one the deposits of ore yielding purer pig.

The amount of phosphorus that can be allowed in finished steel may be taken at not more than one tenth per cent., though this is more by about half than manufacturers care to deal with.

The softer and purer kinds of steel, where great ductility is required, should contain as little phosphorus as possible, the effect of this element being to render iron and steel brittle at ordinary temperatures.

A description of puddling was then given (illustrated in the diagrams), showing the furnace and the reactions that take place during the process, and it was contended that the manual labour of puddling was rendered necessary by the limited range of heat obtainable in puddling furnaces, which is not sufficient to retain iron after it has parted with a large proportion of its alloys in a molten condition, so that the metal has to be removed from the furnace in a spongy state. A comparison was then drawn between the process of purifying phosphoric iron by puddling and the results obtained in the 'Batho furnace,' an improved form of the Siemens regenerative furnace. It was shown that the Batho furnace was reduced to a simple mechanical contrivance, and that the idea of a furnace as a building had been entirely abandoned.

The means of applying the basic lining to the simplified furnace, which consists of detached regenerative stoves and a melting-vessel, connections between the two being made by means of tubes lined with heat-resisting material.

The basic lining is mixed with short fine wire, which is used like hair in plaster on ordinary walls, simply to keep it from cracking and falling off. It was pointed out that the difficulty of applying a basic lining to a vessel of this kind is reduced to a minimum.

The process of treating phosphoric crude iron in this vessel was then described, and reactions given similar to those obtained in the puddling furnace, but more perfect as a natural result of a more perfect heat, producing more perfect reactions. Instead of the metal being drawn from the furnace in a spongy state, it is run out into moulds, fluid and in a more highly refined condition.

Comparison was made with the Bessemer basic process, and it was shown that in this process the oxidising base necessary had, in a large measure, tc be obtained by the oxidation of part of the metallic charge, whereas in the open-hearth treatment the oxide is put in the furnace as oxide.

It was pointed out that the purest homogeneous iron was not in one respect equal to the produce of the puddling furnace.

If highly-wrought iron, like a patent faggoted axle, be subjected after it is superficially cut with a sharp tool to the shock of a falling weight, it will only open to the depth of the cut—the fibre of the metal opening at this point—whereas the purest steel under similar treatment, not having this fibre, would break.

In conclusion, it was stated that the open-hearth process described did not so much supersede puddling as render the manual labour unnecessary, and by natural reaction, under more perfect heat, arrive at a more perfect result.

2. *On the Basic Bessemer Process in South Staffordshire.*
By W. HUTCHINSON.

On account of the great importance of the successful application of a dephosphorising process to South Staffordshire iron, Mr. Hutchinson was requested to give an account of the procedure at the works of the South Staffordshire Steel and Ingot Iron Co. The account included an analysis of the dolomite used in making the basic lining, and a description of the preparation of the lining, together with the basic bricks and converted bottoms. A short description of the process was given. On account of the siliceous character of the metal used it is first blown for a short time in a Bessemer vessel with acid lining, and after partially desiliconising it is transferred to the basic vessel, where the removal of the phosphorus is effected. Analyses were given of the iron before and after desiliconising, and also of the finished product. An account was given of the mechanical tests adopted and of the branches of manufacture for which the material is particularly adapted. The paper concluded with a reference to the basic slag produced during the process.

3. *On the Production of Soft Steel in a new type of Fixed Converter.*
By GEORGE HATTON.

Large and costly plants hitherto generally employed for steel-making being beyond the reach of many iron manufacturers having existing works which they might wish to adapt for steel-making, some rapid and continuous method of steel-making involving only moderate expenditure on plant has long been desirable; and the fixed converter offers many advantages in this direction.

Referring to Sir Henry Bessemer's use of a fixed converter, and the subsequent use of such converters in Sweden, the paper points out the great difficulty always attending the use of fixed converters of the old type, namely, the necessity for maintaining a current of blast through the tuyeres after the blow was finished and during the process of tapping, producing undesirable oxidation of the metal, and describes M. Wittnöfftt's suggestions for dealing with the difficulty, also the Clapp and Griffiths differential piston valve for closing up the backs of the tuyeres.

The type of converter as constructed by the writer at Bilston is next described. It consists of a vessel, not unlike an ordinary Bessemer vessel in outward shape, supported and rigidly fixed on four cast-iron columns; the lower section, containing the charge of metal, having tuyeres through the sides and a solid bottom of silica bricks, is removable, and can readily be replaced by means of a hydraulic ram, which raises it into position or lowers it for removal, as required. The blast boxes are fixed around the casing of the upper section in a position above the metal-line, connection from these to the tuyeres being through cast-iron down pipes, each fitted with a 'baffler' valve (one to each tuyere). These valves are simultaneously closed at the termination of the blow, a small hole through each valve admitting enough blast to support the metal in the converter and keep it out of the tuyeres.

It is claimed that softer and more reliable material is obtained in this vessel than in the ordinary Bessemer one. Owing to the action being less violent, there is less risk of oxidation, as the final changes take place less rapidly; as, instead of the whole bath being constantly penetrated and oxidised—as in the bottom-blown vessel—only about a third of the charge is under treatment at once, a further indirect process of oxidation at the same time being carried on by circulation and admixture of the oxidised iron with the remaining portion of the bath.

This converter has an advantage over small Siemens plants, inasmuch as soaking pits can be used.

Some analyses are given both of soft steel produced and of steel castings, for the manufacture of which this converter is well adapted.

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4. *The Influence of Remelting on the Properties of Cast Iron.*

By THOMAS TURNER.

In the 'Report of the British Association' for 1853 (p. 87) an account is given of an elaborate series of experiments undertaken by Sir William Fairbairn to ascertain the effect of remelting on the mechanical value of cast iron. The metal used was Eglinton hot blast grey iron, which was melted 18 times in an air furnace, tests being performed at each remelting. It was found that the material gradually improved up to the 12th melting, then rapidly deteriorated, becoming white, hard, and weak at the 18th melting. The following analyses, given in the original paper, are due to Professor Calvert:—

	Percentage of		
No. of Meltings	Si	S	C
1	0·77	0·42	2·76
8	1·75	0·60	2·30
10	1·98	0·26	3·50
18	2·22	0·75	3·75

These experiments have been largely quoted in the principal works on engineering, metallurgy, and technical chemistry, and various suggestions have been made to account for the effect observed, and the absence of any apparent connection between chemical composition and mechanical value.

The author has examined specimens of the original bars, belonging to Professor Unwin, who assisted in these experiments. The identity of the specimens is fully assured, and the results obtained have been confirmed by separate analyses performed by Mr. J. P. Walton. In six cases also Professor Unwin retains sufficient for examination at any future time, if such should be necessary. The author's results are as follows:—[1]

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[1] *Journ. Chem. Soc.* 1886, p. 493.

No. of Melting	Total Carbon	Combined	Silicon	Sulphur	Manganese	Phosphorus
1	2·67	0·25	4·22	0·03	1·75	0·47
8	2·97	0·08	3·21	0·05	0·58	0·53
12	2·94	0·85	2·52	0·11	0·33	0·55
14	2·98	1·31	2·18	0·13	0·23	0·56
15	2·87	1·75	1·95	0·16	0·17	0·58
16	2·88	Varied in parts	1·88	0·20	0·12	0·61

These numbers are entirely different from those given by Calvert, but they support the suggestions of Snelus[1] relative to chemical changes during remelting.

5. *Silicon in Cast Iron.* *By* THOMAS TURNER.

The author has prepared samples of cast iron containing various amounts of silicon, and has examined the properties of the product.[2] Cast iron of exceptional purity was prepared by heating wrought iron with charcoal, and to this different quantities of silicon pig were added. The chemical composition of the materials used was as follows :—

Description	Total Carbon	Graphite	Si	P	Mn	S
Original Cast Iron .	1·98	0·38	0·19	0·32	0·14	0·05
Silicon Pig . .	1·81	1·12	9·80	0·21	1·95	0·04

The mixtures obtained were examined both chemically and mechanically, and the results are given in the accompanying table. The tensile and crushing strength was determined by Professor A. B. W. Kennedy, while for assistance in the chemical analyses the author is indebted to Mr. J. P. Walton.

It will be seen that the addition of silicon to white iron causes the separation of graphitic carbon, and produces a grey iron. The effect is therefore to soften the iron. By suitable addition of silicon an iron of any desired softness may be prepared without extra expense, and the author believes that with care in mixing the strength of cast iron could readily be doubled in many cases. A number of manufacturers have already applied the conclusions deduced from these experiments with very beneficial results.

As illustrating the practical value of these researches, the author referred to the work of Mr. C. Wood, who has been using siliceous iron in the foundry with marked success during the past twelve months. By this means Mr. Wood is able to prepare castings with a uniform tensile strength of 12 tons per square inch, using entirely Middlesborough iron. He is also able to make perfectly soft, smooth, sound castings, and to obtain grey iron even in sheets not exceeding one-eighth of an inch in thickness.

The author has recently had an opportunity of performing some experiments at the Rosebank Foundry, Edinburgh. Of these, and of other results obtained at this foundry, he hopes to give an account shortly. In the meantime he takes the opportunity to say that his former conclusions are quite confirmed. Six-test pieces of cast iron were exhibited with tensile strength varying from 15·8 to 18¼ tons per square inch, the average being nearly 17 tons; a result which, so far as the author is aware, has never before been obtained with British cast iron. These samples were not unusually hard to the tool, and the author believes that at such results as these the founders connected with our leading engineering works should aim.

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[1] *Journal Iron and Steel Institute*, vol. i. p. 37.

[2] *Jour. Chem Soc.* 1885, pp. 577, 902; 1886, p. 130. *Journ. Iron and Steel Institute*, 1886, Part I. *Iron*, xxvii. p. 476. *Jour. Soc. Chem. Industry*, 1886, p. 289.

TABLE A.—EFFECT OF SILICON ON THE PROPERTIES OF CAST IRON.

Silicon, per cent. (calculated)	Relative Density at 20° C. (Water at 20° = 1.)		Relative Hardness	Tensile Strength = per Square Inch		Modulus of Elasticity	Crushing Strength per Square Inch		Calculated Tranverse Strength. Bars 1 ft. long, 1 inch square, loaded in the centre		Chemical Analysis						
	Cylinder	Turnings									Total Carbon	Graphite	Combined Carbon	Silicon	Phosphorus	Manganese	Sulphur
				lbs.	tons		lbs.	tons	lbs.	tons							
0	7·560	7·719	72	22,720	10·14	25,790,000	168,700	75·30	2,702	1·206	1·98	0·38	1·60	0·19	0·32	0·14	0·05
0·5	7·510[1]	7·670	52	27,580	12·31	28,670,000	204,800	91·42	3,280	1·464	2·00	0·10	1·90	0·45	0·33	0·21	0·05
1	7·641	7·630	42	28,490	12·72	31,180,000	207,300	92·54	3,370	1·504	2·09	0·24	1·85	0·96	0·33	0·26	0·04
1·4	7·555	7·473	—	31,440	14·04	23,500,000	183,900	82·08	3,498	1·561	2·21	0·50	1·71	1·37	0·30	—	0·05
2	7·518	7·350	22	35,180	15·70	23,560,000	137,300	61·29	3,446	1·538	2·18	1·62	0·56	1·96	0·28	0·60	0·03
2·5	7·422	7·388	22	32,760	14·62	25,450,000	172,900[2]	77·18[2]	3,534[2]	1·577[2]	1·87	1·19	0·68	2·51	0·26	0·75	0·05
3	7·258	7·279	22	27,390	12·23	21,150,000	128,700	57·45	2,850	1·272	2·23	1·43	0·80	2·96	0·34	0·70	0·04
4	7·183	7·218	27	25,280	11·28	15,640,000	106,900	47·74	2,543	1·135	2·01	1·81	0·20	3·92	0·33	0·84	0·03
5	7·167	7·170	32	22,750	10·16	18,720,000	103,400	46·16	2,342	1·046	2·03	1·66	0·37	4·74	0·30	0·95	0·05
7·5	7·128	7·138	42	11,950	5·34	14,750,000	111,000	49·55	1,505	0·672	1·86	1·48	0·38	7·33	0·29	1·36	0·03
10	6·978	6·924	57	10,630	4·75	13,930,000	76,380	34·10	1,252	0·559	1·81	1·12	0·69	9·80	0·21	1·95	0·04

[1] This number is rather low, as the specimen afterwards proved to be somewhat faulty.

[2] The value in this case is probably exceptionally high; a crushing strength of about 60 tons might be anticipated from its position in the series.

In connection with Mr. A. E. Jordan, the author has also examined the condition of silicon in cast iron, and concludes, with Snelus and others, that in the vast majority of cases at least, silicon does not occur in the graphitic form. He believes it to be present in the form of silicide. Recently Dr. Sorby has observed by means of the microscope minute crystals in cast iron, which he believes to be silicon. The author does not consider the evidence in support of this opinion to be conclusive as yet, and contends that, even if these minute crystals should prove to be silicon, in their chemical behaviour they more closely resemble that element in the amorphous than in the graphitic condition.

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6. *The Influence of Silicon on the Properties of Iron and Steel.*

By THOMAS TURNER.

The following is a preliminary account of a series of experiments the completion of which will probably occupy several years. The object in view is to determine the influence of silicon on the mechanical properties of steel as used either for castings or tools, and also on the purest kind of iron met with in commerce.

For the present experiments, which were conducted at the works of the South Staffordshire Steel and Ingot Iron Company, Bilston, iron was taken by means of a small ladle from the Bessemer converter just after the blow was finished, and before any addition of manganese had been made. It was therefore very nearly pure iron, containing not more than one quarter of a per cent. of all substances other than iron. This material was poured into a red-hot crucible of Stourbridge fire-clay, and in which was placed a weighed quantity of silicon pig iron containing 10 per cent. of silicon. After being well mixed together the contents were allowed to solidify in the pot and afterwards examined.

The material was originally rather redshort owing to the absence of manganese, but redshortness did not seem to be at all diminished by a small addition of silicon, and before 0·2 per cent. was reached the metal went to pieces on attempting to roll it red hot. The metal appears to weld equally well with all proportions of silicon which are capable of being rolled, and is very tough when cold. A few hundredths per cent. of silicon caused the metal to remain much quieter on pouring, while about half a per cent. conferred the property of hardening in a remarkable manner. A chisel prepared from this material was very tough cold, and retained its cutting edge very well indeed, and giving a fracture much resembling tool steel. It was however very difficult to work while hot.

The author hopes to be able to give fuller details in a few months.

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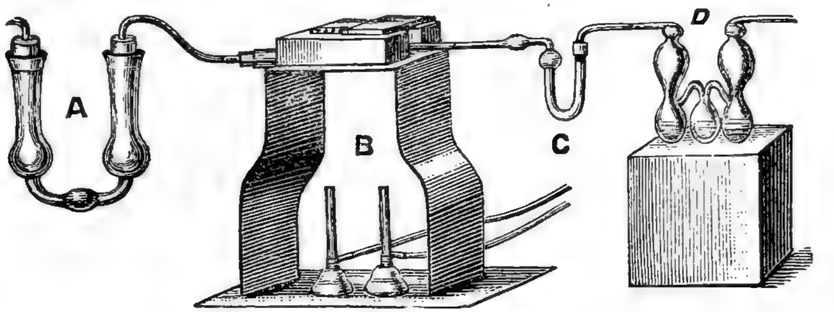
7. *On the Estimation of Carbon in Iron and Steel.*[1] *By* THOMAS TURNER.

The author dissolves from three to five grams of borings in ammonio-copper chloride for the determination of total carbon, or in hydrochloric acid for estimations of graphite. The carbon in the residue is estimated by combustion. The



A. Potash Tube. C. Drying Tube.
B. Combustion Furnace. D. Potash Bulbs.

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[1] *Proceedings Birmingham Philosophical Society*, vol. iv. Part II. p. 404. *Chem. News*, lii. p. 15. *Iron*, xxvi. p. 84.

apparatus for this operation is extremely simple, while the operation itself is rapid, and avoids transference of the carbonaceous residue. Filtration is effected in a short piece of combustion tubing, narrow at one end, and fitted with a filter of ignited sand and asbestos. After drying, combustion is performed in the same tube by means of a very simple combustion furnace, the cost of which is trifling, and which stands on an ordinary working bench. The furnace has also been found useful for a variety of other uses in the laboratory.

Filter and Combustion Tube.

Sketches of the apparatus are annexed.

WEDNESDAY, SEPTEMBER 8.

The following Reports and Papers were read:—

1. *Report of the Committee on Isomeric Naphthalene Derivatives.*—See Reports, p. 216.

2. *Report of the Committee for preparing a new series of Wave-length Tables of the Spectra of the Elements.*—See Reports, p. 167.

3. *On the Chemistry of Estuary Water.*

By HUGH ROBERT MILL, *D.Sc., F.R.S.E., F.C.S.*

Although chemical problems connected with ocean water and oceanic deposits have been attacked by Forchhammer, Dittmar, and others, while recently Norwegian and German investigators have done much to elucidate the conditions obtaining in enclosed and partially enclosed seas, the chemistry of estuary water has been comparatively neglected.

In investigating an estuary the first essential is to ascertain the salinity (ratio of total dissolved matter to water), from point to point, and to trace its variations; the second to perform accurate analyses of the saline and gaseous contents at various positions suggested by the previous salinity observations. The first of these has been done completely for the Firth of Forth, and partially for the Firth of Clyde and some other river entrances in Scotland; the second is in progress. By means of the hydrometer (form used by Mr. Buchanan on the *Challenger* Expedition) the distribution of salinity in the Firth of Forth has been proved to be nearly constant all the year round, while that of the Firth of Clyde is subject to periodical variations through the whole mass of water. The conclusion drawn from the form of the density (salinity) curve for the Forth river-entrance is that mixture of river and sea water takes place by a true process of diffusion which produces and maintains a constant (though not uniform) gradient of density from river to sea. Possibly the different diffusive powers of the various potential compounds, the constituents of which exist in solution, may determine the formation of certain salts, and lead to the preponderance of these in certain places. The truth of this hypothesis will be tested by the second part of the inquiry, which is now being commenced.

Observations of alkalinity by the method of Tornoe showed a marked increase of the (potential) calcium carbonate in solution with decrease of salinity, *i.e.*, the dissolved matter of fresher water was richer in calcium carbonate than that of sea-water.

4. *The Essential Oils: a Study in Optical Chemistry.*
By Dr. J. H. Gladstone, *F.R.S.*

5. *An Apparatus for maintaining Constant Temperatures up to* 500°.
By G. H. Bailey, *D.Sc., Ph.D.*

The apparatus consists of a tube of hard glass, 25 cm. long and 4 cm. in diameter, placed horizontally over a furnace of 6 Bunsen burners, and enclosing a smaller tube in which substances may be heated. Alongside this is the bulb of an air-thermometer, which connects with a U-tube containing mercury. On heating, the mercury column is of course depressed in the near limb of the U-tube, and rises in the further limb, the amount of the depression being indicated by a millimetre scale. The instrument is first graduated by placing a high boiling thermometer in the heating tube, and then constructing from the readings a curve, by reference to which the temperature may be ascertained when the reading on the scale is known.

The gas supply passes through a tube fitting into the further limb of the U-tube arranged as a gas regulator, so that, as the mercury rises in this limb, it cuts down the supply. By raising or depressing this regulator the point at which the supply is cut off is determined, and any desired temperature can thus be maintained in the heating tube. The apparatus has been found reliable up to 500°, and it is possible to measure the temperature with great accuracy, and to keep it constant within at most 5° with the greatest ease. The author suggests its use for determining the temperature of decomposition of salts, melting-points, and for investigations in dynamical chemistry.

6. *On a new Apparatus for readily determining the Calorimetric Value of Fuel or Organic Compounds by Direct Combustion in Oxygen. By* William Thomson, *F.R.S.E.*

This consists of an arrangement by which the organic substance is burned in a small platinum crucible, set in a non-conducting cup or holder, the whole being enclosed by a thin glass inverted test-tube, and the combustion performed under water. The stream of oxygen is directed on to the burning material by a movable narrow brass tube, so that the combustion is absolutely under control. By this means plumbago or anthracite may be easily and perfectly burned, which cannot be done by the apparatus devised by Mr. Lewis Thompson, which consists in burning the material by means of a mixture of chlorate and nitrate of potash. This last arrangement gives inaccurate results and is unscientific, inasmuch as there are many things which modify the results which cannot be measured, and which vary in each experiment.

The gases from the combustion in oxygen pass through water contained in a long thin glass beaker; the glass, platinum, mercury, and brass work used in the apparatus is weighed, and from their specific heat their equivalent in water is calculated—2,000 grammes of water are used for 1 gramme fuel.

7. *On some Decompositions of Benzoic Acid. By* Professor Odling, *F.R.S.*

8. *The Crystalline Structure of Iron Meteorites. By* Dr. O. W. Huntington.

The object of this paper was to show that the true iron meteorites have a common crystalline structure, varying only in details, and not in general character.

In the first place it is shown that the Widmanstättian figures and the Neumann lines are simply the effects of the segregation of impurities during the process of crystallisation parallel to the planes of crystalline growth, and are phenomena similar in all respects to those observed in the crystals of many minerals.

It appears that the Widmanstättian figures, though presenting additional features which cannot be discovered in the Neumann lines, grade into the latter by such insensible steps that no natural division can be made between the two classes of phenomena. It is shown also that the plates, of which both the figures and the lines referred to are sections, are always parallel to faces of one of the three fundamental forms of the regular system, the octahedron, dodecahedron, and cube, and that the complications observed are only due to twinning. Figures were drawn illustrating these points, and representing Widmanstättian plates in all the positions described.

It is further shown that the planes of fracture frequently observed in the iron meteorites are also parallel to the faces of the same three fundamental forms. Such fractures have, in most cases, resulted from the concussion produced by the rapid passage of the meteorite through the air, but may also at times be obtained artificially, and differ in no respect from true cleavage planes, except in so far as the malleability of the metal prevents us from developing the cleavage in the usual way. This cleavage is distinguished from the jointed structure, sometimes resulting from the segregation of impurities and corresponding to the Widmanstättian figures. It appears markedly in some of the most compact meteorites, and often crosses the Widmanstättian plates. Finally, the close agreement of these phenomena with what has been observed in the artificial crystallisation of iron and other materials is pointed out.

This investigation throws no new light upon the origin of meteorites, except so far as it strengthens the opinion that the process of crystallisation must have been extremely slow. The occurrence of large masses of native iron occluding hydrogen gas, and containing nickel, cobalt, phosphorus, sulphur, &c., implies a combination of conditions which the spectroscope indicates as actually realised in our own sun and in other suns among the fixed stars, and the most probable theory seems to be that these masses were thrown off from such a sun, and that they very slowly cooled, while revolving in a zone of intense heat.

SECTION C.—GEOLOGY.

PRESIDENT OF THE SECTION—Professor T. G. BONNEY, D.Sc., LL.D., F.R.S., F.S.A., F.G.S.

THURSDAY, SEPTEMBER 2.

The President delivered the following Address:—

I HAVE felt it a great honour and an especial pleasure to be asked to preside at the meeting of Section C in Birmingham. A great honour, because of the repute of my predecessors; an especial pleasure because, as born in the Midlands, I am naturally proud of the Midland metropolis, its intellectual activity, and its commercial enterprise. Besides this there are few towns in England where I number more friends of kindred tastes than in Birmingham. Geology especially seems to thrive in this district, and little wonder when you reckon among your residents, in addition to a host of other workers, such leaders as Crosskey, *malleus erraticorum,* Allport, who taught me how to work with the microscope, and Lapworth, to whose genius my duller mind is under constant obligation.

The addresses delivered at the annual meetings of the British Association afford a convenient opportunity for what may be termed stock-taking in some branch of science which has especially attracted the attention of the author; for a brief review of past progress; for a glance forward over the rich fields which still await exploration. We may compare ourselves to pioneers in a land as yet imperfectly known, the resources of which are only beginning to be developed. Taking our stand upon some vantage-ground at the border of the clearings, we glance forward over plains as yet untrodden, over forests as yet untracked, to consider in what directions and by what methods of investigation new lands can be won through peaceful conquest, new treasures added to the world's intellectual wealth.

I purpose, then, on the present occasion to offer to you a few remarks upon a branch of geological investigation which appears to me full of promise for future workers. The keynote of my address might be conveyed in the following sentence: 'The application of microscopic analysis to discovering the physical geography of bygone ages.' The ultimate aim of geological researches is obtaining answers, in the widest and fullest sense, to these two problems in the history of our globe—the evolution of life upon it, and the evolution of its physical features. In the former a host of labourers, before and since the epoch of Darwin's great book, have been employed in collecting and co-ordinating facts, and in framing hypotheses by scientific induction. In the latter the workers are fewer, but the results obtained are neither small nor unhopeful. In the past generation, men like Godwin-Austen pointed out the principles of work and gathered no small harvest, but in the present the application of the microscope to the investigation of rock structure has facilitated research by furnishing us with an instrument of precision; this, by disclosing to us the more minute mineral composition and structural peculiarities of rocks, enables us to recognise fragments, and sometimes even to determine the source of the smaller constituents in a composite clastic rock. The microscope, in short, enables us to declare an identity where formerly only a likeness could be asserted, to augment largely in all cases the probabilities for or against a particular hypothesis, and to substitute in many a demonstration for a conjecture.

Once for all, I ask you to bear in mind that this address is mainly a recital of other men's work, so that I shall not need to interrupt its continuity by remarks as to the original observers. The subject is, indeed, one to which I have paid some attention, but I can only call myself a humble follower of such men as Godwin-Austen, 'the physical geographer of bygone periods,' and Sorby, who was the first to apply the microscope to similar problems, and to whom in this class of investigation we may apply the well-known saying, *Nihil tetigit quod non ornavit.*

With the deepest gratitude also I acknowledge the loan or the gift of specimens from Drs. Hicks and Callaway, from Messrs. Howard Fox, Somervail, Shipman, Gresley, Houghton, Marr, Teall, and J. A. Phillips, from Professors Lapworth and Judd. Through their liberality I have had the opportunity of examining for myself the greater part of the materials which have already been described in the principal geological periodicals, and of adding many new slides to my own collection.

The nature of the materials of grits and sandstones has been so admirably treated by Dr. Sorby in his presidential address to the Geological Society for 1881 that I may pass briefly over this part of the subject. I will, however, add a few details in the hope of placing more clearly before you the data of the problems which are presented to us. In order to exemplify the size of the fragments with which we have to deal, I have made rough estimates of the diameters of the constituent grains in a series of quartzose rocks. Sometimes there is much variability, but very commonly the majority of the grains are tolerably uniform, both in size and shape. In a slide from the Lickey quartzite, exposed in the railway cutting at Frankley Beeches, grains, often well rolled, ranging from ·02″ to ·03″ are very common. In a specimen of Hartshill quartzite, they range from ·01″ to ·03″, but the most common size is a little under ·025″. In a quartzite from west of Rushton (Wrekin) a good many grains range from ·03″ to ·05″. In two specimens of quartzite (white and pale grey) from near Loch Maree, the grains commonly vary a little on either side of ·02″, while in a specimen of the 'fucoidal quartzite' (mouth of Glen Logan) much greater variety is exhibited, a good deal of the material being about ·01″ in diameter, but with many scattered grains up to ·03″. The grains in a pale grey quartzite, from the Bunter beds at the north side of Cannock Chase, range from about ·01″ to ·015″, and are very uniform. In a liver-coloured quartzite from the same locality they are about as long, but narrower and sharply angular in form. These will serve as examples of what we may call an average, moderately fine grit or sandstone. It is my impression that in a very large number of ordinary sandstones most of the grains range from about one to three hundredths of an inch. In rocks, however, to which most persons would apply the epithet 'rather coarse-grained,' fragments of a tenth of an inch or more in diameter are common.

It is extremely difficult to give, in general terms, an estimate of the size of the crystalline constituents of ordinary granites, and the more coarsely crystalline gneisses. But speaking of those which enter into the composition of the ground mass, I should say that the individual quartz grains do not often exceed ·03″, and are very frequently between this and ·02″. In the finer-grained granites and more distinctly banded gneisses, and their associated quartziferous schists, about ·01″ is a common size, while in the finer schists (believed by many geologists to be later in date than the aforesaid) they range from ·002″ downwards, and do not generally exceed ·001″. Felspar crystals, where they occur, probably do not differ very materially in area from the quartz, though they are often, as might be expected, rather longer and narrower; mica crystals, cut transversely, are often longer and usually much narrower. Of other constituents, as being either rarer or more liable to change, I will not speak in detail. The individual quartz grains, in the compact and glassy varieties of the more acid igneous rocks, are about the same size as those in an ordinary granite.

Space does not permit me to enter upon the methods of distinguishing between the materials furnished by the different varieties of crystalline schists, gneisses, and igneous rocks of similar chemical composition. For the most important of these I must refer you to Dr. Sorby's address, but I may add that there are others which it would be almost impossible to describe in words, as they can only be learnt by long-continued work and varied experience. I do not pretend to say that in the case of a grit composed of fragments of about ·02″ diameter we can succeed in identifying the parent rock of each individual, but I believe we can attain to a reasonable certainty as to whether any large number of its constituents have been furnished by granitoid rocks, by banded gneisses and schists, by fine-grained schists or certain phyllites, by older grits or argillites, or by lavas and scoria. There seem to be certain minute differences between the felspars from a granitoid rock and from a porphyritic lava, and more markedly between the quartz grains from the two rocks. The latter can generally be distinguished from the polysynthetic grains furnished by certain schists or veins, and these not seldom one from another. Obviously the larger the fragments the less, *cæteris paribus,* the difficulty in their identification. When they exceed one-tenth of an inch the risk of important error is, I believe, to a practised observer comparatively small.

Obviously, also, the shape of the grains leads to certain inferences as to the distance which they have travelled from their original source, and as to the means of transport, but into the details of this I must forbear to enter. I will merely remind you that small angular fragments of quartz are so slowly rounded, when transported by running water, that, if well-rounded grains appear in large numbers in a sandstone, it seems reasonable to suppose that these are, in the main, wind-drifted materials.

Thus every rock in which the constituent particles admit of recognition and of identification may be made to bear its part in the work of deciphering the past history of the globe. Where the constituents have been derived from other rocks we obtain some clue to the nature of the earth's crust at that epoch; where the locality whence a fragment was broken can be discovered, the nature, strength, and direction of the agents of transport can be inferred. Some idea as to the structure and surface contour of the earth in that district, and at that time, can be formed, and thus the petrologist, by patient and cautious induction, may, in process of time, build up from these scattered fragments the long-vanished features of the prehistoric earth, with a certainty hardly less than that of the palæontologist, when he bids the dry bones live, and repeoples land and sea with long-vanished races. The latter study is in vigorous maturity, the former is still in its infancy; so much wider then is the field, so much more fascinating, to many minds, is the investigation. There are many districts which are without fruit for the palæontologist—there are few indeed which, to the petrologist, do not offer some hope of reward. The field of research is so wide that not one nor few men can gather all its fruits. It needs many workers, and it is in the hope of enlisting more that I have ventured to bring the subject before you to-day.

Materials of the coarser fragmental rocks of Great Britain.[1]

I proceed now to give a brief epitome of the constitution, so far as I know it, of our British grits, sandstones, breccias, and conglomerates. I shall exclude, as involving too many collateral issues, the Post-Pliocene beds, and dwell more on the earlier than on the later deposits, because the latter obviously may be derived from the former by denudation, so that it becomes the more difficult to conjecture the immediate source of the constituent particles. Further, in order to avoid controversy on certain questions of classification, or for brevity, I shall occasionally group together geological formations which I think separable.

It may be convenient, however, to call your attention to the localities at which, at the present day, granitoid rocks (many of which may be of igneous origin, but are of very ancient date), gneisses, and crystalline schists are exposed in Great Britain, as well as those where considerable masses of igneous rock, of age not later than Mesozoic, occur. The former constitute a large part of the north-western and central highlands of Scotland and of the islands off its west coast; they are ex-

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[1] I have been obliged to exclude those of Ireland, as I have so little material from that country, and for want of space have not dealt fully with those of Scotland.

posed in Anglesey and in the west and the north of Carnarvonshire; they form the greater part of the Malvern Chain, and crop out at the Wrekin; they occur on the south coast, at the Lizard, and in the district about Start Point and Bolt Head; they rise above the sea at the Eddystone. It is probable that these last are the relics of a great mass of crystalline rock, which may have extended over the Channel Isles to Brittany; also, that we may link with the *massif* of the Scotch highlands the crystalline rocks of Western Ireland on the one hand, and of Scandinavia on the other. Among the indubitably igneous rocks we have granite, or rocks nearly allied to it, in Scotland, in the Lake district, in Leicestershire, and in Devon and Cornwall. Felstones, old lavas, and tuffs of a more or less acid type occur in Southern Scotland, to some amount also in the Highlands, in the Lake district, and in various localities of rather limited extent in West-central England, as well as in the south-west region just mentioned, while in Wales we have, in the northern half, distinct evidence of three great epochs of volcanic outburst, viz., in the Bala, in the Arenig, and anterior to the Cambrian[1] grits and slates. In South Wales there were great eruptions at the last-named epoch and in Ordovician times. I have passed over sundry smaller outbreaks and all the more basic rocks as less immediately connected with my present purpose. It is, I suppose, needless to observe that a coarsely crystalline rock, whether igneous or of metamorphic origin, must be considerably older than one in which its fragments occur.

Cambrian and later Pre-Cambrian.—That the majority at least of the gneisses and crystalline schists in Britain are much older than the Cambrian period will now, I think, hardly be disputed by any who have studied the subject seriously and without prejudice. There are, however, later than these, numerous deposits, frequently of volcanic origin, whose relation to strata indubitably of Cambrian age is still a matter of some dispute. Therefore, in order to avoid losing time over discussions as to the precise position of certain of these deposits, or the particular bed which in some districts should be adopted as the base of the Cambrian, I will associate for my present purpose all the strata which, if not Cambrian, are somewhat older. The latter, however, exhibit only micro-mineralogical changes, and of their origin, volcanic or clastic of some kind, there can be no reasonable doubt; so that the difference in age does not appear to be enormous; that is to say, I include with the Cambrian the Pebidian of some recent authors.

The utility of microscopic research has nowhere been better exemplified than in the case of the oldest rocks of St. David's. Some authors have supposed that the base of the Cambrian series in this district has been 'translated' beyond recognition, others that it has been thrust out of sight by the intrusion of granitic rock. But low down in the series, beneath the earliest beds that have as yet furnished fossils to British palæontologists, there is a well-marked and widespread conglomerate; underlying this, with apparent unconformity, comes a series of beds very different in aspect, chiefly volcanic, and beneath this a granitoid rock. The conglomerate, in places, even without microscopic examination, proves the existence, though probably at some distance, of more ancient rock, as it is full of pebbles of vein-quartz and quartzite; but in other parts it is crowded with pebbles closely resembling the felstones in the underlying volcanic group, and in some parts becomes a regular *arkose*, made up almost wholly of quartz and felspar, closely resembling those minerals in the granitoid rock, of which also small rounded pebbles occasionally occur. One or two fragments of a quartzose mica-schist, which is not known to occur *in situ* in the district, have also been found. It is therefore evident that not only is the volcanic series somewhat, and the granitoid rock considerably, older than the conglomerate, but also that an important series of rocks, some of which were thoroughly metamorphic, was exposed in the district when the conglomerate was formed. I have very little doubt that a study of the finer-grained sedimentary Cambrian beds overlying the conglomerate will corroborate, were it needed, the conclusion which the latter justifies. Passing on to North Wales the coarser beds in the Harlech

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[1] I take the base of the Arenig as the commencement of the next formation, the Ordovician, which thus represents one phase of the Lower Silurian in the variable nomenclature of the Geological Survey.

axis, so far as they have been examined, are found to be full of fragmental quartz and felspar, which is undoubtedly derived from a granitoid rock; some beds being made up of little else. No rock of this character, so far as I am aware, is exposed in this part of Wales, but a ridge of granitoid rock extends from the town of Carnarvon to the neighbourhood of Port Dinorwig. Through this, apparently, the great felstone masses which occupy considerable tracts on the northern margin of the hills between Carnarvon Bay and the valley of the Ogwen have been erupted, and over this comes a series of grits, slates and conglomeratic or agglomeratic beds, overlain ultimately by the basal conglomerate of the undoubted Cambrian series. It was formerly maintained that these felstones were only lower beds of the Cambrian metamorphosed—practically fused by some 'metapeptic' process. This notion, however, was quickly dispelled by microscopic examination. The overlying conglomerate is often crowded with pebbles, identical in all important respects with the felstone itself, which also presents many characteristics of a lava flow as opposed to an intrusive mass, and is no doubt an ancient rhyolite now devitrified. There is some difference of opinion among the geologists who have worked in this district as to the exact correlation of various gritty, conglomeratic or agglomeratic beds which succeed the felstone, as is only natural where disturbances are many, and continuous outcrops generally few. But all agree on the existence of a series, into which volcanic materials enter largely, between the above-named basal Cambrian conglomerate and the felstone. In this, then, and in the basal conglomerate we have again and again more or less rounded fragments of old rhyolitic lavas. We have numerous and varied *lapilli*, probably of like chemical composition. We have grits which are largely composed of quartz and felspar, resembling that in the granitoid rock, together with fine-grained quartzose schists and bits of rhyolite, all mingled together. We have also occasionally, as in the Cambrian conglomerate near Llyn-Padarn, pebbles of the granitoid rock. Further, the basal conglomerate, as near Moel Tryfaen, is sometimes crowded with fragments of gritty argillites. Fine-grained schists, as will be noted, seem to be rare in this district, but, as such rocks occur *in situ* in the Lleyn peninsula, they will probably be discovered more abundantly when the Cambrian conglomerate is examined further in that direction.

Fine-grained micaceous, chloritic, and other schists occupy a considerable portion of Anglesey, and in the neighbourhood of Ty Croes there is an important outcrop of granitoid rock. The former were once regarded as metamorphosed Cambrian, the latter as granite which aided in the metamorphism at the end of the Ordovician period. In Anglesey the earlier Palæozoic rocks are not generally rich in fossils, so that it is sometimes difficult to settle their precise position. The oldest beds which have been thus identified have been placed in the Cambrian (Tremadoc), but some experts have doubted whether quite so low a position can be assigned to them. Hence the exact age of the oldest Palæozoic beds in this island is uncertain, and whether the basal conglomerates near Ty Croes are of the same age as those in Carnarvonshire. This, however, is certain, that some of the Anglesey grits above the basal conglomerate are largely made up of quartz and felspar derived from a granitoid rock. Others include numerous fragments of very fine-grained schists, like those so abundant in the island, and the conglomerate contains pebbles sometimes full two inches in diameter, absolutely identical with the rocks in the adjacent granitoid ridge (the foliated structure distinctive of some parts of it having been even then assumed), together with various metamorphic rocks, some green schistose slaty rocks, and some reddish slates. The last two were, I doubt not, cleaved before they became fragments; probably these were derived from the hypometamorphic series, which Dr. Callaway has described, and which also contains pebbles of the granitoid rocks. Fragments of the characteristic fine-grained schists are, so far as I at present know, less common among the Anglesey grits and conglomerates than one would expect, perhaps owing to their comparative destructibility; but I have found them occasionally and suspected their presence more often. Hence there can be no doubt that older crystalline rocks have very largely contributed to the formation of at least the coarser members of the lower Palæozoics of Anglesey.

Passing now to Central England we come to regions which may be regarded as almost the exclusive property of your local geologists. The Hollybush sandstone on the flanks of the Malvern is, no doubt, largely composed of the finer *débris* of the older rocks of that chain, but the Malvern hills are only an unburied fragment of a vastly larger area of crystalline Archæan rock. This is just indicated some seven miles farther north in the Abberley hills. It crops up at either end of the Wrekin, and for a little space near Rushton, but in the later fragmental rocks of the district we have abundant proofs of its existence. The central part of the Wrekin is composed of volcanic rocks, rhyolites of varied kinds, with agglomerates; these were once regarded by our highest authorities as greenstones intrusive in beds of Ordovician age, but Mr. S. Allport has taught us their true nature, and Dr. Callaway has proved their far greater antiquity. Similar rocks are to be found elsewhere in the neighbourhood of the Wrekin, and in the district farther west. We cannot affix a precise date to the volcanic outbursts of the Wrekin, but we can prove that they are not newer than the quartzite which fringes the hill, as it contains fragments of the perlitic and other glassy rocks of the apparently underlying series. This quartzite is certainly much older than the newer part of the Cambrian, and pebbles of rhyolites, resembling those of the Wrekin, occur in the indubitable Cambrian beds farther west. For instance, a grit at Haughmond Hill is quite full of fragments of volcanic rock, many of them scoriaceous; another suggests the derivation of some of its materials from a mica-schist, while, according to Dr. Callaway, the conglomerates and grits of the Longmynds (which form the main part of the mass) are largely derived from older rocks, the former being crowded with pebbles of purple rhyolite, quartz, felspar, mica, and occasional bits of mica-schist. A most interesting conglomerate, apparently older than the quartzite, occurs at Charlton Hill. This contains more or less rolled fragments of grits, quartzites, and argillites, looking in several cases as if they had undergone, before being broken off, the usual micro-mineralogical changes. It contains also fragments of rhyolite and many of coarse granitoid or gneissoid rocks of Malvernian type, besides numerous grains of quartz and felspar of a like character. Finer-grained gneissoid rocks and schists, micaceous, hornblendic or chloritic, are present in fair amount. The last bear some resemblance to the Rushton rocks, and remind me strongly of rocks which occur in the Highlands and in the Alps, apparently not in the lowest part of the Archæan series. Some also resemble the Anglesey schists. The quartzite itself is largely made up of grains of quartz which appear to me to have been derived from old granitoid rocks. Occasional grains, however, suggest, by their composite structure, derivation from a quartzose rock of finer texture, and, as already said, bits of the Wrekin rhyolite sometimes occur. The same is true of the Lickey quartzite, in regard to all three constituents, in which an occasional grain of microcline, very characteristic of old granitoid rocks, has been observed. The quartz-grains in this and in the former rock are occasionally very much rounded. The Lickey quartzite has lately been shown by Professor Lapworth to overlie rhyolitic rocks, and it is much older than the lowest Silurian. Not improbably it is of the same age, and was once connected with that of the Wrekin district. The Hartshill quartzite, near Nuneaton, has a similar composition, is below Cambrian, and overlies some rhyolitic rocks. Thus these insulated areas prove the existence of an old fragmental series, which is largely composed of materials derived from pre-existing and much more ancient Archæan rocks. It is difficult to assign a date to the unfossiliferous rocks forming the rugged hills of Charnwood Forest, but, as they have been affected by very ancient earth-movements, and there is nowhere any valid evidence of volcanic activity in the true Cambrians, they may be assigned with most probability to the antecedent epoch, which seems to have been one of great disturbance. Microscopic examination has shown that materials of volcanic origin enter largely into the composition of these Charnwood rocks, even the most finely grained; but besides occasional fragments of slaty rock in the breccias, for which a high antiquity cannot be asserted, we find some pebbles of vein-quartz and two or three beds of quartzite. The grains in these appear to have been derived from old granitoid rocks, and not from the porphyritic rhyolites of the district. In one case, at the Brande, they are most conspicuously rolled, and this has happened, though less uniformly, in a grit from near the ruins, Bradgate, which also contains grains of compound structure. In conclusion, I must briefly notice the so-called Torridon sandstone of North-western Scotland, which is in many respects invaluable to the student. That it is not later than the base of the Ordovician is indisputable; that it is underlain by and derived from a mass of Archæan rocks, gneisses, more or less granitoid, with occasional schists, is universally admitted. Its coarser basement beds are crowded with fragments of the underlying gneisses and schists, and since the epoch of their formation no important change has taken place in either the one or the other. The finer beds, though other materials occasionally occur, are largely, sometimes almost exclusively, composed of grains of quartz and of felspar identical in every respect with those in the underlying series. It may be a fact of some significance, for it agrees with what I have elsewhere noticed in very old fragmental rocks, that the felspar appears to have been broken off from the parent rock while still undecomposed, and in many cases is even now remarkably well preserved. It would seem, therefore, as if the denudation of the granitoid rock had been accomplished without material decomposition of its felspar, but I must not allow myself to digress into speculations on this interesting and suggestive fact. While referring to this district I may mention the quartzites, though, strictly speaking, they are Ordovician in age. These in some cases consist all but exclusively of quartz grains derived from the Archæan series, which, however, are generally smaller than those in the Torridon; it would seem as if the felspar of the parent rock had either decomposed *in situ*, or had been broken up in consequence of the longer distance from the source of supply. This quartzite is sometimes of singular purity, containing little or no earthy material, and only rarely a flake of mica or a grain of felspar, tourmaline or epidote (?).

Ordovician-Silurian.—In regard to the earlier of these formations I am better acquainted with the volcanic than with the non-volcanic fragmental beds. Still, so far as I have seen, we find among the latter frequent indications of a supply of materials from regions of crystalline as well as of ordinary sedimentary rocks. The quartzite of the Stiper Stones (possibly earlier than the Arenig) appears to have derived most of its grains from granitoid rocks, and probably the same is true of many of the coarser beds in the Caradoc group of Shropshire and Eastern Wales. The Garth grit of Portmadoc appears to have derived much of its quartz from a like source as the Stiper Stones, but it also contains bits of a fine grained quartzose schist and of older clastic rocks. A grit from the Borrowdale series of Chapel-le-dale contains, in addition, bits of old andesite and probably diabase, with fragments of a rather granitoid gneiss and quartzose schists. Fragments of crystalline rock, both small and large, abound in the Upper Llandovery beds at Howler's Heath, at Ankerdine Hill, in the Abberley district, on the west flank of the Malverns, and at May Hill, thus indicating that early in Silurian times far greater outcrops of crystalline rock existed than are now visible west of the Severn. Mr. W. Keeping[1] calls attention to the abundance of fragments of quartz, felspar, and mica in the 'greywackes' of the Aberystwith district, which give the rock sometimes quite a granitoid appearance, and adds that, in his opinion,[2] 'the abundance of felspar crystals, so general in the Silurian rocks (Upper Silurian of North Wales, South Wales, and the Lake district), points to the neighbouring presence of a vast mass of early, perhaps primeval, igneous rocks as the great source of sediment supply in Silurian times.' What I have seen of the Denbigh grit of North Wales and of the Coniston beds of the Lake district confirms this conclusion. It is true that some of the material may have been supplied by Ordovician volcanic rocks, and that the quartz grains in the specimens which I have examined are not large. But we must remember that the latter can hardly have been furnished by the lavas of the Lake district, and those of North Wales, though richer in silica, do not, so far as I know, generally contain large quartzes. These, indeed, may have been derived from the denudation of Cambrian rocks, but I should doubt the sufficiency of such an explanation. In one specimen, a Denbigh grit from Pen-y-glog, near Corwen, there occurs, besides one of smaller size, a fragment about ·1″ in diameter, exhibiting a

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[1] *Quar. Journ. Geol. Soc.* vol. xxxvii. p. 149, &c.

[2] *Ibid.* p. 150.

micrographic arrangement of quartz and felspar. In Cornwall, among beds which are almost certainly Ordovician or Silurian, we find similar evidence of derivation from much more ancient rocks. The conglomerates of the Meneage district contain, in addition to quartzites, greywackes, and other old sedimentary beds, abundant fragments of a moderately coarse-grained granitoid rock, and occasionally a hornblendic rock similar to the well-known Lizard schist. A series of specimens which I have examined microscopically shows, in addition to compact igneous rocks, apparently volcanic, quartz grains probably derived from granitoid rock, various fine-grained schists and schistose argillites or phyllites, quartzites, grits, and other older clastic rocks. One fragment of schist contains little eyes of felspar, and in general structure reminds me of some in the so-called 'Upper Gneiss' series of N.W. Scotland. Another, a fine-grained mica-schist or a phyllite, exhibits a cleavage transverse to the rumpled foliation.

A rich harvest probably awaits the explorer in the 'greywackes' of the southern uplands of Scotland. A 'Lower Silurian' conglomerate from Kingside, Peeblesshire, contains numerous fragments of igneous rocks, probably of volcanic origin, and bits of granitoid rock, with some which are either very old quartzites or perhaps vein-quartz. These have been crushed and re-cemented before being detached from the parent rock. The basement conglomerate of the Craig Head limestone group (Llandeilo-Bala) is full of rounded fragments of volcanic rocks. These, as in the last-named case, exhibit considerable variation; the majority, however, are probably andesites, and perhaps in one or two cases even basalts. A Middle Llandovery conglomerate from near Girvan is largely made up of fragments which appear to have been derived from very ancient quartzose rocks. The greywacke of rather later age from near Heriot, Edinburghshire, contains, with numerous volcanic fragments, and a little argillite, a few bits of fine-grained quartz-schist, together with grains of quartz and felspar, suggestive of derivation from a more coarsely crystalline rock.

Old Red Sandstone and Devonian.—It is, I believe, indisputable that when the Old Red Sandstone of Scotland was formed a great period of mountain-making had ended and one of mountain-sculpture was far advanced. The conglomerates are often full of fragments of the crystalline rocks of the Highlands, and no doubt the sandstones derived their quartz-grains from the same source. In the southern half of the country, however, as is well known, volcanic materials, more or less contemporaneous, play an important part. I have not been able to examine closely the Old Red Sandstones of England and Wales, but their frequent near resemblance to the sandstones of Scotland suggests a similar derivation. True, the materials may have been sifted from older clastic rocks, but there is nothing specially to suggest this, and the abundant pebbles of vein-quartz, which I have seen in one or two localities, seem rather more favourable to the other hypothesis. I have only examined microscopically a very few specimens of Devonian grit, all from the south side of the county. These certainly seem to have derived their materials, in part at least, from crystalline rocks, both granitoid and schists of finer grain; one specimen also apparently containing some bits of hypometamorphic rock.

Carboniferous.—In Scotland some of the basement beds of this series so closely resemble the Old Red Sandstone that no further description is needed, and the same remark may be made of the very few overlying sandstones which I have carefully examined. In the North of England the basement conglomerates, so far as I have seen them, are made up of earlier Palæozoic rocks, but for many of the great masses of sandstone which occur in the series a source of supply is not so easily found. Dr. Sorby, who has made a special study of the Millstone grit of South Yorkshire, tells us that it is formed of grains of quartz and felspar, apparently derived from a granite, and contains pebbles, sometimes an inch or so in diameter, of vein-quartz, of hard grits, of an almost black quartz-rock or quartz-schist, and of a non-micaceous granite. He also notes one fragment of a greenstone, and another either of a fine-grained mica-schist or of a clay-slate. The granite, he states, more resembled those of Scandinavia than any one now visible in Britain, and the bedding indicated a supply of materials from the north-east. In the Millstone grit near Sheffield he says that the grains appear to be but little worn, as if they had not been drifted from far. A few also appear to have been derived from schists. From what I have myself seen I anticipate that Dr. Sorby's conclusions may be extended to most of the other coarser Carboniferous clastic beds of Northern England, except that, perhaps, as was inferred by Professor Hull, another important, if not the principal, source of supply must be sought on the north-west. The materials of the basement conglomerates and grits in North Wales appear to be either Palæozoic rock or vein-quartz and an impure jasper; but a microscopic study of carefully selected specimens, especially from Anglesey, might produce interesting results. In Central England, as the Old Red Sandstone is commonly absent, and, if present, must have been speedily buried, we should naturally look farther afield for the materials of the Coal Measure sandstones and Millstone grit, where it occurs. But probably we shall be right in including this, as indicated by Professor Hull, with the northern district. He also points out that in the south-western part of England and in South Wales there is good evidence that the materials have been brought by currents from the west. I have only examined one specimen from this region, but it has proved very interesting. It is from a Carboniferous grit near Clevedon, in Somersetshire. About one-third of the rock consists of quartz grains which I should suppose derived from schists or gneisses of moderate coarseness; quite another third of fragments of a very fine-grained micaceous schist, about ·03″ long. It is possible that these may be phyllites, but I think it far more probable that they are true schists. They are very like some of the more minutely crystalline schists of Anglesey, and it is evident in some cases that the rock had been corrugated subsequent to foliation. This grit also contains a few bits of felspar and flakes of mica. I must not forget to mention some curious boulders which have been discovered occasionally in actual coal-seams. Through the kindness of Mr. Radcliffe I have been able to examine some specimens found at Dukinfield Colliery. They are hard quartzose grits and quartzites, bearing a general resemblance to sundry of the earlier Palæozoic rocks. One of the latter is as compact and clean-looking as the well-known quartzite of the north-western Highlands. Besides quartz, and perhaps a little felspar, it contains a small quantity of iron-oxide (?), two or three flakes of white mica, a grain or two of tourmaline, and of a mineral resembling an impure epidote. A similar quartzite has been found by Mr. W. S. Gresley in a coal-seam in Leicestershire, and I have described another from the 'thirteenth coal' at the Cannock Chase Colliery. In each of these quartzites the two minerals last named may also be detected.

Before quitting the Carboniferous series I must call attention to some interesting grits which during the last few years have been struck in deep borings. In the London district a red sandstone, in some places conglomeratic, has been found underlying sundry members of the Mesozoic series. Some have thought this of Triassic age, but inasmuch as it is very doubtful, as we shall presently see, whether the coarser beds of the Triassic formations extended so far to the east, and the dip of the red beds in the well at Richmond agrees better with that of the Palæozoic rocks in other parts of the buried ridge, I think these sandstones more probably older than any part of the Mesozoic series, perhaps not very far away from the base of the Carboniferous. In the boring at Gayton, in Northamptonshire, Lower Carboniferous rocks were succeeded by reddish grits and sandstones. The finer beds much resembled the ordinary Old Red Sandstone, and, like it, suggested a derivation from fairly coarse-grained crystalline rocks. But of the origin of one rock, a quartz-felspar grit, there can be little doubt. I may briefly describe it as very like the Torridon sandstone of Scotland, except that the cement is calcareous. I do not, indeed, claim for it a like antiquity, for I think it far more probably about the age of the lowest part of the Carboniferous series; but it, too, must have been derived from granitoid rocks. While some of the grains are fairly well rounded, others, especially of felspar, as in the Millstone grit of South Yorkshire, do not seem to have travelled very far.

Permian.—The sandstones of the northern area belonging to this formation do not, as far as I have been able to ascertain, afford us much information. Quartz grains, of course, abound, but as they are rather small, it is not possible to be sure whether they have been primarily derived from a granitoid rock or a schist. The former, however, appears to me the more probable source. They also contain fragments of felspar still recognisable, flakes of mica, and possibly a little schorl. The frequent occurrence of crystalline quartz as a secondary formation in these sandstones is a point of much interest, but has no relation to my present inquiry. The breccias near Appleby, Kirkby Stephen, &c., which I have not seen, indicate that at this time, not distant, masses of Carboniferous limestone, and of earlier Palæozoic rocks, were undergoing denudation; but it appears to me improbable that the finer materials of the sandstones were furnished by any rocks in the vicinity.

The Permians of the central area offer a rich field for future work. For the materials of the sandy beds I should conjecture a distant source, but for the pebbles in the conglomerates, and the fragments in the breccias, we need not travel very far afield. The Lower Carboniferous Measures contributed limestone and chert, the former being especially abundant in the conglomerates, but the 'vein-quartz, jasper, slates, and hornstone,' mentioned by some observers, indicate that yet earlier rocks furnished their contingent, while of the igneous materials I will speak directly. I shall pass very briefly over the breccias, so well displayed, for instance, on the Clent and Lickey hills, at no great distance from this town, because I trust we shall have presented to us, in the course of this meeting, a sample of the rich harvest which is awaiting explorers. Earlier investigators looked towards Wales for the origin of these fragments; we shall, I believe, learn that the majority are more probably derived from rocks which, though now almost hid from view, exist at no great distance. Some of the more compact traps may have come from the old rhyolites, which, by the labours of your geologists, have been detected *in situ* beneath the Lickey quartzite, while we may venture to refer the 'red syenite' and 'red granite' to outcrops of crystalline rocks of Malvernian age. These breccias have been regarded as proving the existence of glaciers in the Lower Permian age. It is, of course, possible that floating ice has been among the agents of transport, but after carefully examining the specimens in the museum of the Geological Survey, on which glacial striæ are asserted to occur, I am of opinion that the marks are due to subsequent earth-movements. On only one specimen did I recognise glacial striation, and this pebble is so different from the rest that I think it must have come from drift, and not from the Permian beds.

No less interesting are the Permian breccias of Leicestershire. These have attracted the attention of an indefatigable local geologist, Mr. W. S. Gresley, and to his kindness I am indebted for the opportunity of examining both rock specimens and slices. As might be expected, fragments, which I have no hesitation in referring to the Charnwood series, are not wanting, though hitherto they have not occurred in any abundance; but perhaps the most interesting member is a tolerably hard conglomerate, containing rather abundantly pebbles of a speckled grit and of a compact 'trap.' Microscopic examination of this conglomerate, which varies from a fairly coarse puddingstone to a grit, shows that the above-named speckled grit is composed of small and rather angular fragments of quartz, associated with grains of brownish and greenish material, which may be in some cases decomposed bits of a rather basic lava, in others possibly a glauconite of uncertain origin. But the 'trap' pebbles are yet more interesting. These are the more numerous, and are commonly well rolled. They probably belong, roughly speaking, to one species, but exhibit many varieties. In a single slide I have seen at least six, perfectly distinct. Some are indubitably scoriaceous, others full of microliths of a plagioclastic felspar, others almost black with opacite, others mottled brown devitrified glasses, more or less fluidal in structure. Probably they belong to the andesite group, with a silica percentage not very far away from sixty. In none have I observed any signs of crushing or cleavage, so that I cannot refer them to the Charnwood series, but conjecture that they are relics of volcanoes later in age than the great earth movements which affected that series, though I cannot connect them with the more basic post-carboniferous outbreaks of which we have indications at Whitwick and elsewhere. Quartz grains also occur, and some of these exhibit a rather peculiar 'network' of cracks which is characteristic of this mineral in the rocks of Peldar Tor, Sharpley, &c., and one such grain is attached to a fragment of minutely devitrified rock. Hence, as shown by larger fragments, the Charnwood series has contributed to the materials of this conglomerate, but the more abundant appear to have been derived from volcanic vents, the locality of which is at present undiscovered.[1]

Trias.—The Bunter beds and the lower part of the Keuper consist of more or less coarse materials, while in the remainder of the latter such deposits are rare and local. Hence it is evident that after the deposition of the Keuper sandstones a very different set of physical conditions prevailed. The lower series consists of sandstones and conglomerates; these beds occur in considerable force on the eastern side of the Pennine chain, have a great development in Lancashire and Cheshire, and thin away towards the south-east, almost disappearing in eastern Leicestershire and in Warwickshire. As the Trias is followed southwards, along the valley of the Severn, the Bunter in like way dies out, while the Keuper marls may be traced on into Somersetshire and Devon. In that region also there is a grand development of the lower and coarser members. As might be expected, there are considerable differences between the lower Triassic deposits of the northern and southern areas, so that it will be convenient to speak of them separately. The northern group, as is well known, is separable in the Midland and north-western district into the Lower Bunter sandstone, the Pebble-beds, and the Upper Bunter sandstone, over which come, more or less unconformably, the Keuper sandstones. Pebbles are either absent from, or very rare in every part of the Bunter except the pebble-bed, and are generally small and scarce in the Keuper sandstones, except in the basement breccias. It will be convenient to make a few remarks on them before dealing with the associated sands and sandstones. The pebbles in the Bunter conglomerate are most abundant, and generally attain the largest size in the Midland district. Towards the north-west, though the conglomerate attains a thickness of more than 500 feet, pebbles are rarer and smaller, and this, I believe, is also the case in Yorkshire, though the thickness of the deposit is not so great. I can, however, answer for the occurrence of pebbles of fair size and in considerable abundance for some distance to the north of Retford. In the Midland district they are very frequently from about 2″ to 4″ in diameter, though smaller are intermingled and occasionally some of larger size; these attain in certain localities to a diameter of 6″, or even more. The majority, so far as I know, are well rounded. In this district many different kinds of rock are found in the conglomerate; the most abundant are quartzose—vein-quartz, quartzites and hard grits or sandstones. Besides these we find chert and limestone from the Carboniferous series, various fossiliferous rocks of Silurian, Ordovician, and possibly Cambrian age, with mudstones and argillites, more or less flinty, of uncertain date. Felstones, using the term in a wide sense, are not rare, and granites or granitoid rocks sometimes occur. These, however, together with the scarce fragments of gneiss and schist, are usually very decomposed. A hard quartz-felspar grit, sometimes very like a binary granite, may be found, and I have noticed a peculiar black quartzose rock of rather schistose structure. As the lithology of the Bunter conglomerate has already attracted the notice of more than one author, I shall restrict myself to a brief mention of its more salient features. The most abundant rock is a quartzite, frequently so compact as to give a rather lustrous sub-conchoidal fracture, in which the individual grains can be with difficulty distinguished. In colour it varies mostly from white to some tint of grey, but is occasionally 'liver-coloured.' Rather obscurely marked annelid-tubes are the only organic indications which I have observed in these quartzites, and these are very rare. Under the microscope the rock consists chiefly of quartz fragments, of various forms in different specimens, with an occasional fragment of felspar (sometimes, I think, silicified), a flake of white mica, a grain of tourmaline, and of an impure epidote (?). As a rule it is easy to distinguish this quartzite from the

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[1] I pass by the interesting pebbles of hematite, which have received special attention from Mr. Gresley.

other indurated arenaceous rocks which occur in the conglomerate, especially from those containing fossils.

The above-described quartzites differ in appearance both macroscopically and microscopically from those of Hartshill, the Lickey, and the Wrekin district, but they closely resemble the most compact variety, which I have already described as occurring in boulders in coal. They have also an extraordinary likeness to quartzite pebbles in Old Red Sandstone and Lower Carboniferous conglomerates of Southern Scotland and to the quartzites of the northern and western Highlands, already described, a liver-coloured variety of which, as I have been informed, occurs in the island of Jura. These quartzite pebbles, to my knowledge, may be traced into Lancashire on the one side of the Pennine chain and to beyond Retford on the other. The quartz-felspar grit consists mainly of quartz and felspar, obviously the *débris* of granitoid rock. I have found it at various localities on the northern margin of Cannock Chase and have received specimens from the Bunter beds near the Lickey and near Nottingham. The rock, macroscopically and microscopically, presents an extraordinary resemblance to the Torridon sandstone of North-west Scotland, and differs from every other rock which I have seen *in situ* in any other part of Britain. The nearest approach to it is the quartz-felspar grit, already mentioned as having been struck in the Gayton boring, Northamptonshire, but this has a calcareous cement. The felstones vary from micro-crystalline to glassy rocks more or less devitrified, some being slightly scoriaceous. They may be classified lithologically as quartz-felsites, rhyolites (more or less devitrified), quartz-porphyrites, porphyrites, and old andesites. Some specimens contain a considerable amount of tourmaline, and I have seen this mineral in the vein-quartz pebbles. It also occurs rather abundantly in a very hard, black quartzose grit. I have received varieties of felstone, which I have found on Cannock Chase, from the Bunter beds of the Lickey and from Nottingham. In Staffordshire pebbles of granitoid rock, gneiss, and schist are not only rare, but also generally too rotten to admit of examination; but I found, a few months since, in the conglomerate at Style Cop, near Rugeley, two pebbles of a whitish gneiss, which appeared to me to indicate a secondary cleavage-foliation, such as may be observed in many parts of the Scotch highlands. The black quartz-schist already mentioned exhibits a peculiar 'squeezed-out' structure, which ordinarily indicates that the rock has undergone great pressure.

The sandy matrix and associated sandstones of the conglomerate beds, together with those of the Upper and Lower Bunter, and of the Lower Keuper, consist mainly of quartz grains, most of which appear to have been derived originally from granitoid rocks. They are often more or less angular, but at certain horizons, as described by Dr. Sorby, Mr. Phillips, Mr. G. H. Morton,[1] and others, well-rounded grains are so abundant as to suggest an exposure to the action of the wind. They are often stained red with iron peroxide, and mixed with more or less earthy matter. In Cheshire and Lancashire recognisable grains of felspar have been noticed by Mr. Morton and others, and probably this mineral is, in most cases, the source of the argillaceous constituents which are often intermingled with the quartz grains. Flakes also of white mica are sometimes rather common. So far as I have been able to judge, distinct grains of rolled felspar are commoner in the north-western district than in Staffordshire, where, however, mica-flakes are sometimes rather abundant.

The Keuper sandstones seem to me to differ from the above only in the general absence of the red colour, and in a more even bedding, especially towards the upper part (the waterstones), where they are interbedded with the marls. The appearance of these last suggests that the currents were gradually losing strength, and only capable of transporting the finer felspathic detritus with occasional tiny plates of mica.

The lithology of the lower part of the Trias in the southern area is as yet imperfectly worked out, and a rich harvest awaits the student. My own knowledge of it is but superficial, so that I must pass it by with a brief notice. The

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[1] In an excellent paper published in the *Proceedings of the Liverpool Geological Society*, vol. v. p. 52.

great beds of breccia, so finely exposed on the South Devon coast, are crowded with fragments, sometimes of large size; these have clearly been derived from the older rocks which are still in part exposed to the west and south-west, and probably had once a much greater extension in the latter direction. Fragments of Devonian limestone, grits, and slate, together probably with other Palæozoic rocks, earlier and later, are mingled with granites, resembling those of Cornwall and Devon, and many varieties of more compact igneous rock. The fossiliferous quartzite pebbles which occur mingled with others in the Trias at Budleigh Salterton, have been discussed by the late Dr. Davidson in an exhaustive memoir.[1] He refers the majority of the fossils obtained from them to the Lower Devonian age, but a few are Caradoc, and four occur in France in beds which are either Llandeilo or perhaps a little older. As the first two formations are represented, lithologically and palæontologically, on the opposite side of the Channel in France, and the third is at present only known to occur in the *Grès Armoricain* of that country, he thinks it probable that these pebbles have been derived from rocks which are now concealed beneath the waters of the Channel. It may then, I think, be taken for granted that land to the west and south-west has supplied the materials of the Lower Trias of the southern district of England, and I may add that there is every reason to believe that outliers of the formation itself still exist beneath the sea.

The so-called dolomitic conglomerates, which occur chiefly in Somersetshire, have been so fully worked out by Mr. Etheridge and Mr. Ussher as to require but a passing notice. It is evident that they differ somewhat in date, though probably all may be referred to the age of the Keuper, and that they are local breccias or conglomerates formed around the margin of islands or on a continental coast-line during a gradual subsidence and in comparatively quiet waters.

Jurassic.—Coarse detrital material is not very common in the Jurassic series. The limited Rhætic beds indicate a transition from the peculiar physical conditions of the Keuper to the marine conditions of the Lias, and the sediment in them was probably derived from the same source as the Keuper marls. Great clay beds also occur, as is well known, throughout the Jurassic series; and the sandstones, so far as I have been able to examine them, do not enable me to offer any suggestions as to their origin. Probably some of the grains were originally derived from granitoid rocks, but they may have been directly obtained from other sandstones. A grit, however, in the estuarine series of the lower oolites of Yorkshire (Mr. Philipps's collection) looks as if it might have been partly derived from a schist, but as this is the only rock from the northern area which I have had the opportunity of minutely examining, it would be imprudent to speculate.

Neocomian-Cretaceous.—I have examined very few specimens from the freshwater Neocomians of the South of England, but, so far as I have seen, I should think it probable that the quartz had been derived from old crystalline rocks, though perhaps not immediately. The same remark applies to the sands of the upper and marine series, which, in one instance at least, exhibit exceptionally rounded contours.[2] Among these, however, conglomeratic beds occur which have already attracted some attention. It is obvious that no small part of the materials, as at Farringdon, Potton, and Upware, has been derived from fossiliferous secondary rocks of earlier date. There are also pebbles of vein-quartz and quartzite which, however, may have been obtained by the denudation of Triassic rocks. The 'Lydian stone,' which is abundant in angular or subangular fragments at Potton and Upware, is for the most part chert from the Carboniferous Limestone, or in some cases from Jurassic rocks, but a few specimens may be flinty argillites, and thus of greater antiquity. One or two pebbles of older Palæozoic rock have been found, and a hard quartz grit has occurred, containing among its grains minute acicular crystals, probably of tourmaline. Potton has furnished one or two pebbles which appear to be a devitrified pitchstone, and a large pebble of porphyritic quartz-felsite has been sent to me by Mr. Willet from Henfield (Sussex). These conglo-

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[1] 'British Fossil Brachiopoda' (*Mem. Palæont. Soc.* vol. iv. p. 317).

[2] Professor Rupert Jones has called attention to sand-worn pebbles in the Upper Tunbridge Wells sandstone of the Weald (*Geol. Mag.* Dec. 2, vol. v. p. 287).

merates, together with others in the Upper Neocomian of England, have been so fully described by Mr. Walter Keeping[1] that I need not enter into further details, though I am well aware that the subject is by no means exhausted.

For a like reason I may pass briefly over the remarkable erratics found in the Cambridge greensand.[2] They occasionally slightly exceed a cubic foot in volume, but are generally smaller. Among them are diverse sandstones and grits, probably Palæozoic, granite, gneiss, various schists, quartzites and slates, besides greenstone, a very coarse gabbro or hypersthenite, and a compact felstone. I think it highly probable that many of these erratics came from the north, in some cases almost certainly from Scotland, and were transported by ice, though I am not satisfied that any exhibit true glacial striæ. In the South of England a boulder of old quartzose rock, perhaps a piece of a coarse quartz-vein, crushed and recemented, has been found by Mr. J. S. Gardner in the gault, and in the chalk we have the well-known cases of the granitic rock and other boulders at Penley, near Croydon, and of coal (Wealden or Jurassic) in Kent.[3] Mr. Godwin-Austen describes other instances of pebbles in chalk, and I have received two or three small specimens from Mr. W. Hill, from about the horizon of the Melbourne rock, which, however, have not yet thrown any light on the subject.

Eocene.—Previous writers have called attention to the fact that the sand of the Thanet, Oldhaven, and Bagshot beds is mainly composed of quartz. This is abundantly confirmed by my own observations. So far as I have seen, in all these the grains are not, as a rule, conspicuously rounded. It can hardly be doubted that older sandstones or granitoid rocks lying to the west have furnished the materials of the Bagshot series, which still has so wide an extension in that direction; their lithological similarity would lead us to look towards the same quarter for the materials of the more limited Oldhaven and Thanet beds. The well-rolled flint pebbles in the Oldhaven series, and in occasional layers in the Bagshot, suggest the proximity of a shore-line of Upper Cretaceous rocks.

I have had no opportunity of adding to what has been written on the lithology of the limited Pliocene deposits in England, and, as stated at the outset, have excluded from the scope of this address all beds of later date, which have been so ably discussed by Mr. Mackintosh, Dr. Crosskey, and many other geologists.

Principles of Interpretation.

In attempting to interpret the facts which I have enumerated we must bear in mind the following principles:—

(1) Pebbles indicate the action either of waves of the sea,[4] or of strong currents, marine or fluviatile.

(2) The zone in the sea over which the manufacture of pebbles can be carried on is generally a very narrow one. It extends from the high-tide line to the depth usually of a few feet below low-water mark. It is estimated that, as a rule, there is no disturbance of shingle at a greater depth than 20 feet below the latter. It is therefore probable that a thick and very widely extended pebble bed is not the result of wave action.

(3) The movement of the deeper waters of the sea as a rule is so slight that only the very finest sediment can be affected by it. Now and then great currents like the Gulf Stream, or more locally 'races,' may have sufficient power to transfer pebbles and sand, but instances of this will be exceptional, and confined to rather shallow water. The larger coast currents, however, may transport mud to considerable distances, but in directions parallel with the main trend of the shores.

(4) Except where very large rivers discharge their water into the ocean, or in

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[1] *Geol. Mag.* Dec. 2, vol. vii. p. 414.

[2] Sollas and Jukes-Browne (*Q. J. G. S.* vol. xxix. p. 11).

[3] Godwin-Austen (*Q. J. G. S.* vol. xvi. p. 327).

[4] The waves of lakes also have some rounding effect, but this—except in the case of very large lakes, such as Lake Superior—is not important; and such cases are, of course, not of common occurrence.

some special case of (3), sediment is deposited comparatively near the shores of continents. Even in the case of very large rivers only the finer sediment is carried far from land. The *Challenger* soundings have shown that 150 miles is about the maximum distance from land within which any important quantity of detrital materials is deposited.[1] As a rule (so far as I can ascertain), the coarser sediments are generally deposited within a few miles of the coast. Hence this is fringed by a zone of sediment, which, after passing a maximum thickness within a short distance from the shore, gradually thins away. I doubt whether this detrital fringe is often more than 70 or 80 miles wide; probably the coarser sands do not usually extend for so much as a quarter of this distance. The inertia of the mass of the ocean water quickly arrests the flow of even the mightiest river, or reduces it to a mere superficial current. Hence the great ocean basins are regions where rock-building is carried on slowly and chiefly by organic agency. Their borders bear the burden, and the load taken off the continent is laid down on the bed of the adjacent sea.

(5) Thus rain and rivers are generally more important agents of denudation and transportation than the sea, because unless the land be rising or sinking the zone over which the latter can operate is limited both vertically and horizontally.

(6) The coarser materials of rock are capable of being transported by streams to considerable distances, without serious diminution of volume. Professor Daubrée has proved experimentally that a stream flowing at the rate of about two miles per hour would roll angular fragments of quartz or hard granite into perfectly smooth pebbles after a transit of 25 kilometres ($15\frac{5}{8}$ miles). During this process the fragments lost about four-tenths of their weight. Further transport reduced the volume of the pebbles very slowly. The loss afterwards varied from $\frac{1}{1000}$ to $\frac{4}{1000}$ per kilometre. To reduce a pebble of 2 inches diameter to 1 inch diameter—that is, to diminish its volume by seven-eighths—would require a journey of from about 219 to 875 kilometres (approximately from 137 to 548 miles). This approximation, rough as it is, becomes still less exact as the pebbles decrease in size; the rate of diminution in volume (*cæteris paribus*) bearing a relation to the area of the surface. Thus the smaller the pebble, the further it will travel without material diminution of size. Sand grains are even rounded with extreme slowness. According to the same author a quartz grain $\frac{1}{50}$ inch in diameter requires to be transported by water action some 3,000 miles before losing its angles. On this account the presence in a sandstone of numerous well-rounded grains is taken to indicate the action of wind, for, as is well known, blown sands are much more quickly rounded.[2]

(7) Thus deposits of gravel and coarse sand, of considerable vertical thickness and great extension, are more likely to indicate the immediate action of a river than of a marine current. If limited in extent they may have been formed at the embouchure of a river into a lake or sea. If, however, they can be traced for long distances, they are more probably in the main sub-aerial deposits from rivers.

The following examples may convey some idea of the kind of river which would be required to transport the more important deposits of grits and stones mentioned in the first section of this address:—

The old river gravels of the Sierra Nevada are 'in some places 300 or 400 feet thick and almost homogeneous from top to bottom,' sometimes they even obtain a thickness of 600 feet. Mr. Whitney is of opinion that the fall in these old river channels was probably from 100 to 130 feet per mile. Apparently, however, we need not invoke so large a fall as this. The total fall of the Danube is 3,600 feet, and its length 1,750 miles. From Passau to Vienna the fall is 1 in 2,200, from Vienna to Old Moldova 1 in 10,000. Yet the velocity of the current from Vienna to Basias (15 miles above Old Moldova) is 'from 2 to 3 knots an hour,' depending on the amount of water. This would suffice to transport pebbles of the average size of the English Bunter. Below the Iron-gates the fall is still less rapid, but sand is carried down for a very considerable distance. If then the rivers of the old

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[1] I except floating pumice, cosmic dust, &c., as comparatively unimportant.

[2] See, on the subject of this paragraph, Daubrée, *Géol. Expériment.*, vol. i. sec. 2, Ch. I., and J. A. Phillips, *Q. J. G. S.* vol. xxxvii. p. 21, &c.

continental land resembled the larger streams of Europe they would suffice for the transport of the materials with which we have dealt, especially if aided by coast currents after the *débris* had reached the sea.

(8) If boulders occur in a matrix consisting of fine mud, or mainly of organic material, they must (unless they are volcanic bombs) have floated thither either attached to large seaweeds or entangled in the roots of trees, or supported by ice. If they are rather numerous and a foot or more in diameter, in a marine deposit, the last is the most probable mode of transport. A cubic yard of ice will more than suffice to float a cubic foot of average rock.

Conclusion.

The facts already mentioned, regarded in the light of the above principles, justify, in my opinion, the following inferences as to the past physical geography of our country. At the commencement of the Cambrian period great masses of Archæan rock, granites, gneisses, and schists must have existed, not only on the western side of Britain, but also over a considerable tract of land now covered by the sea. Detritus from this continent became an important constituent in the Cambrian rocks, and in many cases, as at St. David's, in Anglesey, Carnarvonshire, &c., the shore-line must have been very near at hand. With the Cambrian period commences a long-continued subsidence, so that its basement beds at different places are very probably not all of quite the same age. The land surface was from the first irregular, and it is very probable that waves of the sea were fretting away some parts, while rain and river, heat and cold, were still sculpturing others. But among the materials of the ancient land were not only granitoid rocks, gneisses, and schists, but also newer strata more distinctly of clastic origin, memorials of past denudation—quartzites and grits, phyllites and slates, not to mention others—and these, by their intimate structure, sometimes indicate that great earth-movements must have already occurred.[1] In many localities, perhaps as a result of these disturbances, there occurred, towards the conclusion of the Archæan period, great volcanic outbursts—by which, no doubt, numerous cones were built up, and many of the materials of the so-called Pebidian Group were supplied. It is, I think, at present hardly safe to attempt to trace the exact land boundaries of the Cambrian ocean, but the enormous masses of Archæan material which are entombed in the earlier Palæozoic strata of Wales and of North-west Scotland can, I think, only be explained by the proximity of a great continental land—an extension of the present Scandinavian Peninsula—which not improbably had a general slope towards the south-east, the main watershed of which may have lain some distance to the west of the Outer Hebrides.[2] But even over the more central parts of Britain there cannot have been deep or open ocean. We are constantly coming upon the traces of pre-Cambrian and early Cambrian land; some of our Mid-England Archæan masses, like the Malverns, appear to have risen above the water, and to have undergone denudation after the great earth-movements which ushered in the Silurian period. Prior to this, after a time of repose in the Cambrian, at more than one epoch, and in more than one place, there were great volcanic outbursts, which appear to have studded the sea with volcanic islands, and to have added to the heterogeneous materials from which the sediments were now formed. It is evident that in Silurian times the coast-line had extended southward and eastward. The coarse deposits of this age, in Wales, the Lake district, and Southern Scotland, compared with the finer mudstones and limestones of the Welsh border and of England, seem fully to bear out this assumption, which is in accordance with a well-known law of mountain-making. The Old Red Sandstone of Scotland and of Wales indicates

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[1] It is evident, for instance, that the north-west strike, and other effects of folding, had been produced in the Hebridean series of N.W. Scotland before the Torridon sandstone was deposited.

[2] Possibly the comparatively rapid deepening of the Atlantic beyond the 100-fathom line may have some relation to the western outline of this primæval Atlantis.

a yet further continental extension towards the south-east. A great epoch of mountain-making in the Scotch Highlands, which had perhaps been going on at intervals from the beginning to the close of the Silurian period, had now come to an end; the southern uplands had risen up, like a Jura to the Alps. But probably their elevation did not terminate the earth-movements, for the post-Silurian cleavage of the Lake district, and the absence of Old Red Sandstone both here and in Central England, indicate that the Palæozoic land mass continued to extend on its south-eastern flank. The Devonian period introduces us in the greater part of Great Britain to an epoch of limited and exceptional deposits, and of widely prevalent terrestrial conditions. It seems almost certain that the Old Red Sandstones of Scotland and Wales are of fresh-water origin—the deltas of rivers, formed either in lakes or possibly in part as sub-aerial deposits. Streams of considerable volume and of some strength are indicated by the materials. In one case, the Old Red Sandstone of North-east Scotland, we may perhaps discern in the Great Glen some indication of the old river-course. It is easy to ascertain the source of the materials of the Scottish Old Red Sandstones. They are as obviously the detritus of the Highland mountains—then probably a far grander and loftier chain—as the nagelflue and the molasse of Switzerland are of the Alps.

At this time marine conditions prevailed in the south of England. The sea appears to have deepened towards the south, but I suspect that a region of crystalline rocks still existed at no great distance in that direction and in the west. Probably the Brito-Scandinavian Peninsula curved round to the east so as to include some part of Brittany.[1] Another great epoch of subsidence now commenced, commemorated by the formation of the Carboniferous limestone. At this I need hardly glance, as it has been so fully discussed by Professor Hull and other writers. The land sank both in the north and in the south of England. There was deep sea over Derbyshire and Southern Wales, but the ground beneath our feet probably remained above water, forming either a continental promontory or a large island.

There were other well-known interruptions to the sea, which also overflowed a considerable part of Ireland and districts far to the east of England. The Scotch Highlands, however, probably remained above water, for, as is well known, the Carboniferous limestone of Central Scotland overlies a fresh-water formation, and is itself not wholly marine, since it contains coal, and like conditions prevailed in Northumberland.

Gradually, however, the sea shallowed, and terrestrial conditions returned. In the later part of the Carboniferous series we have clear indications of two, or perhaps three, important currents, almost certainly those of rivers, bringing materials, in the southern district from the west; in the northern, from the north-west and probably the north-east. These materials may have been in part derived from older Palæozoic rocks, but the facts when carefully considered seem to indicate that there was also an extensive denudation of crystalline and not improbably Archæan rocks, unless we suppose that great areas of eruptive Palæozoic granite have now disappeared beneath the waters. At any rate, we may perhaps regard the open water between Ireland and Scotland on the one hand, and to the east of the latter country on the other, as significant of a denudation earlier than that of the sea which has in later times divided the British Isles. Another epoch of earth-movements closed—as was to be expected—the Carboniferous subsidence and deposition. We trace one line of flexures and of intense compression along a broad zone, including the south of England, from Germany to Ireland; another less intense over the northern part of our country; the axes of the former flexure striking a little N. of W., of the latter about W.S.W. The one appears to me to indicate a thrust from a great mass of hard, more or less crystalline rock in the S., which probably led to the formation of a mountain chain extending from North-central Europe over the Channel to the southern margin of England. The latter may be explained by the presence of the above-named north-western continent.

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[1] Compare, as an illustration, the curving round of the Alpine chain on the western side of Italy.

In the Permian time terrestrial conditions probably prevailed over a large part of Britain. It is extremely difficult to ascertain the exact circumstances under which the Permian beds of Central England were deposited, but I should think they imply a return to physical conditions not unlike those of the Old Red Sandstone, though perhaps the marine fossils which have been found in Warwickshire may indicate that the water there had some imperfect connection with the sea. I must not discuss the vexed question of the age of the Pennine chain, but must content myself with expressing my opinion that, at most, it can only, as yet, have very partially interrupted the continuity of the water in Northern England. The beds there appear to indicate a supply of materials from the north and north-west, as if the old rivers had not been wholly diverted by the great earth-movements which closed the Carboniferous period. Sir A. Ramsay's view, that the water in which the dolomitic limestone was deposited was more or less cut off from the open sea, seems to me by no means improbable; in any case, it is a rather exceptional formation, and over the greater part of Britain, probably, land sculpture continued, and deposition was on the whole local.

With the Trias a new era commences; physical features had been now produced, which, in all probability, endured through a considerable part of Mesozoic times. The facts which I have laid before you, regarded in the light of the general principles indicated above, compel us to look away from the immediate vicinity for the bulk of the materials, coarse and fine, of which the northern Trias is composed, though neighbouring hills may have furnished occasional contributions, especially to the earlier deposits. The analogy of the Old Red Sandstone, the Calciferous Sandstone of Scotland, and the Nagelflue and Molasse of Switzerland, together with other peculiarities too well known to need repetition, make it in the highest degree probable that the Bunter beds were not deposited in the ocean.[1] Hence they must be either deltas formed in an inland sea or in a lake or true fluviatile deposits. Neither lake nor inland sea appears likely to have been sufficiently large to admit of waves or currents capable of either rounding the pebbles or transporting the materials. We are therefore compelled to fall back upon the action of rivers. The sandy beds of the Bunter indicate a stream flowing from one-third to half a mile an hour, the pebbles one from two to three miles; that is to say, the Upper and Lower Bunter sandstones would require the former rate of movement, the Pebble Beds the latter. Now, we must remember that, in the West Central district, the Lower Trias consists of three wedge-like masses, about 100 miles in length, of which the coarser is probably the more extensive. The comparative uniformity of the deposits in each case indicates a uniformity of flow, and suggests either a large and broad stream, not liable to much variation, or one which, when flooded, quickly made a channel of its valley and deposited mainly at such season. I have the greatest difficulty in understanding how a current of the requisite velocity could be maintained by the water of a river or rivers flowing into a lake or an inland sea, or in explaining the tripartite arrangement of the beds on the hypothesis that a basin was gradually filled up from the northward by a stream which, like the Rhone at the upper end of the Lake of Geneva, gradually advanced its delta by flowing over the materials which it had previously deposited in the basin. Hence I believe that we must regard the Bunter beds as sub-aerial deltas, analogous to the conglomerates in the Siwalik deposits of India,[2] and to the sandstone and nagelflue on the outer zone of the Alps, deposits in all respects very similar to the English Bunter. We may suppose, then, that rivers emerging on each side of the Pennine chain from a mountain land first formed the Lower Bunter sandstones, then, owing to increasing upheaval in the mountain district, and corresponding depression in the lowlands, flowed more swiftly so as to cover this deposit with the Pebble Bed, and lastly, as its former conditions returned, laid upon this the Upper sandstones. I have spoken, for the sake of clearness, as if these

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[1] Compare also the Bunter and Keuper in the region traversed by the German Rhine.

[2] The analogy of the Indian conglomerates was suggested to me by Dr. Blanford. See *Geol. Mag.* Dec. 2, vol. x. p. 514.

were perfectly distinct formations, but it would by no means follow that some part of the finer beds to the south-east might not be contemporaneous with a portion of the coarser beds to the north-west, as the velocity first increased, and then diminished. As I have already said, the materials of the pebbles and of the sand make it impossible to refer the main constituents to local sources. Many of the rocks do not exist in the Midland; there is no reason to suppose that at that time there were in this region masses of land of sufficient area and height to feed important rivers.[1] From currents of any other kind we are precluded, so that I believe we may safely turn our eyes northward and look for the ultimate source of the Triassic sandstones and conglomerates among the older rocks of the Scotch Highlands, and their extension to east and to west, though very probably the materials may have been more directly supplied from Old Red Sandstone and early Carboniferous strata, in remnants of which identical fragments may still be seen. In like way we may regard the Trias of the south of England as the detritus of at least one great river, which flowed from the west or south-west. The materials of the Keuper came from the same directions in each case, but here, I think, we have indications of deposition in an inland sea. Breccias formed on its coasts, and sands were at first deposited in it; but presently the area of water increased, and the coarser materials must have been arrested in the uplands, while the fine sediment which forms the marls may have been carried out into the salt lake and slowly settled down in its calm waters.[2] Its shores may have been hardly more favourable to a vigorous development of life than were its salt-saturated waters; during this period and the preceding Bunter the lowland border of the mountains, like some of the northern districts of India, may have been arid and barren regions of shifting sands.

The Trias of Northern Scotland very probably indicates a repetition on a more restricted scale of the physical conditions of the Old Red Sandstone, but after this we observe signs of an encroachment of the Atlantic on the above-named old area of continental land.

The Jurassic series is represented in Northern Scotland on both the western and the eastern coasts by marine or estuarine beds. This probably indicates important modifications in the river channels, subsidence on the west altering the slopes, reducing the length, and cutting away some of the feeding ground. Traces may still be discerned in England of the two northern rivers, but that which in Triassic times was the larger contributor, appears in Jurassic to have been gradually enfeebled; the other one and the south-western stream seem to have still flowed with some strength. Sands, however, now become comparatively local. Probably the coarser materials, as a rule, did not reach the sea. This appears at all times to have been comparatively shallow and enclosed by land on every side but the south-east. The recent discovery of Oxford Clay beneath the Cretaceous beds at Chatham

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[1] It may be useful to give a rough idea of the quantity of rock which must have been denuded in order to obtain materials for the Bunter beds. Suppose, for purposes of calculation, we consider the Bunter beds, which cover the district from the Cheshire coast to the Midland counties, as forming the section of a cone contained by two planes drawn through the axis so as to include an angle of 30 degrees. If h be the height of this axis, and r the radius of the base, the volume of this figure is $\frac{\pi r^2 h}{36}$. Take, for purposes of rough calculation, $h=\frac{1}{4}$ mile, $r=80$ miles, $\pi=3$; the volume is about 133 cubic miles. Conceive this piled up to form a long mound, in section an isosceles triangle 1 mile high, with a base of 4 miles. The length would be over 65 miles. Thus the materials buried in the Bunter beds of the above-named district represent a chain of hills unfurrowed by valleys 5,000 feet high, 4 miles wide, and 65 miles long. Suppose the Pebble Bed, a like slice of a cone, axis one-tenth of a mile, base 70 miles; the volume is more than 40 cubic miles. Suppose the quartz and quartzite pebbles one-tenth of its volume; these represent a mass of four cubic miles, or a line of hills like the above 1,000 feet high, 2 miles wide, and 20 long.

[2] The lake may have gradually become salt, or possibly the Muschelkalk sea may have for a short space invaded Britain, and then have been insulated like the Caspian.

suggests that a narrow strait running in a northerly direction may have insulated the Palæozoic rocks beneath the London district. The clays of the Lias, Oxfordian, and Kimmeridgian probably indicate a direct discharge of sediment into the sea,[1] the limestones, depression sufficing to convert valleys into fjords, in the upper parts of which sediment was deposited so that the waters of the sea were clear. The deposits of the Purbeck and Weald indicate that the western river still drained an extensive area, and a gradual rise of land in later Jurassic times, especially towards the south, appears to have advanced the river delta eastwards, and to have limited the area of the Jurassic sea on the north.

Towards the end of the Neocomian, owing to a widespread subsidence, the sea once more returned to South-eastern England, and a communication appears to have been opened between it and the Speeton basin. This comparatively narrow strait was a region of considerable denudation and of strong and shifting coast currents.[2] The Cretaceous subsidence at first brought back physical conditions not very different from those prevalent in Oxfordian and Kimmeridgian times, but later on a very considerable depression must have so far submerged the northern continental land as either to break up the parts adjacent to Britain into groups of islands, or at least to flood the valleys so completely as to prevent any discharge of sediment into the sea. The erratics of the Cambridge Greensand suggest that a free communication into the northern ocean was established, anterior to the formation of the Chalk marl, through some part of the present interval between Scotland and Scandinavia, so as to set up a coast current with a southerly drift of shore ice near the eastern part of England: to this also may be due the erosion of the Cambridgeshire Gault.

The larger part of Britain was dry land during the Eocene, though the sea after retreating appears to have again encroached over the southern and eastern districts of England. The sands may indicate that the western river again resumed its course;[3] the extension of the London Clay up our eastern coast suggests that the northern river still flowed. But with the important disturbances which closed the Eocene and ushered in the continental conditions of the Miocene—new flexures along the old east and west lines—the earlier physical features appear to have been finally obliterated, and the sculpture of the English lowlands began. The tale of the volcanic outbursts of Western Scotland has been so well told by my friend and predecessor Professor Judd that I need do no more than recall it to your minds. The Pliocene deposits of Eastern England indicate a new encroachment of the Franco-Belgian Tertiary sea.

Thus ends my sketch—too lengthy, I fear, for your patience, yet too brief to allow of a complete treatment of the subject. It may, however, suffice to indicate that in geology the 'task of the least' is by no means despicable, and that great results may be hoped from apparently small means; that in this search for 'Atlantis through the microscope' we may find it very near at hand, and may discover analogies, as has been indicated in our President's address, between the two borders of the ocean which severs Europe from America. An enlarged study of the materials of our Palæozoic and later detrital rocks may indicate that from very early times there has been a recurrence of similar physical conditions, and that

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[1] The considerable distance to which the clays extend in a southerly direction may possibly indicate that, to the east of Scotland, a communication had now been opened with the northern ocean, which had set up a current along the coast east of the Pennine chain.

[2] As the Speeton beds continue to be clays one would infer a drift from the south, but a current to the opposite direction would be more probable, and it is the opinion of Dr. Sorby that this was the case. His papers 'On the Direction of the Currents indicated by the Coarse Sediments in our British Rocks' are most valuable (*Yorks. Geol. Pol. Soc.* v. 220, &c.) A pebble bed sometimes occurs at the base of the Portland series, apparently resembling, though on a very small scale, those in the Neocomian.

[3] The occasional beds of flint pebbles indicate a neighbouring shore line of Cretaceous rocks rather than the denudation of beds of Cretaceous age, which had been deposited on parts of the western land during the period of depression.

in geology also a recurrence of effects indicates a recurrence of the same causes. The facts which I have brought before you have justified, I trust, my opening remarks as to the rich harvest which yet awaits investigations into the structure of the fragmental rocks. To resume the simile then used, I see the land of promise, stretching far away from beneath my feet, till it seems to melt into the dim and as yet unknown distance. Not speedily will its riches be exhausted. Our hands will long have vanished, our voices will long have been still, before the work of discovery is ended and men have reached the shore of that circumfluent ocean which, at least in this life, limits their finite powers.

The following Papers were read:—

1. *On the Geology of the Birmingham District.*
By Professor C. Lapworth, *LL.D., F.G.S.*

The town of Birmingham lies exactly in the geographical centre of England, midway between sea and sea. This, too, is its geological position, for it is built upon and surrounded on all sides by strata belonging to the New Red Sandstone, the place of which is exactly in the middle of the accepted series of geological formations. To the east of the town lie the gently inclined Neozoic strata of the Jurassic and Cretaceous, &c., dipping in regular order, sheet below sheet, till they become wholly horizontal in the neighbourhood of London. To the west of the town lie the bent, broken, and more or less altered Palæozoic formations, stretching onwards through Shropshire and North Wales, until they attain their greatest amount of wrinkling and metamorphism in the slaty districts of Snowdon and Anglesea. Within the limits of the Birmingham district itself we find almost every stage of transition between these extreme geological types. In some localities, as in the mid-Warwickshire plain, we find the strata as flat and almost as unaltered as in the day in which they were originally laid down. In others, as at the Lickey, they are folded into steep arches, shattered and faulted; and in others, as in Charnwood Forest, they are crushed into slates. Within a radius of thirty miles of Birmingham we find representatives of all the geological formations, from the so-called Laurentian and Cambrian up to the base of the Cretaceous. The Carboniferous rocks of the Birmingham district have long formed the accepted model of those British rock formations which are remarkable from the economic point of view. Its 'Black Country' is Dickens' classical type of a land given over body and soul to mining and manufacture. The local Triassic formation is the British agricultural system *par excellence*, and the Midland plain of Warwick, Stratford, and Worcester is the heart of sylvan England—the Arden of Shakespeare, and the Loamshire immortalised in the works of George Eliot.

Among those who studied the geology of the Birmingham district before the days of the Geological Survey, we find the names of many of those most famous in the annals of British geology:—Professor Playfair, William Smith, Dean Buckland, William Yates, and Sir Roderick Murchison. To Murchison, indeed, the neighbourhood was always a favourite one. Its strata afforded him some of the most striking types of the formations and fossils illustrated in his great work, the 'Silurian System.' The district was mapped about thirty years ago by the officers of the Geological Survey—by Professor J. B. Jukes (a native of Birmingham), Professor Hull (Director of the Geological Survey of Ireland), and Mr. Howell (Director of the Scottish Survey). Jukes's 'South Staffordshire Coalfield' is one of our modern geological classics; and Hull's 'Permian and Triassic Rocks of the Midlands' is the accepted authority upon the Red rocks of Britain. After the survey, until very lately, little geological work was done by Midland geologists. The members of the various local societies rested in the easy assurance that there was nothing more to be accomplished. Within the last few years, however, there has been a great revival of interest. Mr. Samuel Allport's investigation of the microscopical characters of the Midland volcanic rocks inaugurated the recent revival and brilliant advancement of petrography in Britain. Dr. Holl worked out the detailed geology of the Malvern Hills; Dr. Charles Callaway discovered the remarkable Cambrian and pre-Cambrian rocks of the Wrekin; Birmingham geologists themselves have quite recently made several startling discoveries of large areas of Cambrian rocks in much closer proximity to the town; and the interest thus aroused in local geology seems likely to continue.

The most interesting geological strata in the Birmingham district are the supposed Archæan rocks of the Malverns, Charnwood, and the Wrekin, the Cambrian strata of Nuneaton and the Lickey, the highly fossiliferous Silurian of Dudley, the rich coal- and iron-bearing rocks of the South Staffordshire coalfield, the enigmatical Permian breccias of the Clent Hills, and the remarkable 'Pebble Beds' of the local Trias. To the north-west of Birmingham the area around Wolverhampton is crowded with innumerable boulders brought down from the Lake District and the south of Scotland. To the south-west of the town, erratics equally abundant are met with, which have travelled from the high ground of the Arenig in North Wales; while relics of the mammoth and other prehistoric animals have been obtained from the area east of the town in the excavations of Shustoke.

2. *On the Discovery of Rocks of Cambrian Age at Dosthill in Warwickshire.*[1] *By* W. JEROME HARRISON, *F.G.S.*

The little eminence of Dosthill forms part of the western boundary of the Warwickshire Coalfield. It lies close to the Midland Railway (Birmingham and Burton branch), between the stations of Kingsbury and Wilnecote; it is two miles south of Tamworth, and twelve miles north-east of Birmingham. On the Geological Survey Map Dosthill is coloured as a mass of greenstone intrusive in the Coal-measures, and bounded on its western side only by a line of fault.

On May 29, 1882, the author visited the district for the first time. He found the fault on the west side of the hill very sharply defined, the Keuper Red Marls forming a level plain through which the Tame meanders, and from which the camel-backed ridge of Dosthill rises precipitously. The lowest rock seen near this west fault is a hard grit. Above this we find Cambrian grey shales traversed by innumerable worm-borings and invaded by igneous rocks. The latter are of two kinds—a tough dioritic rock, and narrow dykes of a grey, much decomposed rock. One section at the south end of the ridge shows a dyke rising through grey Cambrian shales and spreading out above them. The eastern boundary of Dosthill is also a line of fault by which the Coal-measures have been thrown on end and shattered But there is no evidence that the coal-seams have been 'burnt,' as alleged in the Survey Memoir ('Geol. Warwickshire Coalfield,' p. 49). The whole succession of the strata is very similar to that at Nuneaton and Hartshill, on the eastern side of the coalfield, eight miles to the south-east.

3. *The Cambrian Rocks of the Midlands.* *By* Professor C. LAPWORTH, *LL.D., F.G.S.*

Upper Cambrian rocks occur in several localities within the limits of the Birmingham district—at the Malverns, the Lower Lickey Hills, Nuneaton, the neighbourhood of the Wrekin and Shineton, at Caer Caradoc, and Cardington. The core of the Lickey Hills, near Birmingham, is formed of quartzite, formerly believed to be of Llandovery age. This has been shown by the author and Mr. F. Houghton to be actually of pre-Silurian age, rising unconformably from below the basement beds of the local Silurian, and apparently underlain by volcanic rocks of unknown geological age. The supposed Lower Carboniferous rocks of Nuneaton and Atherston have also been demonstrated by the author and Mr. Harrison to be of Upper Cambrian age, containing the characteristic Agnostidæ and Olenidæ. Detailed descriptions, illustrated by maps, and sections and characteristic fossils, were given of the Cambrian areas of the Lickey and Nuneaton, together with a detailed account of their underlying and intrusive volcanic

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[1] Printed in full in *Midland Naturalist*, Dec. 1886.

rocks. The recognisable sequence of the component strata in the several higher Cambrian areas was shown, their physical relations to the underlying and overlying formations pointed out, and evidences adduced in proof of the conclusion that these rocks are fragments of what was originally a single continuous Upper Cambrian formation, composed of corresponding members, admitting of fairly satisfactory correlation with the Upper Cambrian rocks of other districts, and everywhere reposing upon a great volcanic formation, of much earlier date.

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4. *On the Petrography of the Volcanic and associated Rocks of Nuneaton.*

By T. H. Waller, *B.A.*, *B.Sc.*

The coarse ashes of the more northern exposures near Hartshill are made up primarily of broken up quartz felsite, the minerals and fragments being cemented in many places by thin films of a green, apparently serpentinous, mineral.

The finer-bedded ashes by the 'Tunnel' near Caldecote contain broken felspar crystals, in some cases plagioclase, in others orthoclase; but here the dust seems to have been very fine, especially at times, as some beds appear almost perfectly compact.

A little further south still, in a disused quarry, a rock exactly similar in external appearance, and differing microscopically mainly in the appearing of irregular angular flakes of a green serpentinous mineral, is seen in intimate admixture with a rock having much of the appearance of a quartz felsite.

This latter rock, however, has quite abnormal characters except in very few places. Elsewhere the crystals are broken and angular in the majority of cases, and are packed together with a very dirty-looking groundmass among them. The quartz grains are in many cases crowded with very minute fluid cavities, and are indented with the usual bays into which the groundmass runs, in many cases connecting with almost isolated masses within the crystal.

The felspar is to a large extent plagioclase, but is much clouded with decomposition products. Some of the greenish flakes have the appearance of decomposed mica. The groundmass where well developed shows good flow structure.

Careful examination, both in the field and microscopically, suggests that the andesitic rock mentioned in the next paragraph has flowed over a broken and partly disintegrated surface of quartz felsite.

With these rocks is associated a dark rock, which on examination proves to be composed of plagioclase felspar, and the decomposition products of apparently augite, since a few grains of the latter still remain unchanged. Some of these latter show the twinning that is usual, and also the cleavage parallel to the basal pinacoid which has been described by Mr. Teall in the augite of the Whin Sill close to the junction with the quartz felsite; the rock is distinctly porphyritic, the larger crystals of felspar being set in a mass of very minute felspar crystals, which frequently exhibit the flow of rock in a very marked manner. The porphyritic felspars give extinctions corresponding to Labradorite, or even incline to Anorthite, and have many inclusions which frequently are arranged in lines parallel to the length of the crystal, and are elongated in the same direction.

At the base of the quartzite occur beds of conglomerate containing masses of ashes somewhat coarser in texture than those from the 'Tunnel' above mentioned, and of the quartz felsite. Passing upwards, the felspathic constituent gradually disappears except in one or two bands, and in the typical quartzite but few grains are visible except of quartz. These show by the similarity of the strings of cavities, and, in the lower beds, by the fact that the rounding to which they have been subjected has not been sufficient to entirely smooth away the finger-like indentations of outline, that they were derived from a quartz felsite very similar to, if not actually a part of, the same mass as that previously described.

The diorites which are associated with the quartzites are much decomposed, with the development locally of a good deal of calcite.

5. *On the Rocks surrounding the Warwickshire Coalfield, and on the Base of the Coal-measures.*[1] *By* AUBREY STRAHAN, *M.A., F.G.S. With an Appendix on the Igneous Rocks of the Neighbourhood, by* F. RUTLEY, *F.G.S.*

(By permission of the Director-General of the Geological Survey.)

The discovery by Professor Lapworth of fossils of Lower Silurian age (Cambrian, Sedg.) in some shales underlying the productive coal-measures of Warwickshire has proved that the determination by the Survey of these shales and of some underlying quartzite as Lower Coal-measures and Millstone Grit respectively was erroneous. The beds had been (previous to the Survey) described by the Rev. J. Yates ('Trans. Geol. Soc.' Ser. 2, vol. ii. p. 237) as Silurian, but in consequence of their apparent conformity to the productive measures, and in the absence of fossil evidence, were subsequently identified as above, in spite of a correct view as to their age being held by Professor Jukes. A re-examination of the district has proved that (1) the conformability of the Coal-measures with the underlying shales is apparent only, and not real; (2) the Coal-measures are based by an impersistent sandstone containing pebbles, and resting on the denuded surface of the Lower Silurian rocks; (3) the intrusion of certain igneous rocks (diorites, &c.) in the older series was entirely pre-Carboniferous.

The oldest rocks seen are the Caldecote Igneous Series, which rise from beneath the quartzite between Nuneaton and Hartshill. This series consists of a finely laminated rock, probably a tuff, with intrusions of diabase and quartz-porphyry.

Upon this series rests the Hartshill quartzite, with a well-bedded conglomerate at its base, containing fragments of the Caldecote Series. Upwards this quartzite passes conformably into a thick mass of shales, red in the lower, and grey or black in the upper part. In these shales (the Stockingford Shales of Professor Lapworth) have been found fossils, proving them to be of Lingula Flag, and perhaps in part of Tremadoc age. The shales and quartzite are traversed by sheets of diorite, &c., which generally follow the bedding very closely, but are known to be intrusive by the alteration they have effected upon the shales above, as well as below them, and by their occasionally breaking across the beds.

The base of the Coal-measures has been proved in a colliery at Hawkesbury, and is seen in the railway-cutting at Chilvers Coton, where a fire-clay, based by a few inches of sandstone, is seen resting on the Stockingford Shales. Further north the workable seams rest almost directly on these shales, but near Oldbury a thick pebbly sandstone, resting with a marked unconformity on shales and diorites, forms the base of the Coal-measures. Further on this sandstone thins out again, but reappears with its former character north of Merevale. A similar relation is found at Dosthill, where, however, the want of parallelism between the Carboniferous and Silurian strata is very conspicuous. The impersistent sandstone, forming the base of the Coal-measures here, is coarsely conglomeratic. The descriptions of the base of the Coal-measures of South Staffordshire (Jukes, 'Geol. Survey Memoir') is applicable almost word for word to the Warwickshire localities.

Towards the east the Lower Silurian rocks are overlain by the New Red Marl and Waterstones, the actual boundary being formed for a large part of the distance by a fault, which has been proved in coal-workings at Polesworth, and is seen in Merevale Park. This has been wrongly described ('Coal Commission Report,' 1879, vol. ii. p. 494) as 'one of the grandest lines of fault that can be seen anywhere'; it is, on the contrary, a fault of very small importance, especially towards the south. The Trias is seen in four instances to rest naturally on the old rocks, while the same relation has been proved in several borings made in the plain of New Red Marl of West Leicestershire. The result of these observations is to show that it would be useless to search for Coal-measures beneath the Trias over the part of this plain lying south of Market Bosworth, the Carboniferous rocks having either never

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[1] Published *in extenso* in the *Geol. Mag.* Dec. 3, 1886, vol. iii. p. 540.

extended over the area, or more probably having been deposited in an attenuated form, and subsequently removed in the widespread denudation that preceded the Trias.

Appendix.

The Igneous Rocks are divided by Mr. Rutley into Syenitic rocks (Croft Series); Andesite and Andesitic Tuffs (Caldecote Series); Diorites, Andesites (or Diorites containing Augite), and Basalts (or Diorites containing Olivine), these three occurring as intrusions in the Lower Silurian rocks, and appearing to graduate into one another. The Croft series includes quartz-syenite and a rock intermediate between quartz-syenite and quartz-diorite. The Caldecote Series includes (1) a finely laminated greenish-brown rock, resembling a sandy mudstone, probably an altered andesitic tuff; (2) a rock composed of rounded or corroded crystals of triclinic felspar and quartz-grains in a dark felsitic matrix, and appearing to be a lava-flow or dyke, which has taken up fragments of other rocks in such quantity as to simulate a tuff (the quartz-porphyry previously referred to); (3) a compact purplish-grey rock (the diabase previously referred to), consisting of crystals of triclinic felspar and magnetite in a felsitic ground-mass, which contains minute crystals, believed to be hornblende, in which case the rock would probably be a hornblendic andesite.

The rocks intrusive in the Lower Silurian Shales consist of diorite at Marston Jabet, Griff Farm, Chilvers Coton, Stockingford Cutting, Oldbury, and Dosthill. Others, as at Nuneaton Midland Station and in the Stockingford Cutting, are akin to basalt in their composition.

The breccia at the base of the Hartshill Quartzite is composed of fragments of eruptive rocks and of slate in a purplish matrix. Quartz-grains constitute a large proportion of the rock. The Hartshill Quartzite consists of irregular crystalline grains of quartz with numerous fluid lacunæ, with a few grains of felspar. Rarely microcrystalline siliceous matter occupies small spaces between the quartz-grains.

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6. *On the Halesowen District of the South Staffordshire Coalfield.*
By Wm. Mathews, *F.G.S.*

Details of seven hitherto unpublished sections of sinkings for coal in this district were given in the paper, and the section of the Old Hawne pits, as set forth in Beete Jukes's 'South Staffordshire Coalfield,' was referred to. These sinkings may be divided into the following groups:—

I.

Sinkings near the western edge of coalfield, Wassell, Oldnall Ridge, 540-600 feet above sea-level. The figures give the position of the top of the thick coal, or the measures corresponding therewith:—

Wassell	106 feet above sea.
Oldnall	94 "
Beeches	65 "

II.

Sinkings in the Halesowen Valley:—

Manor	468 feet below sea.
Witley	450 "
New Hawne	357 "
Old Hawne	342 "

III.

Sinking on eastern edge of coalfield:—

Rowley Station	86 feet below sea.

It was shown that the Halesowen Coal-measures lie in a trough, with a steep synclinal section from east to west; and that the various seams which, in their aggregate, compose the thick coal show in that district a marked tendency to separate as they extend southwards, and at the same time to become thinner and to deteriorate in quality; that the Coal-measures rest immediately on the Ludlow Passage beds at Halesowen Manor and Wassell and on the Cambrian quartzite at the Lower Lickey. The paper concluded by a reference to the bearing of these facts on the geological history of the district.

7. *Notes on the Rocks between the Thick Coal and the Trias North of Birmingham and the Old South Staffordshire Coalfield. By* FREDERICK G. MEACHAM, *M.E., and* H. INSLEY.

The most complete sections of these rocks can be seen only in deep sinkings for coal. All other sections in the district expose but little of the rocks overlying the Thick Coal Seams.

Taking the rocks in order, we find the following:—Lying upon the Thick Coal is a set of black, greasy unfossiliferous shales, to 11 inches, followed first by grey shales with ironstone nodules and then by alternations of shales and thin flags coated with carbonaceous films and containing a few fossils of the usual Coal Measure types. These are succeeded by some thin seams of fireclay, and then by the Brooch Coal, which is in turn covered by grey earthy shales with 'Unios,' and this, again, by the well-known Stigmaria beds. Grey and blue shales variegated with irregular brown bands overlie the last, and are succeeded by an earthy conglomerate locally known as the Espley rock. At Hamstead a few seams of fireclay are followed by a representative of the Foot Seam, there only 4½ inches thick. This is succeeded by nine feet of black earthy shale, very fissile, and containing a *Lingula* in abundance, as well as what we take to be casts of *Orthoceras, Euomphalus, Productus,* and *Spirifer*. Casts of *Productus* occur also in the associated ironstone. Fireclays and black bituminous shales succeed, followed by purple and red sandstones. This is at 72 yards above the Thick Coal. Two feet of blue-grey shale containing *Calamites, Lepidodendron,* and impressions of sedge-like vegetation succeed, and are followed by six feet of fireclay. Seven hundred and thirty-two feet of unfossiliferous, variegated marls, with occasional bands of conglomerate, succeed, and are followed by 9 feet of fireclay containing *Asterophyllites, Calamites, Cyclopteris,* and *Neuropteris* in abundance. About four hundred feet of variegated marls succeed, and are generally followed by a thin band of limestone containing *Spirorbis*. More marls, interstratified with hard calcareous bands, rain-pitted and ripple-marked, succeed. These yield *Asterophyllites, Lepidodendron, Sigillaria, Neuropteris, Pecopteris,* &c., and various sedge-like impressions.

At 380 yards above the Thick Coal is a bed of red and brown marl, about a hundred feet thick, exhibing circular markings, which are nearly white on the outer part and dark towards the centre. This zone forms an excellent and constant landmark in searching for coal here, as it has been met with in the same relative position in the Sandwell, Hamstead, and Perry trial sinkings. From their horizon to the surface the rocks consist of marls and sandstones of various colours, with occasional conglomerates of well-rounded pebbles.

Disturbances, periodical and varying in force, are evidenced in the marls and rock-bands dipping to the east at angles from 5½ to 20 and even to 30 degrees. We have met with no fossils nearer the surface than 209 yards, then a Cyclopteris-like leaf, and impressions of reeds occur sparingly.

The question has often arisen in our minds regarding the red rocks of the district we are reviewing. They are set down as Permian by the last Survey, whilst the finding of the fossils enumerated above indicates that they are Upper Coal Measures. If not, then the Coal Measures pass imperceptibly into the overlying Permian, for the lower marls containing Coal Measure fossils differ in no respect from the beds which come to the surface and which are classed as Permian by the Survey.

At Wednesfield some years ago a trial sinking was made on the ground marked Permian. The measures passed through were principally red and yellow marls, and at 100 yards coal, broken, was found, but dipping headlong to the west, in a similar manner to the sinking at Wigmore. The place was abandoned, and some more trials have been made, but not successfully; but still we are of opinion that the coal will be found under Upper and Lower Penn, Tettenhall, Codsall, Hilton, and at depths varying to 800 yards, running away to join the Cannock Chase and Hednesford Coalfields in the same manner that the coal will probably be found to run from Sandwell and Hamstead right away under Birmingham, &c., and joining the Warwickshire Coalfield, where the Thick Coal, as in the Cannock district, is divided into many seams.

Practical geology has already achieved many triumphs, and we venture to think the finding of the Thick Coal at Sandwell and Hamstead is not among the least of them, so far as the Midlands are concerned, and we may look upon the future of this district in the mining world as assured, and especially when coal is found, as above mentioned, on the west side of the old coalfield.

FRIDAY, SEPTEMBER 3.

The following Report and Papers were read:—

1. *Fourteenth Report on the Erratic Blocks of England, Wales, and Ireland.*—See Reports, p. 223.

2. *On the Glacial Phenomena of the Midland District.*

By Dr. H. W. CROSSKEY, *F.G.S.*—See Reports, p. 224.

3. *On the Glacial Erratics of Leicestershire and Warwickshire.*

By the Rev. W. TUCKWELL.

As evidence of a south-western dispersion from Charnwood;—in Stockton, a village midway between Leamington and Rugby, a mass of boulder clay containing abundance of Mount Sorrel granite, of so-called gneiss from Charnwood Forest, large decomposed 'pockets' of red sandstone, blocks of grey sandstone highly glaciated, Bunter pebbles, flints, carboniferous limestone, lias rock of a different texture from that native to the district; also lying loose in the village street, recently enclosed and inscribed, a fine boulder from Mount Sorrel, glaciated, of nearly two tons weight were referred to.

Mount Sorrel and the unmistakable character of its hornblendic granite were described.

The author noted extraordinary profusion of Mount Sorrel erratics as far as Leicester; at Rothley, Thurcaston, Anstey. 'Stone' or 'Ston' is a suffix of nearly all the villages along the line.

A notice was given of a special stone, the largest found in Leicestershire, near Humberston, estimated at twenty tons, partly embedded in boulder clay which is filled with Bunter pebbles and rolled slate from Charnwood. Its enclosure and preservation were suggested.

Attention was called to the reappearance of Charnwood stones from Leicester to Coventry, from Coventry to Stockton, completing the evidence of a south-west stream from the Charnwood elevation throughout the two counties.

4. *The Fossiliferous Bunter Pebbles contained in the Drift at Moseley, &c.*

By A. T. EVANS.

The pebbles contained in the drift are chiefly composed of quartzite, intermixed with fragments of silurian limestone, carboniferous chert, carboniferous sandstone, and Llandovery flags; also a few fragments of flint, granite, basalt, quartz, conglomerate, and a smaller quantity of intensely hard pieces of black siliceous rock. All the above-mentioned fragments are few in number compared with the quartzite pebbles. The pebbles vary in size from half an inch to over a foot in diameter. The fossils contained in the drift-pebbles are exceedingly rare, especially perfect specimens; about one fossiliferous pebble occurs in two or three thousand stones, and this perhaps contains fragments only.

Perfect fossils are seldom met with; when a complete specimen is found it is generally in a good state of preservation. The pebbles contain brachiopods, lamellibranchs, cephalopods, gasteropods, annelids, plants, crinoidal stems, and fragments of trilobites of different species.

5. *Surface Subsidence caused by Lateral Coal Mining.*
By Professor W. E. Benton, *Assoc.R.S.M.*

The author showed that a large amount of coal is annually sacrificed in British coal-mining for the lateral support of neighbouring and disinterested surface proprietaries; and pointed out the results of this sacrifice, together with the considerations which should govern the extent of this support.

6. *Exhibition of some Organisms met with in the Clay-Ironstone Nodules of the Coal-measures in the neighbourhood of Dudley. By* H. Woodward, *LL.D., F.R.S., and* R. Etheridge, *F.R.S.*

7. *Notes on the Discovery of a large Fossil Tree in the Lower Coal-measures at Clayton, near Bradford. By* S. A. Adamson, *F.G.S.*

The author described the discovery of a huge Sigillarian stump, with eight forked Stigmarian roots attached, at Murgatroyd's Fall Top Quarry, Clayton, near Bradford. It was discovered about 12 feet below the surface in the measures between the Better Bed Coal and the Elland Flagstone. The stump of the tree was embedded in soft sandy shale, locally termed 'yellow loam,' the roots resting on a bed of soft blue shale, which some of them penetrate. The following dimensions of the fossil were given:—

Height of stump	3 ft. 9 in.
Diameter of stump (longest axis)	4 ft. 6 in.
" (at right angles to longest axis)	3 ft. 10 in.

The following figures give details of the roots:—

Root	Diameter close to stump	Distance from stump to bifurcation of roots	Distance from point of bifurcation to present termination of root		Greatest length of root
			Right fork	Left fork	
No. 1	1 ft. 9 in.	4 ft.	9 ft. 6 in.	13 ft.	17 ft.
" 2	1 ft. 5½ in.	4 ft.	8 ft.	6 ft. 6 in.	12 ft.
" 3	1 ft. 4 in.	5 ft.	7 ft.	4 ft.	12 ft.
" 4	1 ft. 4 in.	4 ft.	2 ft.	4 ft. 6 in.	8 ft. 6 in.
" 5	1 ft. 5½ in.	7 ft.	1 ft. 6 in.	3 ft.	10 ft.
" 6	1 ft. 6 in.	5 ft. 6 in.	3 ft.	4 ft. 6 in.	10 ft.
" 7	1 ft. 5 in.	7 ft. 6 in.	3 ft.	2 ft.	10 ft. 6 in.
" 8	1 ft. 5 in.	7 ft.	9 ft. 6 in.	7 ft.	16 ft. 6 in.

The diameter of the visible area covered by the ramifications of the roots is, from N. to S. 29 feet 6 inches, and from E. to W, 28 feet, giving a superficial area exposed of 826 feet.

This neighbourhood appears to be prolific in grand examples of the Carboniferous flora, for another fine specimen of *Stigmaria* is to be observed in the same quarry, and in the railway cutting close by a good but much smaller specimen of *Sigillaria* with roots attached was obtained.[1]

8. *On the Discovery of Fossil Fish in the New Red Sandstone (Upper Keuper) in Warwickshire. By the* Rev. P. B. Brodie, *M.A., F.G.S.*

The author observed that, considering the thickness and extent of the New Red Sandstone in Great Britain, the paucity and rarity of fossils were remarkable, especially when compared with the abundant fauna and flora of the Trias in Europe. In a field so comparatively barren any addition, therefore, to either is interesting to the palæontologist. Many years ago the author discovered a ganoid fish—the last apparently of the genus *Palæoniscus superstes*—figured and described by the late Sir Philip Egerton ('Journ. Geol. Soc.' xiv. p. 164) in the Upper Keuper at Rowington (six miles north-west of Warwick); and he now records another discovery of several small fish near there, shortly to be figured and described by Mr. E. T. Newton, and named by him *Semionotus Brodiei*, which is the first time this genus has been recorded from the British Trias. The remains of small Cestracionts are not unfrequent in one particular band of sandstone in Warwickshire and Worcestershire, with occasional footprints in the former county of *Labyrinthodon*. Ganoid fish are so rare that these above named are, as far as the author is aware, the only ones known, with one exception, which cannot be secured, in the Upper Keuper; the curious *Dipteronotus* having been found in the Lower Keuper (waterstones) at Bromsgrove, in Worcestershire, and two new species discovered by Mr. Wilson in the Lower Keuper, near Nottingham. The author gave a section of the quarry containing the fossils above referred to, and stated that he considered that the New Red Sandstone in Warwickshire, as the Rev. J. Mello has adopted in Cheshire, might fairly and advantageously be divided into Upper and Lower Keuper, the two series of sandstones being different lithologically, and being separated by a considerable thickness of red marl, the lower sandstones being especially characterised by remains of *Labyrinthodon* and other peculiar reptiles, a fine and unique collection being preserved in the Warwick Museum.

9. *On the Range, Extent, and Fossils of the Rhætic Formation in Warwickshire. By the* Rev. P. B. Brodie, *M.A., F.G.S.*

The author in this paper first gives an account of the range, thickness, and fossils of the upper portion of the Rhætic formation—viz. the 'white Lias,' supposing that it really belongs to this, but to which it is now generally assigned, showing that it is very rarely seen in conjunction with the underlying shales, and that where they occur in one or two important sections the white Lias is absent. A list of the fossils is given, which are few and ill-preserved, *Ostrea intusstriata* and a species of Avicula (*Monotis*) being the most characteristic. A full account is given of the succeeding grey and black Rhætic shales, with occasional intercalated shelly limestone and sandstone; and though, as a rule, good sections are rare, there were certain railway cuttings which laid open several very interesting and instructive ones, and enabled the author to obtain a series of characteristic fossils, including the Radiate, by no means common and local, the *Ophiolepis Damesii*. It was stated that these occupied a considerable area in the southern division of the county, appearing again on the north-east, near Rugby, and as a rule succeeded by the basement beds (insect and saurian beds) of the Lower Lias, which were in places seen in conjunction with these shales. It was further observed that they probably underlie the Lias in its course through the county; and the author concluded by showing the general range of the Rhætics from the coast of Devon to the coast of Yorkshire; which, although not comparable either in thickness or abundance and

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[1] See *post*, p. 645, for remarks on this tree by Prof. W. C. Williamson; also *Geol. Mag.* Sept. 1886, pp. 406–8.

variety of fossils with the rich, varied, and peculiar Continental series, is still sufficiently marked and important in this county and elsewhere to make it a distinctive and independent formation.

10. *On a Deep Boring for Water in the New Red Marls (Keuper Marls) near Birmingham.*[1] *By* W. JEROME HARRISON, *F.G.S.*

In the district round Birmingham the Keuper sandstone is divided from the Keuper marls by a line of fault running from north-east to south-west (Erdington to Rubery)—roughly along the line of the river Rea.

West of this fault the Keuper sandstone and Bunter pebble-beds occupy the surface, and yield an enormous and unfailing supply of pure water, the Birmingham Corporation alone pumping about eight million gallons daily from three deep wells in this formation. East of the line of fault the Keuper red marls form an undulating band from five to twelve miles in width, the towns and villages on which depend wholly on surface waters, or shallow wells in surface gravels, for their water-supply. As the Keuper sandstone undoubtedly underlies the Keuper marls throughout the whole or the greater part of this tract of East Warwickshire, it is not surprising that attempts have recently been made to reach its locked-up waters by means of deep borings. Some seven or eight years ago the Birmingham Corporation bored in Smallheath Park (the southern suburb of Birmingham) to a depth of 440 feet, entirely in Keuper marls. The object of this paper is to describe a boring made during the present year at King's Heath, three miles south of Birmingham, at the brewery of Messrs. Bates, in search of water. The following rocks have been passed through:—

	Feet
Sands and gravels	36
Boulder clay	20
Red marl	158
Red marl and gypsum	131
Marls and shales, with gypsum	309
Marls and shales	3½
Hard sandy marls and shales	9½
Total depth =	667 feet

At present the boring is temporarily delayed, owing to the breaking of a tool at the bottom of the bore-hole.

From comparisons with the Keuper marls of Staffordshire, &c., the thickness of the Keuper marls at King's Heath can hardly be more than 700 feet. It is to be hoped that the Keuper sandstone will be reached almost immediately, and that its water-bearing properties will be such as to satisfy the requirements of the district.

11. *Notes on a Smoothed and Striated Boulder (exhibited) from a Pre-tertiary Deposit in the Punjab Salt Range. By* W. T. BLANFORD, *LL.D., F.R.S., Sec.G.S.*

The block of stone in question, like another exhibited by Mr. A. B. Wynne, was obtained by Dr. Warth, at Chel Hill, in the Punjab Salt Range. This specimen was sent by Dr. Warth to Mr. H. B. Medlicott, Director of the Geological Survey of India, who forwarded it to the present writer, in the hope of learning the views of those who have most experience of similarly marked boulders, and of ascertaining whether the peculiar characters of the present specimen are due to any particular form of ice action or to any other agency.

The stone consists of a purplish-brown porphyry, apparently an altered felsite-porphyry. This rock is known to occur in Rajputana, near Jodhpur, between 300

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[1] Printed in full in *Geol. Mag.* Dec. 3, vol. iii. p. 453, 1886.

and 400 miles south of the Salt Range, and belongs to a group of beds supposed to be Archæan, and known by the name of Maláni. These rocks may occur nearer to the Salt Range, but the intervening country is imperfectly known, and is much covered with river alluvium and blown sand.

The boulder exhibited measures 7¼″ × 6″ × 3¼″. It is subangular, the two principal surfaces are plane, smooth, finely striated, opposite to each other, and nearly but not quite parallel. Each of these surfaces is bevelled off on one edge by a number of smaller facets, meeting the principal surface and each other at very obtuse angles. Besides the larger plane surface there are on one side five smaller smoothed facets, and on the other two, but one in each case is ill-marked, the angle at which it meets the next surface being so obtuse as to be with difficulty recognised. All the smoothed surfaces on one side are striated in the same direction; those on the other side are striated similarly to each other, but diversely to those on the opposite surface of the block. Those surfaces of the block that are not smoothed are somewhat rounded.

The bed from which the block was obtained is said to abound in similar boulders, but they are not in general smoothed or striated. They are found in an olive-coloured matrix of fine silt. The bed has been described by Mr. Wynne, Dr. Waagen, and Mr. R. Oldham, and a general *résumé* of its geological relations was given in the 'Quart. Journ. Geol. Soc.' for the present year, p. 254. The strata immediately overlying are marine, and contain fossils that are either Palæocene or very high Cretaceous, but the age of the boulder-bed itself is somewhat doubtful. The occurrence of large boulders in a fine silt appears to indicate glacial conditions, as in the Talchir beds of India, of which there is a possibility that this Salt Range bed may be a representative, although most of those who have examined the ground think it to belong to a much later geological period, and associate it with the overlying Upper Cretaceous or Palæocene strata.

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12. *On a Striated and Facetted Fragment from Chel Hill Olive Conglomerate, Salt Range, Punjab.*[1] *By* A. B. WYNNE, *F.G.S.*

Picked up by Dr. H. K. Warth, June 10, 1886.
Latitude, 32° 45′ N.; longitude, 73° 15′ E. (about).
Size, 3¼ inches × 2¼ inches × 2 inches.
Weight, 10¼ ounces.
Material, reddish-brown porphyritic felsite, pale.

Age of containing beds probably late Pre-Tertiary (but said by some to be Palæozoic), smoothed, polished, and striated on twelve different surfaces, giving it at first sight the appearance of an imperfect crystal. Of these surfaces about six are perfectly flat, others somewhat curved.

On the largest surface the striation is fine, nearly in the direction of the longest axis; on other surfaces the striæ cross this direction at various acute angles, ranging from 23° to 80° or 85° from the more axial direction. On some of the faces, making most obtuse angles with each other, the direction of the striæ varies least.

The specimen is slightly marked superficially by the tin-box in which it travelled; its planes show small cavities, once apparently occupied by pyrites crystals, which being dislodged have initiated and caused striation as though they had been used as engraving tools.

From the positions of a large number of the facets (6), all upon one side of the specimen, all contiguous and of unequal size, together with the slight variation in direction of their striation, it would appear that this pebble, with whatever it was embedded in, made about a half-revolution almost around its major axis by six separate stages, and underwent severe grinding and polishing at each stage, to a degree almost artificially perfect.

The state of things which would permit of this action, supposing the pebble to have been grasped and held by a resisting matrix of ice, whatever its bulk, effec-

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[1] Published in full in *Geol. Mag.* Dec. 3, vol. iii. p. 492, Nov. 1886.

tively but about two inches thick, raises the questions, What can these conditions have been? How was the pebble shifted in its ice or other matrix so that not alone was one half of it subjected to the grinding process described, but (presumably at another time) it was turned completely over, and its directly opposite side, even more perfectly smoothed and striated than any other, not to speak of the remaining five surfaces, likewise ground and smoothed, though not as planes?

Supposing ice to have been the agent, what form would it have taken—shore ice, floe ice, ground ice, floating or glacier ice?

SATURDAY, SEPTEMBER 4.

The following Report and Papers were read:—

1. *Report on the Exploration of the Caves of North Wales.*

See Reports, p. 219.

2. *On the Pleistocene Deposits of the Vale of Clwyd.*

By Professor T. M'KENNY HUGHES, *M.A.*, *F.G.S.*

The author cautions observers against inferring too hastily the glacial origin of beds from their containing glaciated boulders. He describes the older drifts of the western part of North Wales, grouping them under two heads:—

1. The Arenig Drift, or that in which boulders were transported from Snowdon and Arenig into the Vale of Clwyd; and

2. The St. Asaph Drift, or that due to the destruction of the older glacial deposits by marine action, during which boulders, which originally were carried on ice from the north, and flints travelled in the shingle round the coast. Most of the shells found in it are of species still living on the adjoining coast. A larger proportion of the shells found in what he considers part of the same series of deposits in neighbouring districts are of a Scandinavian or arctic type, and may belong to an earlier part of the same age.

He then gives an account of the principal caves explored about the Vale of Clwyd, and explains their relation in each case to the drifts of the district; inferring that, while some of the caves themselves may be older than the marine Clwydian drift, and some may possibly be even preglacial, yet that none of the bone-deposits so far found in any of them can be referred to so early a date.

3. *Comparative Studies upon the Glaciation of North America, Great Britain, and Ireland.* *By* Professor H. CARVILL LEWIS, *M.A.*, *F.G.S.*

Observations extending over several years upon glacial phenomena on both sides of the Atlantic had convinced the author of the essential identity of these phenomena; and the object of this paper was to show that the glacial deposits of Great Britain and Ireland, like those of America, may be interpreted most satisfactorily by considering them with reference to a series of great *terminal moraines*, which both define confluent lobes of ice and often mark the line separating the glaciated from the non-glaciated areas.

The paper began with a sketch of recent investigations upon the glaciation of North America, with special reference to the significance of the terminal moraines discovered within the last few years. The principal characters of these moraines were given, and a map was exhibited showing the extent of the glaciated areas of North America, the course of the interlobate and terminal moraines, and the direction of striation and glacial movement.

It was shown that, apart from the great ice-sheet of North-eastern America, an immense lobe of ice descended from Alaska to Vancouver's Island on the western side of the Rocky Mountains, and that from various separate centres in the Cascade, Sierra Nevada, and Rocky Mountains there radiated smaller local glaciers.

The mountains encircling the depression of Hudson Bay seemed to be the principal source of the glaciers, which became confluent to form the great ice-sheet. In its advance this ice-sheet probably met and amalgamated with a number of already existing local glacial systems, and it was suggested that there was no necessity for assuming either an extraordinary thickness of ice at the pole or great and unequal elevations and depressions of land.

Detailed studies made by the author in Ireland, in 1885, had shown remarkably similar glacial phenomena.

The large ice-sheet which covered the greater part of Ireland was composed of confluent glaciers, while distinct and local glacial systems occurred in the non-glaciated area. The principal ice-sheet resembled that of America in having for its centre a great inland depression surrounded by a rim of mountains.

These appear to have given rise to the first glaciers, which, after uniting, poured outwards in all directions. Great lobes from this ice-sheet flowed westward out of the Shannon, and out of Galway, Clew, Sligo, and Donegal Bays, northward out of Loughs Swilly and Foyle, and south-eastward out of Dundalk and Dublin Bays; while to the south the ice-sheet abutted against the Mullaghareirk, Galty, and Wicklow Mountains, or died out in the plains.

Whether it stopped among the mountains or in the lowlands, its edge was approximately outlined by unusual accumulations of drift and boulders, representing the terminal moraines. As in America, this outer moraine was least distinct in the lowlands, and was often bordered by an outer fringe of drift several miles in width.

South of an east and west line extending from Tralee to Wexford is a non-glaciated zone, free from drift. Several local systems of glaciers occur in the south of Ireland, of which by far the most important is that radiating from the Killarney Mountains, covering an area of 2,000 square miles, and entitled to be called a local ice-sheet. Great glaciers from this Killarney ice-sheet flowed out of the fiord-like parallel bays which indent the south-western coast of Ireland. At the same time the Dingle Mountains, the Knockmealdown, and Comeragh Mountains, and those of Wexford and Wicklow furnished small separate glaciers, each sharply defined by its own moraine.

No evidence of any great marine submergence was discovered, although the author had explored the greater part of Ireland, and the eskers were held to be phenomena due to the melting of the ice and the circulation of subglacial waters. The Irish ice-sheet seemed to have been joined at its north-eastern corner by ice coming from Scotland across the North Channel. All the evidence collected indicates that a mass of Scotch ice, reinforced by that of Ireland and England, filled the Irish Sea, overriding the Isle of Man and Anglesey, and extending at least as far south as Bray Head, south of Dublin. A map of the glaciation of Ireland was exhibited, in which the observations of the Irish geologists and of the author were combined, in which was shown the central sheet, the five local glacial systems, all the known striæ, and the probable lines of movement as indicated by moraines, striæ, and the transport of erratics.

The glaciation of Wales was then considered. Wales was shown to have supported three distinct and disconnected local systems of glaciers, while at the same time its extreme northern border was touched by the great ice-lobe of the Irish Sea. The most extensive local glaciers were those radiating from the Snowdon and Arenig region; while another set of glaciers radiated from the Plinlimmon district and the mountains of Cardiganshire; and a third system originated among the Brecnockshire Beacons. The glaciers from each of these centres transported purely local boulders, and formed well-defined terminal moraines. The northern ice-lobe, bearing granite boulders from Scotland and shells and flints from the bed of the Irish Sea, invaded the northern coast, but did not mingle with the Welsh glaciers. It smothered Anglesey and part of Carnarvonshire on the one side, and part of Flintshire on the other, and heaped up a terminal moraine on the outer flanks of the North Welsh mountains. This great moraine, filled with far-travelled northern erratics, is heaped up in hummocks and irregular ridges, and is in many places as characteristically developed as anywhere in America. It has none of the characters of a sea-beach, although often containing broken shells brought from the Irish Sea. It may be followed from the extreme end of the Lleyn Peninsula (where it is full of Scotch granite erratics), in a north-easterly direction, through Carnarvonshire, past Moel Tryfan, and along the foot of the mountains east of Menai Strait to Bangor, where it goes out to sea, reappearing further east at Conway and Colwyn. It turns south-eastward at Denbighshire, going past St. Asaph and Halkin Mountain. In Flintshire it turns southward, and is magnificently developed on the eastern side of the mountains, at an elevation of over 1,000 feet between Minera and Llangollen, south-west of which place it enters England. There is evidence that where the ice-sheet abutted against Wales it was about 1,350 feet in thickness. This is analogous to the thickness of the ice-sheet in Pennsylvania, where the author had previously shown that it was about 1,000 feet in thickness at its extreme edge and 2,000 feet thick at points some eight miles back from its edge. The transport of erratics coincides with the direction of striæ in Wales as elsewhere, and is at right angles to the terminal moraines.

The complicated phenomena of the glaciation of England, the subject of a voluminous literature and discordant views, had been of high interest to the author, and had led him to redouble his efforts toward its solution. He had found that it was possible to accurately map the glaciated areas, to separate the deposits made by land-ice from those due to icebergs or to torrential rivers, and to trace out a series of terminal moraines both at the edge of the ice-sheet and at the edge of its confluent lobes. Perhaps the finest exhibition of a terminal moraine in England is in the vicinity of Ellesmere, in Shropshire. A great mass of drift several miles in width, and full of erratics from Scotland and from Wales, is here heaped into conical hills which enclose 'kettleholes' and lakes, and have all the characters of the 'kettle moraine' of Wisconsin. Like the latter, the Ellesmere moraine here divides two great lobes of ice, one coming from Scotland, the other from Wales. This moraine may be traced continuously from Ellesmere eastward, through Madeley, Macclesfield, to and along the western flank of the Pennine chain, marking throughout the southern edge of the ice-sheet of Northern England. From Macclesfield the same moraine was traced northward past Stockport and Staleybridge to Burnley, and thence to Skipton, in Yorkshire. North-east of Burnley it is banked against the Boulsworth Hills up to a height of 1,300 feet, in the form of mounds and hummocks. South and east of this long moraine no signs of glaciation were discovered, while north and west of it there is every evidence of a continuous ice-sheet covering land and sea alike. The striæ and the transport of boulders agree in proving a southerly and south-easterly direction of ice-movement in Lancashire and Cheshire.

From Skipton northward the phenomena are more complicated. A tongue of ice surmounted the watershed near Skipton and protruded down the valley of the Aire as far as Bingley, where its terminal moraine is thrown across the valley like a great dam, reminding one of similar moraine dams in several Pennsylvanian valleys. A continuous moraine was traced around this Aire glacier. Another greater glacier, much larger than this, descended Wensleydale and reached the plain of York. The most complex glacial movements in England occurred in the mountain region about the Nine Standards, where local glaciers met and were overpowered by the greater ice-sheet coming down from Cumberland. The ice-sheet itself was here divided, one portion going southward, the other, in company with local glaciers and laden with the well-known boulders of the 'Shap granite,' being forced eastward across Stainmoor Forest into Durham and Yorkshire, finally reaching the North Sea at the mouth of the Tees. The terminal moraine runs eastward through Kirkby Ravensworth toward Whitby, keeping north of the Cleveland Hills, and all eastern England south of Whitby appears to be non-glaciated. On the other hand, all England north of Stainmoor Forest and the river Tees, except the very highest points, was smothered in a sea of solid ice.

There is abundant evidence to prove that the ice-lobe filling the Irish Sea was thicker towards its axis than at its edges, and at the north than at its southern terminus, and that it was reinforced by smaller tributary ice-streams from both England and Ireland. It may be compared with the glacier of the Hudson River Valley in New York, each having a maximum thickness of something more than 3,000 feet. The erosive power of the ice-sheet was found to be extremely slight at its edge, but more powerful farther north, where its action was continued for a longer period. Towards its edge its function was to fill up inequalities rather than to level them down. It was held that most glacial lakes are due to an irregular dumping of drift, rather than to any scooping action; observations in England and in Switzerland coinciding with those in America to confirm this conclusion. Numerous facts on both sides of the Atlantic indicate that the upper portion of the ice-sheet may move in a different direction from its lower portion. It was also shown that a glacier in its advance had the power of raising stones from the bottom to the top of the ice, a fact due to the retardation by friction of its lower layers. The author had observed the gradual upward passage of sand and stones in the Grindelwald glacier, and he applied the same explanation to the broken shells and flint raised from the bed of the Irish Sea to the top of Moel Tryfan, to Macclesfield, and to the Dublin Mountains. The occurrence of stratified deposits in connection with undoubted moraines was shown to be a common phenomenon, and instances of stratified moraines in Switzerland, Italy, America, and Wales were given. The stratification is due to waters derived from the melting ice, and is not proof of submergence.

It was held that, notwithstanding a general opinion to the contrary, there is no evidence in Great Britain of any marine submergence greater than about 450 feet. It was expected that an ice-sheet advancing across a sea should deposit shell-fragments in its terminal moraine.

The broad principle was enunciated that, wherever in Great Britain marine shells occur in glacial deposits at high levels, it can be proved, both by striæ and the transport of erratics, that the ice advanced on to the land from out of the sea. The shells on Three Rock Mountain, near Dublin, and in North Wales and Macclesfield, all from the Irish Sea; the shells in Cumberland, transported from Solway Firth; those on the coast of Northumberland, brought out of the North Sea; those at Airdree, in Scotland, carried eastward from the bottom of the Clyde; and those in Caithness, from Moray Firth—were among examples adduced in proof of this principle. The improbability of a great submergence not leaving corresponding deposits in other parts of England was dwelt upon.

It was also held that there was insufficient evidence of more than one advance in the ice-sheet, although halts occurred in its retreat. The idea of successive elevations and submergences with advances and retreats of the ice was disputed, and the author held that much of the supposed interglacial drift was due to subglacial water from the melting ice.

The last portion of the paper discussed the distribution of boulders, gravels, and clays south of the glacial area. Much the greater part of England was believed to have been not covered by land-ice. The drift deposits in this area were shown to be the result in part of great freshwater streams issuing from the melting ice-sheet, and in part of marine currents bearing icebergs during a submergence of some 450 feet. The supposed glacial drift about Birmingham and the concentration of boulders at Wolverhampton were regarded as due to the former agent, while the deposits at Cromer and the distribution of Lincolnshire chalk across southern England was due to the latter. The supposed esker at Hunstanton was held to be simply a sea-beach, and the London drift deposits to be of aqueous origin. Thus the rival theories of floating icebergs and of land glaciers were both true, the former for middle and southern England, the latter for Scotland, Wales, and the north of England; and the line of demarcation was fixed by great terminal moraines. The paper closed with an acknowledgment of indebtedness to the many geologists of England and Ireland who had uniformly rendered most generous assistance to the author during his investigations.

4. *On the Extension and probable Duration of the South Staffordshire Coalfield.* *By* HENRY JOHNSON, *F.G.S.*

After giving an historical sketch of the progress of coal-mining in South Staffordshire, with special reference to the trials in search of coal beneath the Red Rocks, the writer went on to describe in detail the results of some borings put down by the Sandwell Park Colliery Company. After passing through 16 yards of surface drift, containing rounded pieces of coal, limestone, and other rocks, the Permians were entered, having a uniform dip of one in three to the east. The sinking then continued through red rocks until a depth of 80 yards was reached, when red and purple marls set in and continued to a depth of 200 yards, at which point the base of the Permians was reached, and the Upper Coal Measures entered. These Upper Coal Measures (unknown in the parent portion of the coalfield, and composed of blue shales and white sandstones, containing irregularly deposited thin bands of coaly matter) continued until a depth of 287 yards was reached, and after passing through 131 yards of Lower Coal Measures (comprising purple marls, conglomerates, and blue binds) the Thick Coal was reached, at a depth of 418 yards, on May 28, 1874, and proved to be about nine yards in thickness. At 123 yards, and in the red and purple marls, a band of limestone, about 12 inches thick, and containing *Spirorbis carbonarius*, was passed through, this being the first instance in South Staffordshire. The sinking of the 10-feet diameter trial shaft occupied about four years, and the maximum quantity of water encountered in the sinking was about 750 gallons per minute, which, however (after the water-bearing strata to the rise had been drained), diminished to about 40 gallons. It was met with principally in the red rocks of the Permians and in the sandstones of the Upper Coal Measures.

Beautiful and rare plant-remains of Coal Measure types were met with in the Permians, and many others were found in piercing the Coal Measures proper—the former circumstance seeming to suggest that the Permians would perhaps be more correctly named Upper Coal Measures; and if they were coloured on the Geological Survey maps as Coal Measures it would put a different complexion on our geological maps of the country. It would, in any case, be interesting and valuable information to know where the Permians end and the Coal Measures begin.

The whole of the fossils found during sinking operations are now in the able hands of Dr. Henry Woodward, of the British Museum, and they will, no doubt, form an interesting study when thoroughly investigated and described, as they no doubt will be. Since the discovery of the coal in 1874, explorations to the north for upwards of a mile and a quarter, and to the south for about a quarter of a mile, have been made, and the Thick Seam was found to be of average quality and about nine yards thick. It has also been explored for about a quarter of a mile to the east towards Birmingham, and found to first dip rapidly, then slowly, and then almost level, until a small upthrow fault is reached, beyond which it rises gently towards Birmingham. The underground explorations to the west or towards the parent coalfield, together with explorations from the Spon Lane Colliery to the east, have undoubtedly proved Sir Roderick Murchison's theory of the existence of an underground Silurian bank, for, whilst the Spon Lane explorations have extended to where the seam is found partially removed by denudation and in a fragmentary condition on the western slope of the bank, the Sandwell explorations have extended to a point where the seam is lost by a sudden thinning out on the eastern slope, after having been subjected to numerous slight dislocations.

I should mention that the information relating to the Spon Lane side of the bank is from notes kindly supplied by Messrs. Cooksey and Son, who conducted the explorations: that relating to the Sandwell side is from my own personal observations. A large quantity of salt (brackish) water was met with in making the Sandwell explorations, and took a considerable period to drain off.

Benefiting by the discovery at Sandwell, the Perry and Hamstead sinkings were commenced about two-and-a-half miles to the north-east and considerably to the deep of Sandwell, the former being more than two miles and the latter about a mile and a quarter beyond the eastern boundary fault, and both sinkings being confined within the exposed area of Permian, as at Sandwell. The Perry sinking was abandoned after sinking and boring to a total depth of 560 yards, wholly in the Permian Measures, and without any indications whatever of Coal Measures. The Hamstead sinking, after about five years' hard work, ultimately succeeded in winning the Thick Coal at a depth of 615 yards. The failure to discover Coal Measures at the great depth bored to at Perry, and the inclination of the Thick Coal as proved at Hamstead, suggests the existence of a large downthrow fault between the two sinkings. The thickness of Permian passed through at Hamstead is 490 yards, and Coal Measures 125 yards, as against 218 yards of Coal Measures at Sandwell, or 93 yards less. This reduced thickness of Coal Measures may perhaps be accounted for by the presence of 87 yards of Upper Coal Measures at Sandwell, which we do not get at Hamstead. The two sinkings may be said to have proved coal for about one-and-a-quarter miles beyond the previously known coalfield, and to have increased the area several square miles, and it may also be said that they have to a very considerable extent proved the continuity of the coalfield underneath Birmingham, right away to the Warwickshire coalfield, and I venture to think that the results should give encouragement to search in other parts of the coalfield for coal below the Permians. The successful winnings next in importance, since the Association's last visit, are those underneath the basalt of the Rowley Hills. It has been clearly demonstrated that the basalt forms only a comparatively thin capping over the Coal Measures, which lie in regular order beneath and are for the most part unaltered by the close contiguity to the igneous rock, the latter apparently having been forced up through a small opening or openings and spread itself over what was at that period dry land or the bottom of a shallow sea. The Earl of Dudley and others are now raising large quantities of good Thick Coal from underneath this extensive range of hills, which at present form the only remaining maiden portion of the old coalfield from which a supply may be expected for any length of time. It may be of interest to state, as showing the disturbance to which the coalfield has been subjected, that the Thick Coal at the Earl of Dudley's Lye Cross Pits on the Rowley Hills is relatively about 1,000 feet above the Thick Coal at Sandwell, and about 1,800 feet above the Thick Coal at Hamstead. The proximity of the New Red Sandstone to the present confines of the coalfield may perhaps for a time limit future sinkings to the narrow areas of exposed Permians on the east and west flanks; but ultimately the New Red ground will have to be sunk through. The necessity or otherwise of developing further new ground, in order to make up the reduced output which must inevitably soon take place in consequence of the now rapid total exhaustion of the old coalfield, is a question well worth the serious consideration of the district. When we see that no extensions are being made to the west, that the profitable limits in the south are known, that the penetration of the conglomerate beds overlying the Cannock Chase or northern portion is one of great risk and expense (as evidenced by the signal failures of the Fair Oak Colliery and the Cannock and Huntingdon Colliery), and that the parent portion of the coalfield is nearly all gone (and that the only points of future supplies will be the Sandwell and Hamstead district, Cannock Chase, and the Rowley Hills), may not the time have arrived for further search, especially taking into consideration the time that must be occupied before any new undertaking can be fully developed and ready for trading? As showing the capacity of production I would mention that during the last twenty years, 1866–1885 (or the period between this and the previous visit of the Association), the gross quantity of coal raised from the coalfield was 191,277,309 tons, and during the same period the ironstone raised was 8,073,964 tons. The lowest annual output of coal during the twenty years was 8,389,343 tons in 1874, and the highest was 10,550,000 tons in 1872. The output in 1885 was 9,862,497 tons, and the average annual output for the twenty years was 9,563,865 tons. It, therefore, appears that whilst the annual output of coal has been maintained there has been a very remarkable falling-off in ironstone. I find that in 1866 we raised 599,000 tons of ironstone, and that this quantity was increased until in 1875 it reached 715,451 tons, since when it has decreased every year (with the one exception of 1883), until we find it in 1885 as low as 117,726 tons.

The paper concluded with an account of the methods of mining coal at great depths.

MONDAY, SEPTEMBER 6.

The following Papers were read:—

1. *On the Relations of the Geology of the Arctic and Atlantic Basins.* *By* Sir J. WILLIAM DAWSON, *C.M.G.*, *F.R.S.*

The paper was based on examinations of Arctic collections in England, made with reference to a paper now in preparation by Dr. G. M. Dawson.

The conclusions stated were principally as follows: The older crystalline rocks in the Arctic collections correspond with the Laurentian and Huronian of Canada, and there are also specimens which seem to represent the Animike series and the Cambrian coastal series of Nova Scotia and Newfoundland. There is a close correspondence in the Ordovician, Silurian, and Devonian facies of the Arctic basin with those of the eastern plateaus of North America, and the specimens are large and well-developed. This would seem to apply also to the Carboniferous. There is a deficiency in Permian and Triassic remains. The Jurassic seems to be represented, and the Cretaceous flora is similar to that of the western territories of Canada. The beds hitherto considered as Miocene in Greenland are apparently equivalent to the Laramie Cretaceo-Eocene of Canada; and the Miocene and Pliocene are absent, or little represented, as is also the case in eastern Canada. The Pleistocene presents features akin to that of Canada, more especially in the occurrence of marine shells of modern boreal species at great heights on the coast terraces.

It appears that the elevations and subsidences correspond with those of the American land to the southward; that there is remarkable evidence of temperate climates from the Palæozoic downwards, and an absence of glacial deposits except in the Pleistocene and Modern. In the colder periods, however, the Arctic basin may have been buried under permanent snow, or may have been an area of denudation rather than of deposition.

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2. *On the Rocky Mountains, with special reference to that part of the Range between the 49th parallel and the headwaters of the Red Deer River.* *By* GEORGE M. DAWSON, *D.Sc.*, *F.G.S.*

The term 'Rocky Mountains' is frequently applied in a loose way to the whole mountainous belt which borders the west side of the North American continent. This mountainous belt is, however, preferably called the Cordillera region, and includes a great number of mountain systems or ranges, which on the 40th parallel have a breadth of not less than 700 miles. Nearly coincident with the 49th parallel, however, a change in the general character of the Cordillera region occurs. It becomes comparatively strait and narrow, and runs to the 56th parallel or beyond with an average width of about 400 miles only. This portion of the western mountain region comprises the greater part of the province of British Columbia. It consists of four main ranges, or, more correctly, systems of mountains, each including a number of component ranges. These mountain systems are, from east to west:—(1) The Rocky Mountains proper. (2) Mountains which may be classed together as the Gold Ranges. (3) The system of the Coast Ranges of British Columbia, sometimes improperly named the Cascade Range. (4) A mountain system which in its unsubmerged portions constitutes Vancouver and the Queen Charlotte Islands.

The present paper refers to the Rocky Mountains proper. This system, between the 49th and 53rd parallels, has an average width of about 60 miles, which, in the vicinity of the Peace River, on the 56th parallel, decreases to about 40 miles. It is bounded to the east by the Great Plains, which break into a series of foot-hills along its base; to the west by a remarkably straight and definite valley occupied by portions of the Columbia, Kootanie, and other rivers.

Since the early part of the century the trade of the fur companies has traversed this range, chiefly by the Athabasca and Peace River Passes, but till the explorations effected by the expedition under Capt. Palliser in 1858–59 nothing was known in detail of the structure of the range. At the inception of explorations for the Canadian Pacific Railway, Palliser's map was still the only one on which any reliance could be placed, and it applied merely to the portion of the range south of the Athabasca Pass. During the progress of the railway explorations a number of passes were examined, and in 1883 and 1884 that part of the range between the 49th parallel and latitude 51° 30″ was explored and mapped in some detail in connection with the work of the Canadian Geological Survey by myself and assistants.

Access to this, the southern portion of the Rocky Mountains within Canadian territory, being now readily obtained by the railway, its mineral and other resources are receiving attention, while the magnificent alpine scenery which it affords is beginning to attract the attention of tourists and other travellers.

The results of the reconnaissance work so far accomplished are here presented in the form of a preliminary map, accompanied by descriptions of routes and passes, and remarks on the main orographic features of the range.

3. *On the Coal-bearing Rocks of Canada.*

By FRANK D. ADAMS, *Geological Surveyor of Canada.*

As the coalfields of the Dominion are very extensive, the coal-bearing rocks occupying in those portions of the country which have been examined geologically an area of not less than 97,200 square miles, it will be best to consider the fuel supply of each province separately. Nova Scotia, the most easterly of all the provinces, contains probably the most important and certainly the most extensively worked coal deposits in the Dominion. This coal is all bituminous, no anthracite having yet been found. The measures are of Carboniferous age, and although they occupy an area only amounting to about 685 square miles, yet the seams which they enclose are so numerous and so thick that the quantity of coal contained in this area is enormous. There are three important coal-basins in this province, situated respectively in Cape Breton, Pictou, and Cumberland Counties; as well as several others which are of less importance, or as yet undeveloped. The Cape Breton coalfields form the edge of an extensive basin, the greater part of which is hidden beneath the Atlantic Ocean, and rights have been taken out, covering about 100 square miles of submarine coal. The strata are so impervious to water that at a moderate depth the submarine workings are perfectly dry. It has been estimated by the Geological Survey of Canada that the seams now opened in this district contain, in the areas leased for the purpose of working them, over 212,000,000 tons of coal. In composition and general characteristics the Cape Breton coal is very similar to Newcastle coal, and is largely used for domestic purposes and for gas-making. At one time it was shipped very largely to New York and Boston for the latter purpose. It is also largely used as a steam coal. The Pictou basin is remarkable for the great thickness of the coal-seams which occur in it, the main seam in the Dalhousie pit of the Albion mines being as much as 36¾ feet thick. The coal of the Pictou and Cumberland basins is, as a general rule, less bituminous than that of Cape Breton, and belongs rather to the free-burning type. In 1885 there were in operation in Nova Scotia 28 collieries, employing 4,446 men and boys, the total output for the year being 1,352,205 tons. The aggregate sales of Nova Scotia coal for the 100 years ending 1884 was 22,290,937 tons. Of late years, owing to the development of the American coalfields and the increased facilities for transportation, the quantity of Nova Scotia coal sent to the United States has been steadily diminishing. This loss, however, is more than compensated by the greatly increased market in Nova Scotia itself, as well as in the provinces of Quebec and Ontario. Even with the present protective duty of 60 cents a ton, however, this coal from Nova Scotia cannot be profitably carried further west in Canada than Ottawa or Brockville.

In the neighbouring province of New Brunswick the coal-bearing rocks are much thinner and the coal-seams smaller. They are, however, near the surface, and are worked at one or two places in a small way, principally for local use. The coal is easily worked, and will at some future time probably be burned extensively.

Unfortunately no coal is found in the provinces of Quebec and Ontario, which at present contain the greater part of the population of the Dominion; and what is still more unfortunate is the fact that it never will be discovered in either of these provinces in workable quantities, seeing that the formations which underlie them are older than the Carboniferous. Passing, however, still further to the west, immense deposits of coal and lignite are found in the North-west Territories, recently opened up by the Canadian Pacific Railroad. Their occurring in this part of Canada is especially a subject for congratulation, as much of the country is but scantily supplied with wood. A line drawn on the 97th meridian separates in a general way the coal-bearing rocks of America into two classes—those on the east of this line being of Carboniferous age, while those on the west belong to the Tertiary or Cretaceous formation. The rocks, therefore, in which the coals and lignites of the North-west Territories and of British Columbia are formed belong to the latter class. The mineral fuels of the North-west may be divided into four classes, which, however, pass gradually into one another:—

(*a*) True lignites, holding from 10 to 22 per cent. of hygroscopic water.
(*b*) Lignitic coals, „ 5 to 9 „ „
(*c*) True coals, „ 1½ to 5 „ „
(*d*) Anthracite,

The true lignites are found in the eastern part of the territory, none but true lignites, for example, occurring in the district of Assiniboia. As we go west towards the Rocky Mountains the lignite gradually improves in quality, being firmer and holding less water, until in the disturbed and folded strata toward the base of the mountains it becomes a true coal, while in one of the basins of coal-bearing rocks which occur in the mountains themselves, and which are very much disturbed, *anthracite* is found. This gradual change from lignite to anthracite is one of the most remarkable examples of the results of pressure and disturbance to be found anywhere. The coal deposits of this great tract of country are situated so that they can be easily mined; many of them can be worked by simple levels run in from the deep river valleys. The only locality where much coal is taken out at present is near Lethbridge, in the Belly River, where the North-western Coal and Navigation Company work a seam of very good lignite coal 5 feet 4 inches in thickness. The mine is connected with the line of the Canadian Pacific Railroad by a branch line 107 miles in length, and large quantities of the coal are shipped east to Manitoba and used by the railway for their locomotives. Taking the minimum thickness of the seam at different points along an outcrop of 66 miles, and assuming a workable width of only one mile, the seam alone would contain 330,000,000 tons of coal. It is now ascertained from the known outcrop that a large part of the plains is underlain by coal at a workable depth, but this one seam will serve to show the immense quantity of coal which can readily be obtained. Preparations are now being made for working the anthracite mentioned above as occurring in the Rocky Mountains on an extensive scale. The deposit is near Banff, on the line of the Canadian Pacific, and the anthracite will probably be largely used not only by the railway, but also in Winnipeg, where it will compete with the American hard coal now used in that city. In British Columbia, the most westerly province of the Dominion, there are also very extensive coal deposits, which are especially valuable owing to the absence of good coal elsewhere on the Pacific coast of North America. The only known deposit of anthracite on the Pacific coast occurs on the Queen Charlotte Islands.

Bituminous coal is largely mined on Vancouver Island, four collieries being at work during the past year, with a total output of 365,000 tons. The largest colliery, known as the Wellington, works a seam 9 feet in thickness, while the Nanaimo, which has been in operation nearly thirty years, works two seams, the upper being from 6 to 10 feet thick, while the lower has a thickness of 7 feet. Most of the coal raised is shipped to San Francisco, but some is sent to Alaska and some to the Sandwich Islands.

Blocks of almost every coal mentioned in this paper were to be seen in the Canadian Court of the Colonial and Indian Exhibition. The author desires to acknowledge his indebtedness to the Reports of the Geological Survey of Canada, to the Reports of the Departments of Mines of Nova Scotia and of British Columbia, as well as to several gentlemen who have kindly given him information on certain points connected with the subject.

In 1885, 1,717,205 tons of coal were raised in Canada, being nearly double the amount raised in 1875.

4. *On the Coal Deposits of South Africa.*[1]

By Professor T. Rupert Jones, *F.R.S., F.G.S.*

In Cape Colony native coal is chiefly obtained from the Stormberg range, near Cypher-gat and Molteno, not far from Burgersdorp. The geological arrangement of the strata is—

Karoo Formation.
- Upper—Stormberg Beds (with Coal).
- Middle—Beaufort Beds (with Dicynodon, &c.).
- Lower—Kimberley Shales and Conglomerates (equivalent to the Ecca Beds, according to Mr. Dunn); Ecca Beds with the great Ecca or Dwyka Conglomerates.

The Stormberg Coal.—In the southern part of the Stormbergen, at and near Molteno, the coal, worked in numerous adits and pits, seems to belong to one main 'seam,' made up of several layers, of which 34¾ inches are coal and 15¾ inches shale. Another seam, with about 50 inches of coal and 9 inches of shale, coming out at the foot of Bushman's Hoek, not far from Molteno, is probably at a somewhat different level. Faults may have disarranged the stratification here and there. On the Indwe River, in the Dordrecht district (about fifty miles eastward), a seam of coal with shale partings (7′ 6″ of coal and 6′ 7″ of shale) occurs at a different level from that of the foregoing; but the workings on all the seams in the two districts are said to be within 300 or 400 feet above the level of the Karoo sandstone lying below (Dunn, 'Report,' 1878, p. 20; and Green, 'Report,' 1883, p. 24).

The coal is very laminar, with impressions of ferns and cycadaceous leaves, and flattened carbonaceous tree-trunks, without any 'seat-earth.' In these composite coal-seams some of the 'laminæ are made up of a large number of alternations of thin plates of coal and very thin films of black mud,' which give rise to the large percentage of ash. One seam gives coal of different value at two diggings, at Molteno and Van Zyl's, a mile distant. In the latter case the microscope shows that 'the carbonaceous portion seems to be intermingled, and, as it were, wrapped up, in the most intimate way, with the mineral matter of the ash.'

The several exposures, natural and artificial, of these Stormberg coals (near Burghersdorf, on the Indwe and on the Kraii River) are described in detail by Mr. E. J. Dunn, Mr. F. W. North, and Professor A. H. Green in their respective reports. Outcrops of coal may be looked for on the slopes of the Stormberg and adjacent hills in strata at or about the same level as those at Bushman's Hoek in the Stormberg.

Some large examples of the coals themselves were shown in the Colonial and Indian Exhibition, and are described in the official catalogues.

The geological age of the great Karoo series of strata, as shown by the fossils, and by their relative position to the Palæozoic rocks of the Witteberg and Zuurberg, is probably Permi-triassic or Lower Triassic. Their possible relationship

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[1] Published in full in the *Mining Journal,* Dec. 4, 1886.

to certain Mesozoic beds near the eastern coast of the colony, and their possible equivalency to some Indian and Australian formations, has been ably discussed by Dr. Blanford, F.R.S. Some Palæozoic plant remains of real old Carboniferous age have before now been sent to England from the neighbourhood of the Stormberg, but it is very doubtful if they were really found there.

Coal in the Free State and Transvaal.—North of Burghersdorp occasional exposures of grey and black shales, with thin layers of coal, occur south and north of the Orange River, and then, with wider intervals, in the Orange Free State up to the Sand River, north of Winburg, but without any valuable yield of coal; and so on to the Vaal valley, where the Walsch runs into it, and further on, particularly at the junction of the Wilge and the Vaal. Hereabouts the late G. W. Stow found useful coal exposed for some distance along the river and its tributaries. The 'black band,' as he called it, is thicker here than at the Sand River. At the latter place he found this band to contain about 18 inches altogether of coal. At the Taaibosch sprint, however, near the mouth of the Wilge, he exposed, under superficial *débris,* black shales with 15 feet of coal.

Still further north and north-east the same horizontal Stormberg sandstones and shales extend in force (2,300 feet thick, according to Mr. Penning, 'Quart. Journ. Geol. Soc.' vol. xl. p. 663) through the Orange Free State into the Transvaal. Here it occupies an area of about 56,000 square miles. Were the coal-seams continuous this would be a grand coalfield; but the same remarks apply here as in the Stormberg.

The Natal Coal.—The Klip River Coalfield is about forty by twenty miles in area, and there are other, but inferior, fields. The seams vary from two or three inches to three or four feet in thickness. In Natal, as in the Cape Colony, the coal-seams are compound, being divided by thin shales; but this deterioration of the fossil fuel is not so general in Natal. In one case (main coal, near Umraki) 'in a total thickness of 10 feet 9 inches there is only about 3 inches of parting; and many others . . . show good workable sections free from earthy matter' (North's Report, 1881, p. 13). 'The whole of the deposits are of very lentiform nature, especially the coal-seams themselves' (*loc. cit.*). As in Cape Colony numerous trap-dykes traverse the Karoo strata, and occasionally the coal-seams have been affected by these igneous rocks.

The Ecca Beds.—The Ecca beds (including the Koonap beds, 'Quart. Journ. Geol. Soc.' vol. xxiii. 1867, p. 172), underlying the Reptiliferous Karoo sandstones and shales, contain fossil wood and plant remains (ferns, &c.) in both the western and the eastern districts of Cape Colony; also some traces of coal here and there. The diamantiferous and carbonaceous shales of Kimberley are regarded by Mr. Dunn as their northern equivalent. About 1878 Mr. Dunn found an inlier of highly inclined and faulted coal-bearing strata in the Ecca beds at Buffel's Kloof, on a spur of the Camdeboo Mountains, between Graaff Reinett and Beaufort-West; and again at Brandewyn's Gat, by the Leeuwe River, on a spur of the Nieuweldt, 36 miles south-west of Beaufort-West and 100 miles west of Buffel's Kloof. He has described also the anthracite and highly carbonaceous limestone found in the same Ecca beds near Buffel's River, on the Beaufort and Cape Town line of railway (see his 'Report on the Camdeboo and Nieuweldt Coal,' 4to, 1879; and 'Geol. Mag.,' 1879, pp. 551–4).

Mr. Dunn has suggested that coal may be found, by boring into the Ecca beds under the Karoo sandstones and shales, over some hundreds of square miles of a great central basin in Cape Colony ('Report on a Supposed Extensive Deposit of Coal underlying the Central Districts of the Colony,' 4to, 1886). Around the edges of the basin thin leaves of coal have been found in these black shales; at Buffel's River with the black limestone; at Kimberley and De Beer's mines as thin layers and seams of impure coal up to an inch in thickness. In Natal in these same rocks (well represented at the Foot of the Town Hill, Pietermaritzburg, Dunn, 'Report,' 1886, p. 11). These are the 'Pietermaritzburg shales' of Dr. Sutherland. A coal-seam fifteen inches thick occurs at Compensation Flats; and probably boring near Ladysmith Flats, where these same rocks underlie, would bring to light the thicker seams at a lower horizon than the Newcastle and Dundee coal-seams

(Dunn, 'Report,' 1886, p. 11). Mr. Dunn has ventured to predicate thicker coal-beds in the interior of this great central basin of the Cape Colony region, and has recommended that borings be made at certain places south of Hope Town.

Carboniferous (Palæozoic) Rocks in Cape Colony.—Fossils belonging to real old Carboniferous species have been found at the Kowie mouth (by Mr. Neate, at Port Alfred) and by Mr. Wylie and Dr. Rubidge and others in the Swellendam district; but although the Wittebergen at the Cape and the Zuurbergen in Albany contain rocks probably of Carboniferous age, no coal-beds have yet been noted there.

Lignite in the Cape Flats, and *Peat* at the western foot of the Draakensberg in Orange Free State, remain only to be alluded to.

5. *On the Kerosine Shale of Mount Victoria, New South Wales.*
By Professor W. BOYD DAWKINS, *F.R.S.*

The kerosene or paraffin shale of New South Wales, so valuable for its large yield of good hydrocarbons, occurs in the area of the Blue Mountains, where I examined it in 1875 in the Carboniferous strata under very much the same conditions as seams of coal; it passes on the one hand into a 'bituminous' shale, and on the other insensibly into coal. The Mount Victoria seam, ranging from twelve to eighteen inches in thickness, and with a shale roof and floor, passes westwards into a valuable deposit at Hartley Vale, thirty-eight inches in thickness, and still further to the west, at Piper's Flat Creek, is represented by a layer eight inches in thickness embedded in a coal seam, twenty-four inches of splint coal being above, and sixteen inches of dull coal below. It is therefore lenticular, like the cannel coal of the Lancashire coalfield.

Under the microscope it presents a finely granular mass of fossil resins embedded in a meshwork of clayey material, the former being composed in part of obscure broken-down spores, and the latter apparently of a mud deposited from muddy water at the time of the deposition of the former.

The two are so intimately associated that the ash maintains the same shape and almost the same size as the shale before burning; the resinous element has probably been deposited by muddy water in basins existing in the Carboniferous forests, and its association with the coals can only be accounted for on that hypothesis, which also will account for its gradual passage into shale. In the associated blue shales *Glossopteris* and *Vertebraria* are the two predominant forms, but there are also forms undistinguishable from *Calamites* and *Lepidodendron*, both of which, as well as *Sigillaria* and *Stigmaria*, have been obtained from the New South Wales coalfield by the late Rev. W. B. Clarke.

6. *On the Character and Age of the New Zealand Coalfields.*
By Sir JULIUS VON HAAST, *K.C.M.G., F.R.S., F.G.S.*

The coal of New Zealand is of Cretaceous or Tertiary age. Recent researches by von Ettingshausen on the fossil flora lead to the conclusion that the coals of the Grey, Buller, Pakawau, and Wangapeka Beds should be classed with the Cretaceous; the rest—Shag Point, Malvern Hills, &c.—as true Tertiary. The Cretaceous coals are bituminous and of excellent quality; they occur in beds varying from 8 to 50 feet in thickness. The rocks have been much disturbed and faulted, and the coals range from 600 feet below the sea to nearly 4,000 feet above it. The Tertiary coals vary in character. In the Malvern Hills are found all varieties, from brown coal to good anthracite. In some cases, of thick seams capped by basalt, the upper part is anthracite, the lower part brown coal.

The development of the coal resources is proceeding rapidly, the output having increased from 162,218 tons in 1878 to 480,831 tons in 1884, whilst the amount imported has decreased.

7. *On the Geysers of the Rotorua District, North Island of New Zealand.*
By E. W. BUCKE.

The author of this paper has recently returned from the Lake district of New Zealand, where he spent eighteen months, and had exceptional opportunities for making observations upon the volcanic phenomena of the district. The largest geyser in New Zealand, that of the White Terrace of Rotomahana, is now destroyed; the three next in size are those of Pehutu, Waikiti, and Wairoa, all of which are situated close together at the back of the native village named Whakarewarewa, about three miles to the south of the Rotorua township, and these are particularly described in the present communication. The author was able to determine by soundings the depth of the tubes of several geysers of this district, and in the case of an extinct one, that of Te Waro, he was let down the tube. He found that this tube, at a depth of 13 feet from the surface, opened into a chamber 15 feet long, 8 feet broad, and 9 feet high, and that from one end of this chamber another tube led downwards to an undetermined depth.

Living entirely among the natives for many months, and speaking their language, the author was able to test the power claimed by the natives of being able to predict the outbursts of the geysers. He is convinced that by constant observations on the direction of the wind and the condition of the atmosphere the natives have learnt to prognosticate the movements in all these hot springs with wonderful accuracy. He was also able to prove that during the whole time of his residence in the district certain of the geysers were only in eruption when the wind blew from a particular quarter.

8. *Note accompanying a Series of Photographs prepared by Josiah Martin Esq., F.G.S., to illustrate the Scene of the recent Volcanic Eruption in New Zealand.* *By* Professor J. W. JUDD, *F.R.S., Pres.G.S.*

Owing to the great enterprise and energy shown by the managers of the local newspaper-press in New Zealand, very full and graphic accounts of the volcanic outburst of June 10 have already reached this country, and have been copied into the English papers. On the day of the eruption Dr. James Hector, C.M.G., F.R.S., Director of the Geological Survey of New Zealand, started for the locality, and his preliminary report, accompanied by maps and plans, has been published. Dr. Hector concludes that the eruption was a purely hydrothermal phenomenon on a gigantic scale, and that it was unaccompanied by any ejection of freshly molten lava either in the form of fragmental matter or of lava-streams. I have been favoured by Mr. J. E. Clark, F.G.S., with specimens of the material ejected during the eruption, and the microscopic examination of these seems to support Dr. Hector's conclusions.

It is a most unfortunate circumstance that the beautiful sinter-terraces of Rotomahana appear either to be blown to fragments or covered up under the enormous masses of mud thrown out in that locality. It luckily happens that a number of most excellent photographs, which illustrate very beautifully the characters of the wonderful sinter-formations, have been obtained. Mr. Josiah Martin, F.G.S., has especially devoted himself to the study of the district, and the series of photographs now exhibited constitute an invaluable record of the characters of the district destroyed by the eruption. These photographs show the points at which the volcanic cones were formed upon Tarawera, and the beautiful characters of the White Terrace (Te Terata), and of the Pink Terrace (Otukapuarangi), and the other wonders which surround the now destroyed lake of Rotomahana.

Now that the European settlement has been formed at Rotorua, a great service would be rendered to science if a meteorological station could be established there, and by simultaneous observations of the atmospheric conditions and of the state of activity of the numerous hot springs, the question of the exact relations between these two sets of phenomena clearly established. When we remember that a fall of one inch in the barometer is equivalent to the removal of a load of nearly 90,000 tons over every square mile of surface, the effect produced on a district where steam issues whenever a walking-stick is thrust into the ground must be enormous. What is especially needed, however, by vulcanologists is a carefully tabulated series of records, in the place of the general statements which have hitherto been published on this most important question.

The photographs exhibited illustrate the following localities:—

A. Mount Tarawera, the scene of the great volcanic outburst, with the sites of the new craters and the great fissure.

B. Rotomahana (the Warm Lake) and the wonders on its shores now entirely destroyed.

1. A number of views of the geyser Te Terata (the White Terrace) in eruption, and of the sinter-terraces leading down to the lake. Also of the deposits formed by the overflow of its waters charged with silica.
2. The Pink Terrace (Otukapuarangi).
3. The steam vents known as the Great Ngahapu, the Steamer, and the Great Blow Hole.
4. The Geyser-tube of Koingo.
5. The extinct Geyser called 'the Green Lake.'
6. The old terrace-mound of Ruakiwi.
7. The broken and decomposed terrace of Waikanapanapa.
8. The mud volcanoes of Waikanapanapa.
9. The Valley of Desolation.

9. *On the Geology of the newly discovered Goldfields in Kimberley, Western Australia. By* EDWARD T. HARDMAN, *F.R.G.S.I.*

During the past few months attention has been drawn to Western Australia by announcements in the public press, both British and colonial, of the discovery of a payable goldfield in that colony.

The first paragraph was a telegram from Perth, W.A., to the Colonial Office, stating that 400 ounces had been brought down; shortly after 620 ounces were reported, as well as a nugget of 19 ounces, and also one of 29 ounces. Great excitement was caused in Australia by these announcements, and a 'rush' greater than that of 1851 was predicted. Later accounts show that this 'rush' is taking place. Miners are flocking to the new El Dorado in numbers from South Australia, Victoria, New South Wales, from the great mining colony of Queensland, and even from New Zealand—two men from which obtained 1,100 and 300 ounces of gold respectively, as stated in a private letter dated July 5, 1886.[1] According to a letter from the Surveyor-General there must be now nearly 3,000 men on the fields. The goldfield is therefore an accomplished fact. It had long been a disappointment and reproach to Western Australia that it was not gold-producing, and this idea was almost confirmed when Mr. E. Hammond Hargraves visited a portion of it and reported adversely; and it came to be believed that further search was almost hopeless. In 1883, however, a large surveying expedition was sent up to the Kimberley district, and to this party Mr. Hardman was attached as geologist. During the first year the author saw many indications pointing to the existence of gold, but was unable to test it practically, owing to adverse circumstances. In the next year he was more fortunate, and discovered gold along the rivers Margaret, Elvire, and Ord for 140 miles. The announcement telegraphed to Perth was received with great enthusiasm, and several parties of prospectors went up to the country, the results of their labours verifying the author's prediction as to the capabilities of the gold-field, and justifying the rush now taking place.

The importance of the discovery could hardly be exaggerated. It supplied a want long felt in Western Australia—namely, an attraction for emigrants, which the most glowing accounts of the really fine pasture, abundance of water, and healthy climate had failed to produce. The author was confident it would have a

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[1] To Mr. W. H. Baily, Geological Survey, Ireland.

very beneficial effect in drawing a large population to this at present most thinly peopled colony, which with an area of more than one million square miles contains but 35,186 whites.

Kimberley is the extreme northern part of the colony, extending between lat. 13° S. and 19° 30′ S., and its area—134,000 square miles—exceeds that of the British Isles by 18,000 square miles.

The author described the geology of the district, which is in part composed of low flat ground, while in places it is very mountainous, the Leopold Ranges having an area of probably 20,000 square miles. There are many large rivers. The rocks comprise Archæan granites, gneiss, and schists; Lower Palæozoic sandstones and limestones, Carboniferous sandstones and limestones, Upper Tertiary beds, and Post Pliocene and Recent deposits. There were extensive outbursts of granite and a great *floetz* deposit of Basaltic and other trap rocks, forming a vast plateau, the known area of which is at least 3,000 square miles, and is called the Great Antrim Plateau. These rocks are undoubtedly of Lower Palæozoic age, and in extent are therefore probably unique.

The known area of the gold-bearing country (schists, &c., with quartz veins) is not less than 2,000 square miles. Quartz reefs are very numerous, and will no doubt be extensively worked in the future. At present the mining is alluvial.

A map was exhibited showing the geology of over 20,000 square miles of the district.

10. *Statistics of the Production and Value of Coal raised within the British Empire.* By RICHARD MEADE.

The following statistics are taken from official sources, and are in all cases the latest which can be obtained.

QUEENSLAND.

Production and value of *coal* in each of the ten years ending 1885:—

Year	Quantity	Value	Year	Quantity	Value
	Tons	£		Tons	£
1876	50,627	26,470	1881	65,612	29,033
1877	60,918	25,659	1882	74,432	33,603
1878	52,580	21,272	1883	104,269	44,927
1879	55,012	22,759	1884	129,980	54,160
1880	58,052	24,573	1885	209,500	Not given

Authority.—Blue Books of Queensland for each of the above named years.

NEW ZEALAND.

Production and value of *coal* in each of the following years:—

Year	Quantity	Value
	Tons	£
1881	337,262	269,809
1882	421,764	316,623
1883	480,831	360,622

Authority.—Blue Books, Perth, for each year.

VICTORIA.

Production and value of *coal* in each of the ten years ending:—

Year	Quantity	Value	Year	Quantity	Value
	Tons	£		Tons	£
1875	—	—	1880	$2\frac{1}{2}$	3
1876	1,095	1,642	1881	—	—
1877	2,420	3,630	1882	10	13
1878	—	—	1883	428	599
1879	—	—	1884	Not given	3,280

Authority.—Mineral statistics of Victoria for each of the above-named years.

NATAL.

Production and value of *coal* in each of the following years:—

Year	Quantity	Value
	Tons	£
1882	5,000	1,000
1883	5,000	1,000
1884	Not given	Not given

Authority.—Blue Books.

INDIA.

Production and value of *coal* in each of the following years:—

Year	Quantity	Value
	Tons	£
1881	997,543	498,771
1882	1,130,242	565,121
1883	1,315,976	657,988

THE CAPE OF GOOD HOPE.

Production and value of *coal* in each of the following years:—

Year	Quantity	Value
	Tons	£
1882	19,765	—
1883	19,956	—
1884	9,000	7,250

Authority.—Agent General, London.

Tasmania.

Production and value of *coal* in each of the ten years ending 1884 :—

Year	Quantity	Value	Year	Quantity	Value
	Tons	£		Tons	£
1875	7,719	Not given	1880	12,219	Not given
1876	6,100	„	1881	11,163	7,856
1877	9,470	„	1882	8,803	6,228
1878	12,311	„	1883	8,872	7,526
1879	9,514	„	1884	7,194	6,381

Authority.—Blue Books of statistics of the colony of Tasmania for each of the above-named years.

Canada.

Production and value of *coal* in each of the following years:—

Year	Quantity	Value
	Tons	£
1881	1,307,824	686,607
1882	—	—
1883	1,646,487	672,035
1884	1,876,643	619,336

United Kingdom.

Production and value of *coal* in the United Kingdom in each of the following years:—

	Quantities	Value
England and Wales—	Tons	£
1882	135,857,066	39,519,057
1883	142,385,416	40,493,257
1884	139,448,660	38,504,885
1885	137,953,797	36,348,585
Scotland—		
1882	20,515,134	4,541,935
1883	21,225,797	5,503,628
1884	21,186,688	4,885,693
1885	21,288,586	4,746,423
Ireland—		
1882	127,777	57,417
1883	126,114	57,258
1884	122,431	55,605
1885	109,035	44,400
United Kingdom—		
1882	156,499,977	44,118,409
1883	163,737,327	46,054,143
1884	160,757,779	43,446,183
1885	159,351 418	41,139,408

11. *The Relations of the Middle and Lower Devonian in West Somerset.* *By* W. A. E. USSHER, *F.G.S.*

This paper deals with the relations of the Foreland grits to the Lynton beds and Hangman grits with which they are successively brought into juxtaposition by fault.

A patch of Lynton beds on the north of the fault at Oare dipping conformably to the subjacent Foreland grits in the vicinity seemed to the author sufficient to prove the position of the Foreland series at the base of the Devonian strata of North Devon according to the generally accepted view; but he found on the east of Luccot Hill, where the Foreland and Hangman grits were in juxtaposition, it was impossible to fix upon any definite line of demarcation, either by lithological characters or dip; although beyond a zone of debatable ground the general distinctive characters of each grit series were perfectly apparent.

This difficulty caused the author to lend a willing ear to a suggestion of Mr. Champernowne that the Foreland and Hangman grits might really be the same series, the appearance of conformable superposition of Lynton upon Foreland beds at Oare being ascribed to inversion. According to this view the downthrow of the fault at Oare would be to the north.

The object of the paper is to discuss the evidence in favour of and against this suggestion, its important bearing on the mapping of the area entitling it to this consideration.

The author advances five points in favour of the hypothesis; the relative merits of these he then discusses briefly seriatim, and points out three considerations adverse to the hypothesis, and some reasons why such difficulties as are experienced in drawing boundaries between the Foreland grits and Hangman beds might reasonably be expected to occur. He considers the arguments against the hypothesis of the identity of the Foreland and Hangman groups, more especially those derived from the typical characters and mode of succession of the rocks composing each group, to be too strong to be entertained without positive evidence in its favour. The author then briefly disposes of the possibility of the absence of the Lynton beds east of Luccot Hill being due to unconformable overlap of Hangman upon Foreland rocks, pointing out that if such were the case conglomerates ought to be found in the Hangman series, and the junction should also be marked by discordant relations of dip and strike.

12. *Supplementary Note on Two Deep Borings in Kent.* *By* W. WHITAKER, *B.A., F.G.S., Assoc.Inst.C.E.*

The paper 'On Deep Borings at Chatham,' communicated in abstract to the last meeting of the Association, was afterwards read, with various additions, to the Geological Society. Since then, however, further information has been got, some of which is of importance, especially in view of the fact that the South Eastern Railway Company is about to make a deep trial-boring at Dover.

The boring at Chattenden Barracks, near Chatham, has been finished, being taken to a depth of over 1,160 feet, the bottom of the Gault being reached at 1,162 feet, where sand (Lower Greensand) was found and water got. In my account of the section it was left, in Gault, at 1,103 feet, and I ventured to say that 'some 60 feet more would reach the bottom of that formation': this happened in 59 feet. I did not venture, however, to predict the finding of Lower Greensand, as, from the thinness of that series at Chatham, a little southward, it was quite possible that it might soon disappear northward.

The almost exact correspondence of the combined thickness of Chalk and Gault here, 872 feet, with the same total at Chatham (875 and 878 feet in two borings) is noteworthy. Of course there is no Upper Greensand, which formation is absent at the outcrop on the south.

The Dover boring has been carried a few feet deeper and abandoned. I have visited the site, and procured a good set of specimens of the bottom clays, of which we had but a few small pieces before.

These specimens have been carefully examined, and the result of this examination is, I think, worthy of notice. As regards fossils it is simply negative, my colleagues, Mr. G. Sharman and Mr. E. T. Newton, after washing and sifting pieces of many specimens, were unable to detect any organism, with a solitary exception, and *that* was a single example of a species of *Rotalia*, which, struggling into existance in Silurian times, has managed to survive to the present day! I have some doubt, too, whether this one fossil may not have fallen down the bore. Anyway it proves nothing. As regards the character of the beds, however, I think that a reasonable conclusion may be inferred from the specimens.

In my published account certain beds are referred, with some doubt, to the Lower Greensand. The reference is wrong and the doubt right. The top five feet, of the forty-nine credited to Lower Greensand, really belong to the base of the Gault, and the bottom thirteen feet to the Wealden, as I believe. The Lower Greensand is left, therefore, with only thirty-one feet of clayey sand. It is curious that specimens from the bottom part (838 to 848 feet) are exactly like the corresponding specimens from the bottom part of the Lower Greensand in the Chatham boring (932 to 943 feet), the two sets having about the same vertical extent (10 or 11 feet).

These specimens remind one of the division known as the Sandgate Beds, and I am inclined to think that this division alone occurs at Dover, the Folkestone Beds above and the Hythe Beds below having thinned out, although both those divisions are thicker than the Sandgate Beds at the outcrop.

The clayey beds beneath have been proved to a thickness of some 80 feet, the boring ending at about 930 feet. In my paper I spoke of chalky matter occurring in them, but in this I was wrong. The white specks in the small specimens first seen certainly looked calcareous, but the examination of better specimens has shown that they are anything but that. Indeed, the prevailing character is the absence of any effervescence when the clays are treated with hydrochloric acid; in many cases peculiarly fine-grained whitish beds simply absorb the acid, without any effervescent action.

On comparing the specimens with other clays they were found to be unlike any of the marine Cretaceous and Jurassic clays, and it seemed to me that their affinities lay rather with the Wealden series, and probably with the lower, or Hastings division, than with the Weald Clay.

I have only lately been able to test this by the help of a set of specimens that Mr. G. Maw has been kind enough to send me. On examining them I found that three specimens of Weald Clay, from Surrey, effervesced readily, which is perhaps not surprising, as they came in two cases from close to Horsham stone and in the other from near a Paludina bed. Nine specimens from a more distant district, Dorsetshire, did not effervesce; but one can hardly give the exact position of these in the Wealden Series. Ten specimens from the Ashdown Series, the lowest division of the Hastings Beds, not only, in some cases, resembled Dover specimens in character (I speak from memory, not having had the two sets side by side), but in every case refused to notice the presence of hydrochloric acid.

Should this classification be right it serves to strengthen very much the conclusion, in my paper, that Dover is on all grounds a good site for a deep trial-boring,[1] for it looks as if the bottom part of the great Wealden Series came there within 600 feet of the surface in the low ground, the boring described being on a site 280 feet above the sea.

13. *On the Westward Extension of the Coal-measures into South-eastern England. By* Professor W. Boyd Dawkins, *F.R.S.*

Geological evidence is conclusive that the valuable coalfields of South Wales and of Somerset are connected with the equally valuable coalfields of North France and of Belgium, some 1,200 square miles in extent, by a series of isolated fields or basins concealed by the newer rocks. The coal-bearing rocks of Northern France

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[1] *Quart. Journ. Geol. Soc.* vol. xlii. p. 44.

pass westward, in the direction of Calais, and plunge under the newer rocks near Condé, from which point to Therouanne they extend, and are worked over two Departments, their discovery being due to borings carried on at the expense of the French Government. Therouanne is the furthest point to the west, where they have been worked. At Calais, about thirty miles still further to the west, they have been proved in a deep boring for water, at a depth of 1,092 feet below the sea. From this point westward they have not been struck until we reach Somersetshire.

The borings for water, however, made in the London area show that the water-worn Primary rocks which come to the surface in the West of England, and in Northern France and Belgium occur under London at a depth of less than 1,200 feet below ordnance datum, and that they are highly inclined, as in those regions. These rocks are of the Silurian and Devonian ages, and their high inclination implies that the strata are thrown into a series of folds which, in some neighbouring area, must bring in the Carboniferous rocks.

The strata of the North French and Belgian Carboniferous rocks, if carried westwards into South-eastern England, as Mr. Godwin-Austen has shown, would bring them in the district between Hythe and Sandwich. These circumstances have afforded me sufficient reasons for choosing Dover as a good site for a deep boring, which has been undertaken by the directors of the South-Eastern Railway, with the intention of proving the westward extension of the Calais measures, which are only twenty-seven miles distant to the east in the line of strike. It starts at the foot of Shakespeare's Cliff, about thirty feet above ordnance datum, and in the lower chalk at a point about 160 feet above the Gault. The older rocks will probably be struck at that point at a depth of less than 1,000 feet—probably very much less. It must be noted that if the Calais section be repeated at Dover, and the chalk maintains its uniform thickness on both sides of the Channel, the latter boring starts at a point 851 feet below the former in the rocks. On the other hand, the Gault at Dover will probably be found thicker than at Calais, and the Wealden beds, absent from Calais, may be expected at Dover. These, however, in Mr. Whitaker's opinion, are of no considerable thickness.

The probability that the coal measures will be struck in this district is rendered greater by the discovery of a mass of bituminous mineral in a fissure in the chalk north of Dover, that has probably—as Mr. Godwin Austen pointed out in his evidence before the Coal Commission—been derived from the Coal-measures below. By the kindness of the Council of the Geological Society, I have been allowed to make a minute examination of Mr. Austen's specimens, and I find that the mineral properly is a pitch, which has resulted from the distillation of coal.

The interest attaching to this experimental boring is very great. If the Coal-measures are proved, a discovery of vast importance will be made. If, on the other hand, rocks older than the Carboniferous are struck, they will offer a basis for further borings, which will ultimately result in the discovery of the hidden coal-fields of South-eastern England, and cause as great an economic revolution in that region as that which has been caused in France and Belgium by the discovery of the coalfields underneath the Chalk.

TUESDAY, SEPTEMBER 7.

The following Reports and Papers were read:—

1. *Report on the Fossil Plants of the Tertiary and Secondary Beds of the United Kingdom.*—See Reports, p. 241.

2. *On Canadian Examples of supposed Fossil Algæ.*

By Sir J. William Dawson, *C.M.G., F.R.S.*

Markings of various kinds on the surfaces of stratified rocks have been loosely referred to Algæ or Fucoids under a great variety of names; and when recently the attempt was made in Europe more critically to define and classify these objects, a great divergence of opinion developed itself, of which the recent memoirs of Nathorst, Williamson, Saporta, and Delgado may be taken as examples.

The author, acting on a suggestion of Sir R. Owen, was enabled in 1862 and 1864, by the study of the footprints of the recent *Limulus polyphemus*, to show that not merely the impressions known as *Protichnites* and *Climactichnites*, but also the supposed fucoids of the genera *Rusophycus*, *Arthrophycus*, and *Cruziana* are really tracks of Crustacea, and not improbably of Trilobites and Limuloids.[1] He had subsequently applied similar explanations to a variety of other impressions found on Palæozoic rocks.[2] The object of the present paper was to illustrate by a number of additional examples the same conclusions, and especially to support the recent results of Nathorst and Williamson.

Rusichnites, *Arthrichnites*, *Chrossochorda*, and *Cruziana*, with other forms of so-called *Bilobites*, are closely allied to each other, and are explicable by reference to the impressions left by the swimming and walking feet of Limulus, and by the burrows of that animal. They pass into Protichnites by such forms as the *P. Davisii* of Williamson, and *Saerichnites* of Billings, and *Diplichnites* of the author. They are connected with the worm-tracks of the genus *Nereites* by specimens of *Arthrichnites*, in which the central furrow becomes obsolete, and by the genus *Gyrichnites* of Whiteaves.[3]

The tuberculated impressions known as *Phymatoderma* and *Caulerpites* may, as Zeiller has shown, be made by the burrowing of the mole-cricket, and fine examples occurring in the Clinton formation of Canada are probably the work of Crustacea. It is probable, however, that some of the later forms referred to these genera are really algæ related to *Caulerpa*, or even branches of Conifers of the genus *Brachyphyllum*.

Nereites and *Planulites* are tracks and burrows of worms, with or without marks of setæ, and some of the markings referred to *Palæochorda*, *Palæophycus*, and *Scolithus* have their places here. Many examples highly illustrative of the manner of formation of these impressions are afforded by Canadian rocks.

Branching forms referred to *Licrophycus* of Billings, and some of those referred to *Buthotrephis*, Hall, as well as radiating markings referable to *Scotolithus*, *Gyrophyllites* and *Asterophycus*, are explained by the branching burrows of worms illustrated by Nathorst and the author. *Astropolithon*, of the Canadian Cambrian, seems to be something organic, but of what nature is uncertain.

Rhabdichnites and *Eophyton* belong to impressions explicable by the trails of drifting seaweeds, the tail-markings of Crustacea, and the ruts ploughed by bivalve mollusks.

Dendrophycus, *Dictyolites*, some species of *Delesserites*, *Aristophycus*, and other branching and frond-like forms, were shown to be referable to rill-marks, of which many fine forms occur in the Carboniferous of Nova Scotia, and also on the recent mud-flats of the Bay of Fundy.

The genus *Spirophyton*, properly so called, is certainly of vegetable origin, but many markings of water action, fin-marks, &c. have been confounded with these so-called 'Cauda-galli fucoids.'

On the other hand some species of *Palæophycus*, *Buthotrephis* and *Sphenothallus* were shown to be true algæ, by their forms and the evidence of organic matter, and *Haliserites*, *Barrandeina*, and *Nematophycus* were shown to include plants of much higher organisation than the algæ. With reference to the latter, it was held that the form to which the name *Prototaxites* had been given was really a land plant growing on the borders of the sea, and producing seeds fitted for flotation. On the other hand, certain forms to which he had given the name *Nematoxylon* were allied to algæ in their structure, and may have been of aquatic habit; very perfectly preserved specimens of these last had been recently found, and had thrown new light on their structure.

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[1] 'On Footprints of Limulus,' *Canad. Nat.* 1862. 'On the Fossils of the Genus *Rusophycus*,' *ibid.* 1864.

[2] 'On Footprints and Impressions of Aquatic Animals,' *Am. Journ. of Science.*

[3] *Trans. Royal Society of Canada*, 1883.

The author proposed to apply to all these problematical plants, having a tissue of vertical and horizontal tubes, the general name *Nematophyteæ* or *Nematophyton*.

The paper referred to the history of opinion on these objects and the bibliography of the subject; but this, as well as detailed descriptions, are omitted in this abstract.

3. *On Bilobites.* *By* Professor T. McKenny Hughes, *M.A.*, *F.G.S.*

The author pointed out that the views of previous writers on this subject might be grouped generally under two heads:—

1. One was that the fossils in question represent a solid organism, which had been buried in the sand or mud, and had left only the cast of its body; that the organic matter had all disappeared and the form had been modified by the various changes which the rock had since undergone. Some believed that nereites, for instance, was the actual cast of the body of a marine annelid allied to nereis, while others considered that all such bilobites as Cruziana were the impressions of portions of marine algæ.

2. Another view was that all the fossils such as those above mentioned were tracks left by animals on the surface of the sand or mud, and filled by the next flood with sand, which took the cast of the depression.

It had been observed by various previous authors that the bilobites were sometimes in relief on the upper side of the slab as it lay in place, and this was urged as evidence that in some cases, at any rate, they represent solid cylindrical bodies like the stems of some well-known sea-weeds.

He had examined the typical sections in Nantffrancon, where the *Cruziana semiplicata* was the characteristic fossil, and found that it was always *in relief on the upper side* of the slab (except where so compressed that the upper and lower sides of the cylindrical body were both driven in, so as to give a double down-curved surface). The side ornamented with the herring-bone pattern was the upper side; the lower was a smooth longitudinally furrowed groove.

He had found somewhat similar tracks in beds of sandstone in the mountain limestone in Westmoreland, where the tracks were in high relief on the upper side of the slabs, and when this compressed cylindrical body was removed a smooth shallow track was seen in what had been the surface of the sand. The ornamented side was uppermost. The layers of sand, instead of thinning out against this ridge-like body, were lifted over it without any appreciable diminution of thickness, so as to appear, not so much as if they had been laid down over this cylindrical body, when it was lying on a sandy surface, but rather as if they had been lifted so as to form an arched tunnel by the protrusion of some solid body, such as a burrowing animal, between the layers of previously deposited sand. There were different patterns on successively overlying layers, as if the effect of continuous scooping work was more apparent on the lower, and the periodic lift-forward of the animal's body chiefly affected the upper layers. There were also holes at regular intervals from the median groove of the bilobite passing up through two or three of the superincumbent layers.

He observed further that in the same beds there were plants with the carbonaceous matter still preserved; and from this he inferred that, had there been any vegetable tissue around the bilobites, there was no reason why it should have disappeared in that case only.

On the whole, he arrived at the conclusion that the bilobites he exhibited were neither vegetable remains nor the surface tracks of animals, but were the burrows of animals which bored between the layers of sand, packing their tunnels behind them with the sand excavated in front, and that at regular intervals they communicated with the surface by means of the holes observed passing through the overlying layers. He considered that the observations of Albany Hancock on the burrowing crustacea at the mouth of the Tyne offered the best explanation of the phenomena, and would extend his inferences.

4. *On recent Researches amongst the Carboniferous Plants of Halifax.*
By Professor W. C. Williamson, *LL.D., F.R.S.*

At the Southport meeting of the British Association a small grant was made to my friend, Mr. Cash, of Halifax, and myself, in aid of our exploration of the fossil flora of the Lower Carboniferous strata of Halifax and the surrounding districts. Circumstances over which we had no control prevented our reporting upon the results of that grant; but since there are important reasons why those results should be recorded, I now bring them before the Association in the shape of a communication instead of a Report.

The plants of the Halifax beds are much more exquisitely preserved than are those of the Oldham beds of the same age. This fact has enabled us to throw additional light upon the organisation of several of the plants obtained from the Oldham deposits and previously described. Structures hitherto unobserved have been detected, and others seen but obscurely have been made clear.

In the dominant group of the Lycopodiaceæ nothing has been discovered requiring us to modify our previous views respecting these plants; and it is gratifying to know that many of our co-workers on the European Continent have now materially mitigated their opposition to those views. Thus, our French friends, who have hitherto so determinately insisted upon the Gymnospermous character of *all* the Sigillariæ, have now advanced so far as to admit the Cryptogamic and Lycopodiaceous character of the vertically grooved forms of that genus—which really means most of our British forms of Sigillaria—and we have not the slightest doubt but that the remaining forms will have to be surrendered to us in like manner. We now have under investigation three or four Lepidodendroid branches, which appear to be new, and which are awaiting their turn of publication; we have also obtained much additional information respecting the Stigmarian roots of these arborescent Lycopods, which will be embodied in a monograph about to appear in the forthcoming volume of the Palæontographical Society.

Many new specimens of Calamite have been obtained, in each of which the woody zone is invested by the characteristic bark previously described. They all, without exception, confirm conclusions already announced, viz., that the longitudinal and transverse grooves and constrictions seen in the common casts of the medullary cavity of the Calamite, are entirely absent from the exterior of the cortex. Here again some of our Continental friends, who have hitherto insisted upon the Gymnospermous affinities of some of the Calamites, have made an important concession to our interpretation of these objects. M. Grand-Eury has now announced his conviction that the plants which the French Palæo-botanists have hitherto included in the genus *Arthropitus* are really the vascular zones of true Cryptogamic Calamites.

Since this genus Arthropitus includes all our British specimens of which the internal organisation is preserved, and since also the hypothesis of the Gymnospermous nature of the genus Arthropitus was chiefly based upon the discoveries of M. Grand-Eury himself, his change of view seriously weakens the influence of those who still cling to what we regard as erroneous opinions. All honour to M. Grand-Eury for his courage in acting otherwise.

Closely associated with the Calamite is the strobilus known as Calamostachys Binneana, upon which our researches have thrown fresh light. In the examples previously figured from the Oldham beds the central axis of the spike of fructification appeared to consist entirely of a mass of barred vessels. But our Halifax specimens have enabled us to determine that this axis consists of a solid central medulla composed of parenchyma, the cells of which are somewhat elongated vertically, and which is enclosed more or less completely in a thin cylinder of barred and spiral vessels; the bands of these vessels are certainly much thicker along certain vertical lines than in the intermediate spaces. We have also obtained a fresh example of the remarkable heterosporous form of Calamostachys published in Part XII. of the 'Organisation of the Fossil Plants of the Coal-measures,' and which latter example previously constituted the only known specimen of a Calamitinean plant with the bisexual fructification. This second example seems to establish clearly the distinctness of this fructification from that of the allied Calamostachys Binneana; and I now propose that it should be known as Calamostachys Casheana, after my energetic colleague, Mr. William Cash, of Halifax.

We have also obtained some additional knowledge respecting the elegant little stem known as Kaloxylon Hookeri. We have now not only obtained specimens in which each of the six radiating wedges of vascular tissue has a distinct crescent of phlœm on its periphery, but we also find that the curious cortex enclosed within the well-defined and thick epiderm was abundantly intermingled with small vertically elongated canals or lacunæ. Besides this, Halifax has furnished numerous specimens which we were at first inclined to regard as a distinct species of Kaloxylon, since, in it, the radial vascular exogenous wedges were much less fully developed than is the case with the numerous examples previously figured from the Oldham coals. But we have now got reason for thinking that most of these new specimens, at least, are roots of Kaloxylon Hookeri, with zylem bundles, externally to which a centrifugal exogenous zone was developed in some examples, though more feebly than was the case in the aërial stems. Some of these specimens of roots are abundantly surrounded by smaller rootlets.

A still more valuable discovery will be laid before the Botanical Section at this meeting of the Association. It is a new species of Heterangium, closely resembling in many respects the Heterangium Grievi, from Burntisland, described in one of the earlier parts of 'The Organisation of the Fossil Plants of the Coal-measures.' But it is clearly distinguished from that plant, not only by the possession of a marvellously developed phlœm or bast zone traversed by magnificent phlœm-rays, but by other peculiarities in the structure of its true cortex. To this important plant the name of Heterangium Tiliæoides will be given.

Besides the objects to which we have thus specially called your attention, we have obtained numerous fragments of plants, which, as stray leaves, stems, and fruits found floating upon the wide ocean, tell of an unknown flora hidden in some uninvestigated corner of the earth and suggest that there are yet unknown plants concealed within the coal-mines of Yorkshire and Lancashire. In former years similar fragments have guided our researches, and in several instances we have been rewarded by the discovery of their true affinities; but many remain respecting which we know nothing beyond their existence. They show us, however, that we must continue our labours until we have unearthed their history, whilst the fact that similar waifs and strays of former years now possess recognised names and habitations stimulates us to perseverance.

A word or two in conclusion about the fine specimens of Stigmaria, a notice of which was brought before this Section by Mr. Adamson on Friday last,[1] and which will be described in my memoir on Stigmaria ficoides now passing through the press. This specimen settles, most conclusively, several questions of fact respecting which even some of our German friends appear to be still in doubt, whilst it is equally conclusive against some most extraordinary views respecting Stigmaria promulgated by M. Rénault, of Paris. The specimen itself is the finest of its kind hitherto obtained in any part of the world. It demonstrates that Stigmaria is a root, and not a rhizome; that four primary roots radiate from the base of an erect stem; that each of these roots dichotomises twice in close proximity to the base of the parent stem, and that beyond the second branching no further divisions take place; thenceforth the undivided roots extend to considerable though varied distances. These latter portions are obviously identical with those referred to by some Continental authors as being something wholly different from the ordinary Stigmarian roots.

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[1] See p. 628.

5. *Note on the recent Earthquake in the United States, including a telegraphic dispatch from Major Powell, Director of the United States Geological Survey.*[1] *By* W. Topley, *F.G.S., Assoc.Inst.C.E., Geological Survey of England.*

This paper described the effects of the earthquake at Charleston, which took place on the evening of August 31, so far as they could be gathered from telegrams received to date. The most important of these was one kindly sent by Major Powell, the Director of the United States Geological Survey, in reply to inquiries cabled by the author: this telegram is printed in full below, and the information therein contained need not be given here.

Mr. Topley observed that during the last ten days there had been earthquake disturbances over a very wide area of the earth's surface. On the night of Friday, August 27, there were shocks all over Greece and in a smaller degree all over the east Mediterranean area. This earthquake wave apparently travelled from west to east. It was felt at Malta, Calabria, and Naples, and thence it travelled eastwards as far as Alexandria. It did not appear to have been felt west of southern Italy, probably because its westward area of propagation was there beneath the sea. Possibly it was only a coincidence, but if so a very curious one, that the earliest important earthquake disturbances in the United States were on Thursday, the 27th, and Friday, the 28th, but there had been slight premonitory shocks for two or three days before. The principal shock was that of Tuesday night, August 31. This had, however, been succeeded by shocks, fortunately of less intensity, which had been felt over a still wider area. As late as Sunday night there were shocks at Charleston. An important point in Major Powell's despatch was the evidence of the rapid transmission of the main earthquake wave. According to the telegram it travelled over the 900,000 square miles at from 25 to 65 miles per minute; but there might be some error in the telegram here, as by comparing the times given in the telegram with the distances on a map he (Mr. Topley) found that the velocity varied from 36 to 140 miles per minute. [The greatest velocities since ascertained are:—To Toronto, 170 miles per minute; to Washington, 148 miles.] There did not seem to be any relation between the intensity and time and the surface distance from the area of origin. This last, indeed, they would not have expected to find. They would rather have looked for rapid transmission along certain lines or through certain rock masses. The last important earthquake in the eastern United States, that on August 10, 1884, was carefully investigated by Professor Carvill Lewis. This was found to range along the eastern side of the Appalachian Mountains, nearly along the line where the old earth-movements had been greatest. The area most affected by the recent earthquake was a vast plain of Tertiary and Cretaceous rocks. The older rocks underlay these at unknown depths. [At least 2,000 feet, and may be as much as one mile.] It might perhaps be found that the transmission of the shock to distant points had depended in part upon the range of the harder and older rocks beneath. This was very evidently the case with the East Anglian earthquake. In this earthquake the great structural damage was confined to a small area. The distant points at which it was felt were in most cases upon or near to the exposure of the Palæozoic rocks, and Birmingham was one of these distant points. In other cases earthquakes were known to be related to lines of fault. Mr. M'Gee had been sent by Major Powell to investigate the effects of the earthquake at Charleston, and he found the local evidence, such as the direction of the fissures, contradictory and difficult of explanation. They need not wonder, therefore, at being yet unable to understand the wider question connected with its range and transmission. The local phenomena were in part described in Major Powell's telegram. Fissures had been opened in the ground, some of which ranged north and south, others east and west. From these fissures mud and sand were ejected. Several telegrams spoke of stones falling from the air, and, although there was plainly much exaggeration in these accounts, it was possible that some stones were ejected

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[1] A few important corrections necessitated by subsequent researches (chiefly by the United States Geological Survey) are inserted within brackets.

far into the air and subsequently fell to the ground. One interesting point in connection with earthquakes was the influence they had on wells and springs, and in these respects the American earthquake had had important results. Water now stood where none occurred before, and in certain places springs had been dried. The gas wells at Pittsburg were affected. It was too early yet to theorise on this side of the Atlantic, but at present the earthquake seemed best explained by referring it to some widely acting seismic disturbance, indications of which were previously given by the geysers of the Yellowstone and by premonitory earthquakes in South Carolina. It would probably be found, however, that its range and local intensity had been controlled by the distribution of the rock masses, or by old lines of earth movement and earth weakness.

The following is a copy of Major Powell's telegram:—'Earthquake most severe on record in United States, and affected greatest area. Origin along line of post-quaternary dislocation on eastern flanks of Appallachian, especially where it crosses central North Carolina. Slight premonitory shocks in the Carolinas for several days, moderately severe shocks occurring near Charleston, August 27 and 28. The principal shock, causing great destruction in Charleston, originated in central North Carolina, August 31, at 9.50 P.M.—75 on meridian time. [2.50 A.M. September 1, Greenwich time.] Thence the shock spread with great rapidity in all directions, with velocity varying from 25 to 65 miles a minute over area of 900,000 square miles—one quarter of United States, from Gulf of Mexico to Great Lakes and southern New England, and from Atlantic seaboard to Central Mississippi valley. In the Carolinas it was accompanied by land-slides, crevasses, and great destruction of property. Half of Charleston in ruins, and about 40 lives lost. No sea-wave yet reported. A second moderately severe shock at Charleston, 8.25 A.M., September 1; minor shocks followed at increasing intervals. The principal shock was felt over this vast area in intervals of 15 minutes, and recorded at some principal points on scale of intensity of 5 as follows:—Raleigh, 4, at 9.50 P.M.; Charleston, 5, at 9.54; Cedar Keys [Florida], 2, at 10.05; Knoxville, 3, at 9.55; Memphis, 4, at 9.55; St. Louis, 1·2, at 10.00; Milwaukee, 3, at 10.06; Pittsburg, 4, at 10.00; Albany, 2, at 10.00; Springfield (Mass.), 1, at 10.00; New York, 2, at 9.53.'

6. *Sixth Report on the Volcanic Phenomena of Japan.*
See Reports, p. 413.

7. *Report on the Volcanic Phenomena of Vesuvius and its neighbourhood.*
See Reports, p. 226.

8. *On the Heat of the Earth as influenced by Conduction and Pressure.*
By the Rev. A. IRVING, *B.Sc., B.A., F.G.S.*

The author, referring to the treatment of this subject by previous writers, in particular Professors Green and Prestwich, draws attention to two physical considerations of some importance, which appear to have been overlooked in the discussion of the subject.

1. In the case of a homogeneous sphere of uniform conductivity throughout, a little consideration of the geometry of the sphere shows us that heat proceeding by conduction from the centre to the circumference must distribute itself through spaces which increase in area by the square of the distance from the centre, that the 'law of inverse squares' in fact applies here to the *intensity* (temperature) of heat so transmitted. It follows from this that if we take $r =$ the radius of such a sphere, and $d =$ the distance of any point within the sphere from the centre, the gradients of the curve for the increase of temperature with *depth* will be according to the formula

$$(r-d)^2,$$

the temperature increasing as the squares of the depths.

Of course in the case of the earth's sphere there are many modifying circumstances, each affecting the value of one or other of the factors of the formula

$$Q = K . A \frac{v_2 - v_1}{n} t,$$

which represents the quantity (Q) of heat which passes through a homogeneous plate of an area $= A$, a thickness $= n$, with opposite faces at constant temperatures v_2 and v_1 in the time (t), the coefficient of conductivity of the material being represented by K.

Among such modifying circumstances may be mentioned:—

(1) Variations in the material of rock-bodies, variations in the actual temperatures of the same rock, variations in the orientation of the crystalline architecture of many rocks, occurrence of mineral-veins and lodes as good conductors, all affecting the value of K.

(2) Variations in the capacity for heat of different rock-materials.

(3) The unequal distribution of underground water.

(4) The presence, in places, of air in the cavernous spaces of many rocks.

(5) The mean temperature of the superficial strata as determined by latitude, together with surface-conditions (such as extensive forests, sandy deserts, snowfields and glaciers, dry land or ocean bed), all affecting the value of the term v_1 in the formula, in every case influencing, and in some preventing altogether, radiation at the surface.

When all these conditions are considered there would still, however, appear to be a considerable margin for increase, as deduced from the hypothetical case, even though in the case of the earth the problem is still more complicated by the varying heat-producing causes in operation (pressure, crushing, friction, chemical action) throughout the mass.

2. The physical value which we attach to the terms 'weight' and 'gravity' leads, with a little reflection, to the recognition of the fact that the same *mass* of matter is not as heavy (and therefore exerts less pressure) within the mass of the earth as at the exterior, since it is acted upon by the two opposite attractions of the mass 'above' and the mass 'below' it. The latter diminishing, and the former increasing with depth, the weight of the same mass of matter diminishes as it is made to approach the centre of gravity of the earth; and when that coincides with its own centre of gravity the body is evidently altogether without weight.

The determination of the curves which shall accurately represent the above two principles requires the application of advanced mathematics; but it is not difficult to see that the curve of temperatures would have steep gradients for *increase,* and the curve of pressures a less steep gradient for *decrease,* so that the two curves (starting from the same origin) would *intersect,* and, in so doing, indicate realisable conditions necessary for *liquefaction at varying depths.*

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9. *A Contribution to the Discussion of Metamorphism in Rocks.*

By the Rev. A. Irving, *B.Sc., B.A., F.G.S.*

The main object of this paper is to draw more attention than is usually given to the physical and chemical side of metamorphic phenomena. As a step towards the possible fixing of a more definite nomenclature for metamorphism, it is proposed to exclude from it all such phenomena as the alterations which may arise in the character of a rock from the removal in solution (as in dolomitisation of some limestones), or the addition by infiltration (as in amygdaloids) of a mineral.

All cases of true metamorphism may be included under the two heads of (i.) Metatropy, (ii.) Paramorphism.

(i.) *Metatropy.*—This term has been suggested by its sister-word 'allotropy,' which is applied in chemistry to those modifications which one and the same chemical (elementary) body may assume by changes in its *physical* properties. Using the word 'metatropy' with rather more latitude, it is proposed to include under this head such rock-changes as (*a*) the conversion of a limestone into a crystalline marble, (*b*) the conversion of grauwacke into hornstone or porcellanite, (*c*) the conversion of seam-coal into anthracite, and that into graphite, (*d*) the conversion of anhydrite into gypsum, together with some other cases in which minerals constituting rock-masses (*a*) acquire a crystalline form by taking up water, or (β) have their crystalline form altered (polymorphism) by a change in their proportion of water of crystallisation or by crystallisation at different temperatures (*e.g.*, carbonates of lime and magnesia). 'Devitrification' of glassy rocks (*e.g.*, tachylite, obsidian)—at once the most interesting and most obscure of metatropic changes—is believed by the author, from the consideration of a large number of chemical facts known in connection with the modifications of such bodies as sulphur, phosphorus, arsenic, silica, borax, metaphosphoric acid, sodium metaphosphate (all of which occur in the glassy or vitreous modification) to consist essentially of a *change* in *molecular structure.* Further this change appears to proceed, in all cases, by the gradual building-up of more stable and more complex molecules out of the less stable and less complex molecules, of which the body appears to be made up in the vitreous condition; and this change the author conceives to be connected with the loss of *latent heat of vitrification,* to which a large number of facts connected with the behaviour of the above-named bodies, as well as those arrived at from recent researches into the properties of artificial glasses, seem to point. M. Daubrée's researches are referred to as showing how heat and pressure combined may, by increasing enormously the solvent action of water, aid in the process.

(ii.) *Paramorphism.*—A term to include all those instances of metamorphism which consist *essentially* of the decomposition to any extent of the original mineral-constituents of a rock with the production of new minerals of a different chemical composition within the rock. Such changes may take place in two ways; (1) in the *dry way*, when reactions between contiguous minerals are set up by their being brought into a state of fusion; (2) in the *wet way* (probably by far the more common) from the presence of interstitial water, acting, at high temperatures and pressures (*a*) as a direct solvent, (*b*) indirectly by the transfer of mineral matter by percolation through the rock-mass, a process immensely facilitated by crushing, and favoured by the easy access of water along junction-planes; the true explanation, perhaps, of many of the known instances of (*a*) the development of new minerals in 'contact metamorphism' (*e.g.*, in the hornstones of the Hartz and in the Triassic limestones of the Predazzo region), (*b*) the apparent transition of true crystalline schists into granite. Such a theory is a very different thing from the 'hydrochemical theory' of Bischof and of those who have followed him.

Chemistry, and especially *thermal* chemistry, enables us to make such deductions from the *nebular hypothesis* as to throw great light upon the order of succession in the kinds of deposits of which the earth's crust has been built up, and points to the first oxidation of hydrogen at very high temperatures, but under an enormous atmospheric pressure, as a fact which must have occurred at a very early stage; and this the author regards as the main factor in the development of those primary characters of the Archæan gneisses and schists (though other characters have been subsequently induced) which distinguish them, on the one hand from the highly siliceous materials which were previously concentrated in a state of dry fusion, and on the other from all the later formations, beginning with the Silurian, which have the character of ordinary aqueous deposits (though often subsequently metamorphosed in various ways and degrees) in true aqueous basins, and under atmospheric conditions approximating to those which prevail at the present time. The occurrence within the crust of conditions, effectively the same as those which are regarded as having been universal at the earth's surface in Archæan times, as the result of the combined action of pressure, crushing, friction (shearing and sliding), and superheated water, is fully recognised; but these are regarded as exceptional local developments of the conditions necessary to produce the highest degrees of metamorphism. Tangential pressure, arising from contraction of the crust, is regarded as the primary cause of these local developments, as well as of less marked phases of 'regional metamorphism' of later periods. The frequent and extensive unconformity observable between the Archæan and the Silurian (and younger) formations, as well as the occurrence in them (down even to the Cambrian) of rolled and worn fragments of Archæan schists and gneiss, with the distinctive characters of those rocks impressed upon them prior to their deposition in their present habitat, are pointed to as facts confirmatory of the above theory.

10. *On the Influence of Axial Rotation of the Earth on the Interior of its Crust.* *By* John Gunn, *F.G.S.*

The author stated that the effect produced by axial rotation upon the exterior surface of the earth in its primitive heated condition was well known, but the effect upon the interior crust had been overlooked; that it is incumbent upon him to prove that the condition of the earth beneath the exterior crust is such as to render axial rotation not merely a probable, but an indisputable agent of pressure upon the surrounding crust.

He proves that the crust is pliable, and that fluids exist beneath it at a depth of a few miles, not exceeding twenty, by the opinions of the most eminent scientists, and especially of Professor Prestwich, whom he quotes freely from, and refers to his able treatise, published in the 'Proceedings of the Royal Society,' on the Agency of Water in Volcanic Eruptions, with Observations on the Thickness of the Earth's Crust.

The author states that an abundance of facts prove the existence of such a fluid as would be subject to axial rotation, which, being *nil* at the centre of the globe, increases in power and velocity as it approaches the surface.

The question arises as to whether the power of rotation, which he humbly submits must exist, is not modified, and perhaps overcome, by centripetal gravitation. He refers, as a proof of the reality of its agency, to its coincidence with seismology. Diurnal rotation answers to the mildest form of seismology observed at Japan; annual and more extended rotations answer to the intermittent rumbling and shocks of earthquakes throughout the world; precessional perihelionic and the most extended revolutions allowed by astronomers answer to the changes induced by the inclination of the axis of the earth.

The author alluded to the tendency to revolve noticed by Mr. White and others in some buildings at Colchester during the shock lately experienced there as indicative of rotating power; also to the sequence and succession of earthquakes observed by Professor Sedgwick as travelling generally from east to west, and expressed his extreme diffidence in his own opinions, which nevertheless he was desirous to publish, as possibly there might be some reality in the effect he attributed to the axial rotation of the earth, notwithstanding it had been overlooked by writers on the subject.

Mr. Gunn is of opinion that the force of internal rotation, combined with that of earthquakes, has a bearing upon the ingenious theory of Dr. I. Evans, that the shifting of portions of the earth's crust may be due to it; also that many of the contortions of the Drift seen at Cromer, in Norfolk, and in the Eifel district, and at Corfu and many other places, are due to the same cause.

GEOLOGY SUB-SECTION.

1. *Notes on some of the Problems now being investigated by the Officers of the Geological Survey in the North of Ireland, chiefly in Co. Donegal.* *By* Professor E. Hull, *LL.D., F.R.S.*

The author stated that the investigations of the Survey were confined to the counties of Antrim and Donegal; and, restricting his observations to the latter, he said the chief problem was whether or not there were two great series of metamorphic rocks unconformable to each other, the older referable to the Archæan age, the newer to the Lower Silurian.

Some reference was made to the great faults and foldings of these beds, which were stated to range generally in N.N.E. and S.S.W. lines. It was considered that the granites might belong to at least two periods—the intrusive being distinct both in age and structure from the metamorphic granite and gneiss. Other points noticed were the occurrence of numerous basaltic dykes, probably of Tertiary age, traversing the gneissose rocks; and the marginal representatives of the Lower Carboniferous period.

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2. *Notes on the Crystalline Schists of Ireland.*
By C. CALLAWAY, *D.Sc., M.A., F.G.S.*

The author gives a summary of results obtained by a preliminary survey of the principal areas of Irish metamorphic rocks, viz.—

1. Donegal, including parts of the adjacent counties of Londonderry and Tyrone.

2. Connemara, extending the term to cover the region lying between Westport, co. Mayo, and the granitic mass west of the town of Galway.

3. The south-eastern corner of the county of Wexford.

In each of these areas the following facts were observed:—

(*a*) A series of hypometamorphic rocks, consisting typically of fine-grained schists, altered grits, and quartzites. A clastic structure is more or less distinct in the three areas, but is least evident in Connemara.

(*b*) A group of highly crystalline schists, displaying no trace of an original sedimentary origin, dipping as if it passed below the hypometamorphic rocks. At Wexford there are true gneisses. In Connemara the rocks are less felspathic, the chief types being quartzose gneiss, quartz-schist, mica-schist, hornblende-schist, quartzite, and crystalline limestone. This description will also apply to Donegal.

(*c*) Granite, underlying (*b*), and in Connemara and Donegal clearly intrusive.

The author urges that this analogy is not due to the metamorphic action of the granite; for—

1. The mineral characters apparent in the schists adjacent to the granite are uniformly distributed through the lower series from bottom to top.

2. The evidence collected is hostile to the view that this lower series ever graduates into the upper.

It is concluded that the balance of proof is in favour of the Archæan age of the bulk of the Irish schists.

1. In the Wexford district the schists are thrown against Cambrian and Ordovician rocks by faults, and do not pass into them in the localities alleged by the Irish Survey.

2. In Connemara conglomerates of Llandovery age contain large rounded fragments, not only of the older schistose series, but also of its intrusive igneous rocks.

3. In the Ulster region the metamorphic area is separated from the Ordovician rocks of Pomeroy by a ridge of granite and diorite three miles in breadth.

The lithological analogies between the Irish schists and the Archæan rocks of Anglesey and other British metamorphic districts are also of weight in the argument.

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3. *The Ordovician Rocks of Shropshire.*
By Professor C. LAPWORTH, *LL.D., F.G.S.*

In this paper the author gave a brief review of the history of discovery and opinion respecting the Lower Palæozoic rocks of Wales and the west of England, and pointed out that the results developed of late years by British and foreign geologists made it clearly evident that Murchison's Silurian system, as defined in the later editions of 'Siluria,' was in reality composed of three distinct geological systems, and that of these three the only one which belonged to him by right of discovery and correct description was the so-called Upper Silurian, which was therefore the only true *Silurian System.* The lowest known fossiliferous system (the Primordial Silurian of Barrande) was not discovered by Murchison, but by Sedgwick, who regarded it as the lower half of his own *Cambrian System,* and it ought, as a matter of justice and convenience, to retain that name only. The intermediate system (claimed as Lower Silurian by Murchison, and as Upper Cambrian by Sedgwick) belonged to neither, for its life-types are wholly distinct from those of the true Cambrian below and of the true Silurian above. This distinction must be recognised by a distinct title. The Silurian was named by Murchison after the ancient British tribe of the *Silures,* who inhabited South Wales and Central Shropshire, where its rocks attain their fullest development. The rocks of the disputed intermediate system, however, are most fully developed in North Wales—the land of the equally ancient tribe of the *Ordovices.* The author had proposed, in 1879, that this middle system should be entitled the *Ordovician System,* after this old tribe, and the name is gradually coming into use among geologists.

During the last few years the sequence and fossils of the Ordovician strata of Shropshire have been studied in detail by the author; and their igneous rocks, both interbedded and intrusive, have been worked out by Mr. W. Watts. A general summary of his own conclusions was communicated by the author, and illustrated by maps, sections, and lists of characteristic fossils.

Ordovician strata occur in two distinct districts in Shropshire, in the district of Shelve and Corndon, to the west of the Longmynd, and in the Caradoc district, to the east of that range. In both districts these strata are overlain unconformably by the basement beds of the Silurian, which rest transgressively upon every zone of the Ordovician in turn.

In the Shelve and Corndon district, the Ordovician rocks repose at once upon the highest known strata of the local Cambrian, and are arranged in the following (ascending) order:—

SHELVE SERIES—

(*a*) *Stiper Group,* consisting of the well-known Stiper quartzites and their associated strata.

(*b*) *Ladywell Group,* composed of the dark shales and flagstones of Mytton, Ladywell, and Hyssington, with *Dichograptidæ* and *Ogygia Selwynii,* &c.

(*c*) *Stapeley Volcanic Group*—Andesitic lavas, ashes, and interbedded shales.

MEADOWTOWN SERIES—

(*a*) *Weston Group of Grits,* flagstones, and dark shales.

(*b*) *Middleton Group,* composed of dark shales with *Didy. Murchisoni,* and calcareous flagstones with *Ogygia Buchii* and *Asaphus tyrannus.*

(*c*) *Rorrington Group* of intensely black shales with *Cœnograptus* and *Leptograptus.*

CHIRBURY SERIES—

(*a*) *Aldress Group,* composed of the *Spy Wood* calcareous *grit,* and the *Aldress* Graptolithic shale.

(*b*) *Marrington Group,* including the *Hagley* volcanic ashes and shales, and the *Whittery* ashes and overlying shales.

The only Ordovician rocks occurring east of the Longmynd are those forming the local *Caradoc Series* of the author (the Caradoc formation of geologists). The basement beds of this series rest unconformably upon all the older rocks of the district—upon the so-called Uriconian, Longmyndian, Wrekin quartzite, and Shineton shales—and its component zones are each covered up unconformably in turn by the basement beds of the Silurian. This isolated Ordovician series is composed of the following members:—

CARADOC SERIES—

(*a*) *Hoar Edge* conglomerate, grits, and limestone.

(*b*) *Harnage Shales.*

(*c*) *Chatwall Sandstone.*

(*d*) *Longville Flags.*

(*e*) *Onny,* or *Trinucleus Shales.*

The Shelve series answers generally to the strata commonly designated *Arenig*; the Meadowtown series includes the typical members of Murchison's *Llandeilo*; and the Chirbury and Caradoc series correspond broadly to Sedgwick's *Bala* formation of North Wales.

Some of the most characteristic fossils of each of the Ordovician subformations and zones were given, and it was shown how naturally the physical and palæontological sequence agrees with that of the corresponding Ordovician rocks of Britain and Europe. The peculiar physical conditions of the Shropshire area in Ordovician times, as indicated by the very different lithological characters of the strata upon the opposite sides of the Longmynd, was pointed out; the evidences for the geological horizons and relationships of the volcanic rocks indicated in outline, and the known facts respecting the folding and faulting, and pre-Silurian erosion of the Ordovician rocks briefly referred to. In conclusion, it was pointed out that the clearness and simplicity of the sequence, and the highly fossiliferous nature of its strata, render it tolerably certain that this Shropshire succession will form the general standard to which all other British Ordovician strata must ultimately be referred.

4. *On the Silurian Rocks of North Wales.*
By Professor T. M'Kenny Hughes, *M.A., F.G.S.*

The author begins by describing some sections in the Silurian rocks of North Wales. Some of them are in the lower part, some in higher beds. He gives lists of fossils from the various horizons in each. He then, by means of these and by what he calls syntelism, that is, the occurrence of similar sequences of beds of the same characters, lithological or other, points out the corresponding parts of the various sections described.

He then does the same for the Silurian of the eastern borders of the Lake district, and, having in this manner constructed a vertical section of each, compares the two districts and shows that there is an identical series in each, with all the important zones of one represented in the other, except that in the part of North Wales which he has worked out he has not yet detected beds as high as the newer part of the series in the Lake district.

5. *Notes on some Sections in the Arenig Series of North Wales and the Lake District.* *By* Professor T. M'Kenny Hughes, *M.A., F.G.S.*

In this paper the author describes a number of sections across the Arenig series in different parts of England and Wales, and endeavours to explain some apparent discrepancies in what is generally a remarkably constant set of beds.

He starts with the Portmadoc section, where he considers that the chief differences of opinion have arisen from mistakes in the explanation of the geological structure of the district, especially from the wrong identification of some grit bands on opposite sides of important faults.

Following the series to the north he shows that, although they vary in thickness, the principal zones are still represented near Carnarvon; and, discussing the question of the unconformity of these beds on the Lower Cambrian, he points out that the Lower Cambrian rocks are seen to vary so much both in character and thickness within short distances in the neighbourhood of the existing outcrop of the Archæan that any argument founded upon their thinning-out or their different texture must be received with distrust in an area where they are known to have been deposited on the flanks of mountain ranges of Pre-Cambrian age.

He then describes some localities in the Lake district where the occurrence of the same zones has been determined, and explains by overlap, rather than unconformity, the difficulties, palæontological and stratigraphical, which have arisen in the interpretation of those areas.

6. *On the Lower Palæozoic Rocks near Settle.*[1]
By J. E. Marr, *M.A., F.G.S.*

The sections have been described by Prof. Hughes ('Geol. Mag.' vol. iv.) and by myself ('Proc. York Geol. and Poly. Soc. N. S.' vol. vii.)

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[1] Printed in full in the *Geol. Mag.* Dec. 3, vol. iv. p. 35, 1887.

The following gives the results of further work, the beds being enumerated in ascending order:—

1. *Bala beds* = zone of *Dicellograptus anceps* (Nich.), containing besides this fossil *Diplograptus cf. pristis* (His.), *Trinucleus seticornis* (His.), *Dindymene ornata* (Linn. ?), *Cybele Loveni*, (Linn.), &c.

These beds show resemblances to Swedish Trinucleus shales.

2. *Stockdale Shales.* Beds of this age are a conglomerate, succeeded by a few inches of leaden blue shales, and four inches of calcareous rock with *Phacops elegans*, &c. The supposed pale shales formerly described are weathered beds of the next series.

3. *Lower Coniston Flags*, zone of *Monograptus priodon*, with *M. personatus* (Tullb. ?), and *Retiolites Geinitzianus* (Barr.)

4. *Austwick Pits*, apparently unfossiliferous.

5. *Upper Coniston Flags*, seen at Studrigg, and in Arco wood, Combes, and Dryrigg quarries. Zone of *Monograptus colonus* (Barr.) contains also *M. bohemicus*, (Barr.) and *M. Rœmeri* (Barr.), with numerous other fossils.

The succession is quite similar to that in the Lake District and elsewhere, but the Birkhill graptolitic fauna is entirely absent, and the conglomerate and *Phacops elegans* zone perhaps represent only the upper part of the Stockdale shales (Pale slates).

7. *Note on a Bed of Red Chalk in the Lower Chalk of Suffolk.*[1]

By A. J. Jukes-Browne, *B.A., F.G.S.*

The section exposing this stratum was discovered during an excursion made last June by Mr. W. Hill, F.G.S., and the author. It occurs in a quarry near West Row Ferry, about two miles west of Mildenhall; here a band of red marly chalk is seen near the entrance, dipping westward at a low angle, but soon becoming horizontal and running along the whole face of the quarry.

As seen in the centre of the quarry, the band consists of marly chalk, which is brick red at the top, pink in the middle, with a base of grey marly chalk containing hard lumps or nodules; the whole being about 5 feet thick, and resting on a bed of hard nodular grey chalk, below which alternating beds of hard and softer grey chalk are seen for 14 feet.

The quarry lies between the outcrops of the Totternhoe Stone and the Melbourn Rock, and is opened in a shallow synclinal trough, so that there must be a second outcrop with an easterly dip along a line nearer to Mildenhall, but of this no indication was found. The horizon of the red band is considered to be about the centre of the zone of *Holaster subglobosus*, and to be at least 100 feet above the base of the chalk marl. It is clear, therefore, that it has no connection whatever with the red rock which forms the base of the chalk at Hunstanton and in Lincolnshire.

It is well known, however, that the Lower Chalk of Lincolnshire contains two other bands of red chalk, and the author's examination of this district for the Geological Survey enables him to compare the Suffolk and Lincolnshire sections in detail. The West Row bed closely resembles the lower of the two red bands which are seen in the quarries near Louth, and as this occurs very nearly on the same horizon, he has little hesitation in correlating them with one another as homotaxial beds, though they may not be identical, because they do not appear to be continuous across the intervening space in Norfolk and Lincolnshire.

No other exposure of this red chalk was found in Suffolk, and in the north of that county the whole of the Lower Chalk lies beneath the Fens. It is brought up again by a fault on the north side of the Brandon River, and the outcrop of the same red chalk was seen in the bank of a dry pond at Feltwell St. Mary, in Norfolk, so that the band is in all probability continuous between Mildenhall and Feltwell.

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[1] Published in the *Geol. Mag.* Dec. 3, vol. iv. p. 24, 1887.

8. *On Manganese Mining in Merionethshire.*
By C. Le Neve Foster, *D.Sc.*

Manganese ore is now being worked in the Cambrian rocks at several places near Barmouth and Harlech. It occurs in the form of a bed varying from a few inches to 4 feet in thickness; the average thickness is 18 inches to 2 feet. The undecomposed ore contains the manganese in the form of carbonate, with a small proportion of silicate; but at the outcrop it is changed into a hydrated black oxide. Some of the outcrops of the manganese bed are erroneously marked on the geological survey maps as mineral veins, though Sir Andrew Ramsay was of opinion that the deposits were not true lodes. Recent workings show plainly that the deposits are truly stratified beds, or possibly various outcrops of one and the same bed, extending over a considerable area.

The ore contains from 20 to 35 per cent. of metallic manganese, and is despatched to Flintshire and Lancashire for the manufacture of ferro-manganese. The new Merionethshire mines are the first instance of workings for carbonate of manganese in the British Isles.

9. *On the Exploration of Raygill Fissure, in Lothersdale, Yorkshire.*
By James W. Davis, *F.G.S.*—See Reports, p. 469.

WEDNESDAY, SEPTEMBER 8.

The following Papers and Reports were read:—

1. *On the Basalt of Rowley Regis.* *By* C. Beale.

The basalt of Rowley Regis appears at the surface as an irregular, roughly triangular mass, having the base (rather more than one mile and a half wide) towards the north, and with a length of about two miles and a quarter. Its thickness varies much; in quarries the exposed face of rock amounts to 150 feet; at Rowley Hill Colliery it was about 300 feet thick. The rock also varies much in structure; it is divided by layers of 'rotch,' or decomposed basalt; the lower beds of the solid rock are fine-grained, those above are often more coarsely crystalline.

2. *On the Mineral District of Western Shropshire.*
By C. J. Woodward, *B.Sc.*

The minerals of Western Shropshire occur in the Llandeilo Flags, which, as will be seen by reference to the ordnance map, occupy a patch of country, of a somewhat pear-shaped section, the base of which is to the south-west, and the narrow portion to the north-east. In the flags occur patches of the so-called greenstone of the survey, and there are numerous bands of felspathic ash, the outcrop of which has a general direction of north-east and south-west. The mineral lodes run generally east and west, in many cases crossing the felspathic bands.

Many mines have been opened in the district, but at the present time only three are worked, viz., Roman Gravels, Snailbeach, and Wotherton; the last named is a barytes mine, and the two former are lead mines. Some years ago, in one of the levels of Snailbeach mine, were found extremely fine rhombs of violet and pink calcite, with brilliant crystals of quartz, blende, galena, and pyrites. These fine showy crystals are now scarce, but some examples are preserved in the office of the mine. The galena commonly shows faces of the octahedron and cube, and occurs, or did occur, in masses of some hundredweights. The Roman Gravels mine yields galena and blende, but principally in the massive form. At some of the disused mines are to be found fine crystals of blende, not only of the usual dark colour, but also in small crystals of an orange red, and still more rarely of a light yellow colour. Barytes occurs somewhat plentifully at Snailbeach, and Witherite is also met with.

The vein of barytes at Wotherton has been worked for sixty years. Mr. W. Yelland, who had charge of the mine a few years ago, has supplied me with the following particulars:—The lode is in some places upwards of twenty feet wide, and is divided into two parts by a vein of greenstone, technically termed a 'horse' or rider. The rider is traversed by narrow bands of barytes. In some parts of the lode the rider disappears altogether, or is very narrow. A boss of greenstone projects from the foot wall, and from this issue bands of stone traversing the lode in an oblique direction, until they come in contact with the hanging wall.

Cavities containing crystals occur in the lode, the cavities being filled with fine clay of a bluish tint. Proceeding from one of the cavities, which was carefully examined, were two thin fissures, also containing clay, and from which on tapping water ran out. The crystals just referred to by Mr. Yelland are particularly clear, and exhibit many crystallographic forms. Mr. H. ~~S~~. Miers, of the British Museum, has examined these crystals ('Nature,' xxix. p. 29), and notes the following forms: 101, 012, 110, 014, 011, 100, 010, 001, 412, 212, 111, 232, 432, 214, 112, 034, besides two doubtful planes of the complicated symbols 15.1.15 and 19.1.18.

Specimens illustrating the author's remarks were lent by Messrs. Waters and Son, of Shrewsbury, by Mr. Dennis, Managing Director of the Snailbeach Mine, and also by Mr. Job, of the same mine. These, together with others sent by Mr. Jasper Moore, M.P., have been placed in the Natural History Room of the Exhibition for examination.

3. *The Anorthosite Rocks of Canada.* By FRANK D. ADAMS.

This series of rocks has also been called the Upper Laurentian or Norian series. The name anorthosite is perhaps preferable, as it refers to their distinguishing characteristic as compared with the orthoclase rocks of the Lower Laurentian, viz. the predominance in them of plagioclase or anorthose felspar. These rocks form detached areas in the great Laurentian districts, and bear a strong resemblance in part to the gabros and gabrodiorites of Scandinavia, and in part to the labradorite rock of the same country. It is, however, by no means certain that the rocks of the two countries are of the same age. At least nine of these areas are now known to exist in Canada, and there is also one in the State of New York. In addition to plagioclase, which generally predominates largely, these rocks contain rhombic and monoclinic pyroxenes (including augite, diallage, hypersthene, and probably enstatite), olivine, magnesia, mica, spinel (including both pleonaste and picotite), garnet, iron ores, pyrite, and apatite. Orthoclase is seldom or never found, except in veins cutting the anorthosite. The hornblende, mica, and pyroxenes are intimately associated and often intergrown, all of them sometimes being found in the same thin section. Garnet occurs sparingly, and generally near the contact of the anorthosite with the gneiss. When the olivine comes against plagioclase it is always bounded by a double concentric zone, the outer zone consisting of hornblende, and the inner, or that next to the olivine, consisting of a pyroxene. While the iron ores associated with the Lower Laurentian gneisses are generally free from titanium, those associated with the anorthosite rocks are always highly titaniferous; a fact which makes the study of these rocks a matter of considerable economic interest. The anorthosite varies a good deal in composition, some areas, for instance, being rich in olivine, while others are destitute of that mineral, and different portions of even the same area often showing wide differences in this respect. The rock also shows a good deal of variation in structure. It is rarely quite massive, frequently well foliated, but usually consists of a rather coarsely crystalline ground mass through which are scattered irregular strings and masses composed of iron ore, bisilicates, and mica, as well as larger porphyritic crystals of plagioclase. Even when it is tolerably constant in composition there is generally a great variation in size of grain, coarse and fine alternating in rude bands or rounded masses. In the case of some of the areas there can be but little doubt that the anorthosite is eruptive; in others, however, it seems to be interstratified with the Laurentian gneiss, and in one of them to merge imperceptibly into it. The original relations of the rocks are, of course, much obscured by the effects of subsequent heat and pressure. The evidence at present, however, seems to indicate that these anorthosites are the result of some kind of extravasation, which in those early times corresponded to what in modern times we call volcanic eruption.

4. *On a Diamantiferous Peridotite and the Genesis of the Diamond.*

By Professor H. Carvill Lewis, *M.A., F.G.S.*

The discovery of diamonds at Kimberley, South Africa, has proved to be a matter, not only of commercial, but of much geological interest. The conditions under which diamonds here occur are unlike those of any other known locality, and are worthy of special attention.

The first diamond found in South Africa was in 1867, when a large diamond was picked out of a lot of rolled pebbles gathered in the Orange River. This led to the 'river diggings' on the Orange and Vaal Rivers, which continue to the present time. In 1870, at which time some ten thousand persons had gathered along the banks of the Vaal, the news came of the discovery of diamonds at a point some fifteen miles away from the river, where the town of Kimberley now stands. These were the so-called 'dry diggings,' at first thought to be alluvial deposits, but now proved to be volcanic pipes of a highly interesting character. Four of these pipes or necks, all rich in diamonds and of similar geological structure, were found close together. They go down vertically to an unknown depth, penetrating the surrounding strata. The diamond-bearing material at first excavated was a crumbling yellowish earth, which at a depth of about fifty feet became harder and darker, finally acquiring a slaty blue or dark green colour and a greasy feel, resembling certain varieties of serpentine. This is the well-known 'blue ground' of the diamond miners. It is exposed to the sun for a short time, when it readily disintegrates, and is then washed for its diamonds. This 'blue ground' has now been penetrated to a depth of 600 feet, and is found to become harder and more rock-like as the depth increases.

Quite recently, both in the Kimberley and De Beers mines, the remarkable rock has been reached which forms the subject of the present paper.

The geological structure of the district and the mode of occurrence of the diamond has been well described by several observers. As Griesbach, Stow, Shaw, Rupert Jones, and others have shown, the diamond-bearing pipes penetrate strata of Carboniferous and Triassic age, the latter being known as the Karoo formation. The Karoo beds contain numerous interstratified sheets of dolerite and melaphyr, also of Triassic age, the whole reposing upon ancient mica schists and granites. The careful investigations of Mr. E. J. Dunn demonstrate that the diamond-bearing pipes enclose fragments of all these rocks, which fragments show signs of alteration by heat. Where the pipes adjoin the Karoo shales, the latter are bent sharply upwards, and the evidence is complete that the diamond-bearing rock is of volcanic origin and of post-Triassic age.

The diamonds in each of the four pipes have distinctive characters of their own, and are remarkable for the sharpness of their crystalline form (octahedrons and dodecahedrons), and for the absence of any signs of attrition. These facts taken in connection with the character of the 'blue ground' indicate, as Mr. Dunn has pointed out, that the latter is the original matrix of the diamond.

Maskelyne and Flight have studied the microscopical and chemical characters of the 'blue ground,' and have shown that it is a serpentinic substance containing bronzite, ilmenite, garnet, diallage, and 'vaalite' (an altered mica), and is probably an altered igneous rock, the decomposed character of the material examined preventing exact determinations of its nature. They showed that the diamonds were marked by etch figures analogous to those which Professor Gustav Rose had produced by the incipient combustion of diamonds, and that the 'blue ground' was essentially a silicate of magnesium impregnated with carbonates.

The 'blue ground' often contains such numerous fragments of carbonaceous shale as to resemble a breccia. Recent excavations have shown that large quantities of this shale surround the mines, and that they are so highly carbonaceous as to be combustible, smouldering for long periods when accidentally fired. Mr. Paterson states that it is at the outer portions of the pipes, where the 'blue ground' is most heavily charged with carbonaceous shale, that there is the richest yield of diamonds.

Mr. Dunn regards the 'blue ground' as a decomposed gabbro, while Mr. Hudleston, Professor Rupert Jones, and Mr. Davies regard it as a sort of volcanic mud. Mr. Hudleston considers that the action was hydrothermal rather than igneous, the diamonds being the result of the contact of steam and magnesian mud under pressure upon the carbonaceous shales, and likens the rock to a 'boiled plum-pudding.'

The earlier theories as to the origin of the diamond have, in the light of new facts, quite given way to the theory that the diamonds were formed in the matrix in which they lie, and that that matrix is in some way of volcanic origin, either in the form of mud, ashes, or lava.

The exact nature of this matrix becomes, therefore, a matter of great interest. The rocks now to be described are from the deeper portions of the De Beers mine, and were obtained through the courtesy of Mr. Hedley. They are quite fresh and less decomposed than any previously examined. Two varieties occur, the one diamantiferous, the other free from diamonds, and the lithological distinction between them is suggestive. The diamantiferous variety is crowded with included fragments of carbonaceous shale, while the non-diamantiferous variety is apparently free from all inclusions, and is a typical volcanic rock.

Both are dark, heavy, basic rocks, composed essentially of olivine, and belong to the group of peridotites. Both are of similar structure and composition, differing only in the presence or absence of inclusions. The rock consists mainly of olivine crystals lying porphyritically in a serpentinic ground-mass. The olivine is remarkably fresh, and occurs in crystals which are generally rounded by subsequent corrosion. The principal accessory minerals are biotite and enstatite. The biotite is in crystals, often more or less rounded, and sometimes surrounded by a thin black rim, due to corrosion. Similar black rims surround biotite in many basalts. The biotite crystals are usually twinned according to the base. The enstatite is clear and non-pleochroic. Garnet and ilmenite also occur, the latter often partly altered to leucoxene. All these minerals lie in the serpentinic base, originally olivine.

This rock appears to differ from any heretofore known, and may be described as a dunite porphyry or saxonite porphyry. The diamond-bearing portions often contain so many inclusions of shale as to resemble a breccia, and thus the lava passes by degrees into tuff or volcanic ash, which is also rich in diamonds, and is more readily decomposable than the denser lava.

It seems evident that the diamond-bearing pipes are true volcanic necks, composed of a very basic lava associated with a volcanic breccia and with tuff, and that the diamonds are secondary minerals produced by the reaction of this lava, with heat and pressure, on the carbonaceous shales in contact with and enveloped by it.

The researches of Zirkel, Bonney, Judd, and others, have brought to light many eruptive peridotites, and Daubrée has produced artificially one variety (lherzolite) by dry fusion. But this appears to be the first clear case of a peridotite volcano with peridotite ash.

Perhaps an analogous case is in Elliot County, Kentucky, where Mr. J. S. Diller has recently described an eruptive peridotite which contains the same accessory minerals as the peridotite of Kimberley, and also penetrates and encloses fragments of carboniferous shale, thus suggesting interesting possibilities.

5. *On the Metamorphosis of the Lizard Gabbros.*[1]

By J. J. H. Teall, *M.A.*, *F.G.S.*

After recapitulating the facts established by previous observers as to the mineralogical and structural characters of the Lizard gabbros, the author pointed

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[1] Published in full in the *Geol. Mag.* Dec. 3, vol. iii. p. 481, 1886.

out that these gabbros differ from those of the Tertiary volcanic district of the west of Scotland in being largely composed of saussurite and hornblende, and in frequently exhibiting a foliated structure. He described certain types of foliated gabbro under the terms *flaser-gabbro, augen-gabbro,* and gabbro-schist, and discussed the origin of the foliation. He concluded that it (the foliation) was the result of the deformation of the solid rock-masses by the intense mechanical forces that have acted upon the district, and he attributed the replacement of felspar and diallage by saussurite and hornblende in a great measure to the same agency.

6. *Introduction to the Monian System of Rocks.*

By Professor J. F. BLAKE, *M.A., F.G.S.*

It has already been recognised by various authors that there are in several parts of Wales a group of rocks which are older than the Cambrian system. Certain of them have received names such as Dimetian, Arvonian, Pebidian, but as a whole they have only been recognised as Pre-Cambrian or Archæan. They are best developed in the island of Anglesey, and a study of them in that region shows that they form a well-defined system, of quite equal importance to the Cambrian or Ordovician, and presenting very well marked and peculiar characters. It is proposed, therefore, to create for them a new 'system,' the 'Monian,' after the place of their development, which shall take its place below the Cambrian as the oldest series of stratified rocks, without being a full member of the great group known as Archæan. The system is divisible into two parts; the Lower is remarkable as presenting a transition from true crystalline gneisses into earthy slates, the Upper for the development of vast masses of volcanic débris, with infusions of quartz and calcite, and containing also as intrusive masses rocks of peculiar character which may be called 'Dimetite.' The rocks of St. David's belong exclusively to the Upper Monian.

7. *On the Igneous Rocks of Llyn Padarn, Yr Eifl, and Boduan.*

By Professor J. F. BLAKE, *M.A., F.G.S.*

These masses have been claimed as Pre-Cambrian, but the evidence obtainable on the north side of Llyn Padarn does not warrant this conclusion. Cambrian rocks are found to the west; no *remarkable* conglomerate lies between them and the quartz-felsite mass, but on the eastern side is one with enormous blocks of the felsite and of other, probably Cambrian, rocks. This is conterminous with the igneous mass rising into crags at Clegyr and Moel Tryfan. The felsite of Moel Gronw is a distinct and later outburst. The mass north of Llyn Padarn consists in ascending order of felsite, brecciated felsite, agglomerate, felsite of different character, agglomerate and ash, indicating an outburst to a level above the earlier deposited rocks, and therefore immediately exposed to denuding influences. It is believed, therefore, that this mass may be best interpreted as a submarine eruption in the middle of Cambrian times, *i.e.*, younger than the Cambrian rocks to the west, and older than the conglomerate which is locally derived from it, and also older than those slates which lie to the east. There is no other conglomerate comparable with this, and the outburst of Moel Gronw has no conglomerate on its western side.

The igneous rocks of Yr Eifl and Boduan come up in irregular masses and clearly overlie the Ordovician slates, after the manner of intrusive igneous rocks. They show a rather remarkable system of horizontal (columnar?) jointing, which gives them a very bedded aspect as seen from a distance, disappearing on closer examination and only affecting some part of the massif. The Boduan mass may be possibly contemporaneous, as the overlying slates are somewhat conglomeratic, but there is not the slightest evidence of either of these being either Cambrian or Pre-Cambrian in age. The case is different with the 'Rhos Hirwain syenite.'

8. *On an Accurate and Rapid Method of estimating the Silica in Igneous Rocks.* *By* J. H. PLAYER.—See Reports, p. 471.

9. *On a new Form of Clinometer.* *By* J. HOPKINSON, *F.L.S., F.G.S.*—See Section A, p. 557.

10. *On Concretions.* *By* H. B. STOCKS.

A concretion may be defined as a more or less spherical mass of rock-matter collected around some organic substance, or upon itself, to form a nodule.

Concretions occur in many rocks, and vary very much in their composition.

The following are examples:—

Hydraulic Limestones occur as concretions in the Lias and other formations; they are of a grey colour and very hard. They are used for the preparation of hydraulic cement.

Baum Pots are nodules occurring in the shale of the coal-measures; they are very much like hydraulic limestone in appearance, being hard and of a grey colour.

Coal Balls are thus named because they occur in the coal; they are of a brownish colour and nearly spherical.

Acrespire is a form of concretion occurring in the Millstone Grit. These acrespires are greyish or brownish in colour and very hard; some are of immense size.

Dolomite occurs as concretions in the compact magnesian limestone.

Flint occurs as concretions in a variety of shapes in the chalk.

Imatra Stones occur in a marly formation in Finland.

Sphærosiderite occurs as spherical masses on various iron ores.

Clay Ironstone occurs as concretions in the shales of the coal-measures; these concretions are round but flattened, and of a grey colour. This form of ironstone is the ore used at Lowmoor in the smelting for iron.

Limonite occurs in concretions in the chalk; some are formed by the oxidation of nodules of iron pyrites.

Iron Pyrites occur as concretions in the chalk; most of the concretions show a radiated structure.

Oxide of Manganese occurs as concretions on the bed of the Pacific. These nodules are forming at the present time. They generally enclose some fragment of a shell or bit of pumice as a nucleus.

Coprolites are concretions occurring in the greensand and other formations; some of them are the fossil dung of reptiles, but most of them are concretions.

Pseudocoprolites occur in the Crag; they resemble coprolites in composition.

As to the formation of these concretions little is at present known, and I wish to draw attention to the manganese nodules which are at present forming, and which, if examined, I am sure would throw light upon the subject.

11. *On a Scrobicularia Bed containing Human Bones, at Newton Abbot, Devonshire.* *By* W. PENGELLY, *F.R.S., F.G.S.*—See Section H, p. 841.

GEOLOGY SUB-SECTION.

1. *The Corndon Laccolites.* *By* W. W. WATTS, *M.A., F.G.S.*

The paper began with an account of two groups of ashes and lavas, of andesitic composition, which had been mapped by the author and Professor Lapworth in the neighbourhood of the Corndon Mountain, in Montgomeryshire. The lower of the two groups is of Upper Arenig, while the upper is of Llandeilo-Bala age. Each set strikes N.N.E. and S.S.W., and forms an important escarpment, while the upper set is folded over the central anticline of the district, and thrown again into a syncline between Mucklewick Hill and Pell Rhadley Hill. The major part of the paper was occupied by a description of the stratigraphy of the intrusive dolerites or diabases of the region, in which some new and striking features had been discovered.

These intrusive masses show, on the map, as large or small patches or as long dikes striking in the same direction as the sedimentary rocks. Quarry and other sections described clearly showed that these masses were not simple dikes or bosses of the kind usually depicted in the published sections of the district, but had altered sedimentary rocks resting conformably above and *below* them, so that in appearance they were lenticles bearing some resemblance to the Henry Mountain Laccolites described by Gilbert. Instead, however, of owing their position to conditions of simple hydrostatic equilibrium, these intrusions were shown to be intimately connected with the folding which the district had suffered, and to stand to it in the relation of effect rather than of cause. The Corndon and neighbouring Laccolites have been forced, by hydraulic pressure, into spaces formed in the summit of the main anticline, and were dammed down by the resisting mass of the rigid ash-beds above them, so that the rock was intruded into soft shales between the hard rocks of the Grit mine below, and the Stapeley (Upper Arenig) ash-beds above. In the Linley Laccolite the intrusion was partly defined by the same ash-beds, but, where the arch was broken, by the lower beds of the Silurian, while the Wilmington Laccolite was entirely defined by the Silurian beds, the diabase resting on the upturned edges of various members of the Ordovician sequence. These and the other examples displayed clearly that the whole of the intrusive rocks of the district might be reduced to one single system, being everywhere due to the effects of lateral pressure operating upon alternating beds of rigid and soft rocks, between and amongst which spaces, due principally to folding and secondarily to faulting, were produced, and into these hydraulic pressure forced the molten rock. Intrusion can no longer be regarded as a mere sporadic and meaningless phenomenon, but constitutes another volume of facts to speak for the extreme importance of lateral pressure in giving to a rock region many of its structures and phenomena; and when this is once clearly understood, it will acquire a new meaning in unravelling those portions of earth history of which the records are found in the present structure of the rocks.

In conclusion, the author thanked Professor Lapworth for suggesting many of these ideas to him, and for help in understanding the precise meaning of the evidence gathered. He also expressed his gratitude for a grant from the Royal Society in aid of the petrographical work.

2. *Fourth Report on the Fossil Phyllopoda of the Palæozoic Rocks.*—See Reports, p. 229.

3. *On the Discovery of* Diprotodon Australis *in Tropical Western Australia (Kimberley District). By* EDWARD T. HARDMAN, *F.R.G.S.I.*

To explain the extreme interest of this discovery it is necessary to recapitulate briefly the history of the animal.

Its remains, plentifully found in the south-eastern and eastern parts of Australia, prove that it was a gigantic marsupial, probably belonging to the Macropodidæ, or existing kangaroo family. Of immense size, its bulk was equal to that of a rhinoceros, or even of an elephant; the skull alone, as indicated by a specimen in the Natural History Department of the British Museum, being 3 feet long.

The head of the largest existing kangaroo is about 9 inches long, and his height, sitting erect, about 5 feet 6 inches. Arguing from proportions, therefore, it might be supposed that the diprotodon would in a similar posture be 18 feet high. However, though resembling in its dentition the living kangaroos, and, like them, herbivorous in its habits, its anatomy shows important differences. The hind legs were shorter and very thick, the fore limbs longer and capable of rotation. The anatomy of the foot differs from that of existing leaping kangaroos, and combines the character of that of the wombat with those of the Mylodon and Mastodon.[1] It is therefore apparently a connecting link between Macropus and Phascolomys.

Its characteristics have been fully described by Sir Richard Owen in many well-known works, and the chief interest attached to the present relic lies in its being the only one discovered in Western Australia, and, besides, further north, within the tropics, than any hitherto known of.

The first discovery of *Diprotodon* was made by Major—afterwards Sir—Thomas Mitchell (then Surveyor-General), in 1836, on the Bell River, a tributary of the Macquarie, and some 200 miles south-west of Sydney.[2] It was associated with other extinct marsupials in a breccia cave in the limestone, and was named by Owen *Diprotodon optatum,* since altered to *australis.*

The associated fossils were *Dasyurus laniarius* (or *Thylacoles*), *Macropus atlas, M. Titan, Phascolomys Mitchelli,* and other indeterminate species.

Diprotodon was subsequently found in many other parts of Eastern Australia; in the southern districts of New South Wales, at Murrumbidgee River, lat. 34° 30′ S., and many other places; in Queensland it was obtained in King's Creek; in the Darling Downs, and on the great dividing range of that district, in the Condamine River; and finally in Maryvale Creek, lat. 19° 30′ S; where it occurs in alluvial breccia, associated with other extinct marsupials and crocodiles' teeth.[3]

This was its furthest point north until the present discovery.

In Victoria its remains are found in many localities, one of the chief being near Mount Macedon, about forty miles from Melbourne.

Similar remains have been met with in South Australia, as at Welcome Springs, and at Hergott's Springs, 500 miles north of Adelaide.

This so far had been the known range of *Diprotodon.* It had never been heard of in Western Australia until in 1883 the author, then attached to an exploring and surveying expedition in Kimberley as Government Geologist, was fortunate enough to find a single bone, which has been pronounced by eminent palæontologists[4] to be the head of the femur of the extinct kangaroo.

The specimen was found in the bed of the Lennard River, in lat. 17° 20′ S., and long. 125° E., and about 80 miles from King Sound. This river cuts a deep cañon through a 'barrier range' of limestone, at this point two miles wide; and the cliffs above the river-bed rise to a height of 300 to 400 feet. The range is named Napier Range, and the gorge, from the difficulties to passage it presents, was called the 'Devil's Pass.' Just below the western entrance of the gorge the bone was picked up (a large coloured photograph was exhibited showing the scene). The rocks are Carboniferous limestone, honeycombed by caves, and the author considers that the bone may have been washed during heavy floods out of one of these. Owing to want of provisions and the bad condition of his horses, the author could not remain to examine these caves, but was reluctantly compelled to turn back.

The discovery shows that the animal had an immense range, both of geographical and climatal *habitat,* being equally able to sustain the severe cold at times of the southern and mountainous districts and the intense heat of the western tropical region.

Photographs of the bone were exhibited; the bone itself was in the Colonial and Indian Exhibition.

4. *Twelfth Report on the Circulation of Underground Waters.*—See Reports, p. 235.

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[1] Professor Owen's Report on Extinct Mammals of Australia, *Rep. British Assoc.* 1844, p. 23 *et seq.*

[2] *Three Expeditions into the Interior of Eastern Australia,* Major T. L. Mitchell, vol. ii. p. 359 *et seq.*

[3] R. Daintree, 'Geology of Queensland, *Q.J.G.S.* xxviii. p. 274.

[4] Prof. McCoy, Dr. Woodward, and R. Etheridge, jun.

5. *On the Stratigraphical Position of the Salt Measures of South Durham.* *By* Professor G. A. LEBOUR, *M.A.*, *F.G.S.*

The beds above the main mass of the magnesian limestone in Durham are seldom exposed at the surface, as the south of the country is covered by a thick spread of drift. The presence of salt deposits having, however, been proved some years ago in the adjoining part of Yorkshire near Middlesbrough, several borings for working them in the form of brine were soon put down in the flat country between the Tees and the coast south of Seaton Carew. There are now altogether some fifteen or sixteen such borings, most of which have reached beds of salt at depths varying from 600 feet to over 1,200 feet. These have thrown much light upon the rocks, hitherto scarcely known in this part of England, which lie between the Rhætic and the great Permian magnesian limestone of Durham. The author exhibited sections of these beds, and gave reasons for suggesting that much of the salt-measures of this district is probably the representative of the Upper or *Rauchwacke* Permian of Germany.

The following table summarises fairly the classification tentatively suggested by the author:—

Avicula contorta beds (proved in Eston shaft and boring)	Rhætic.
7. Red and green marls, with gypsum (known only south of the Tees)	Upper Trias.
6. Red sandstone	
Unconformity (?)	
5. Red sandstones and marls	(? Lower) Trias.
Unconformity (?)	
4. Red marly sandstones, marls, with lenticular beds of anhydrite, gypsum, and salt, and fœtid limestone in variable bands towards the base	Upper Permian. (Rauchwacke).
3. Main magnesian limestone	Middle Permian.
2. Marl slate with fish-bed	
1. Yellow sands	Lower Permian.
Unconformity.	
CARBONIFEROUS ROCKS.	

6. *On the Carboniferous Limestone of the North of Flintshire.*[1] *By* G. H. MORTON, *F.G.S.*

In the year 1870 I described before the Association the subdivisions into which the carboniferous limestone of North Wales is naturally divided by clear lithological characters, and in 1877 more fully described the subdivisions of the formation as they occur in the Eglwyseg ridge, near Llangollen. Since then the whole of Flintshire has been examined, and the original classification found to extend to the sea-coast at the north of the county. Although the subdivisions are not piled up, one over the other, in a precipitous outcrop, the succession is as clearly shown between Prestatyn and Meliden as at Llanymynech and Llangollen, and the uniform character of each subdivision along the intervening forty-four miles of country is remarkable.

The following four subdivisions of the carboniferous limestone are all well exposed in a fine mural section three and a-quarter miles in length, from Castell Prestatyn on the north to the end of Moel Hiraddug on the south, and occur in the following descending order:—

Upper Black Limestone.—A black, fine-grained, thin-bedded limestone, containing very few fossils, but including *Posidomya Becheri* and the remains of many plants. Thickness, 200 feet.

Upper Grey Limestone.—A dark-grey thin-bedded limestone with thin seams

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[1] Published *in extenso* in the *Proceedings of the Liverpool Geological Society*, vol. v. p. 175.

of interstratified shale, containing numerous fossils, including *Productus giganteus* and corals. Thickness, 500 feet.

Middle White Limestone.—A white or light-grey thick-bedded limestone, containing very few fossils. Thickness, 600 feet.

Lower Brown Limestone.—A brown or dark-grey irregularly-bedded limestone, containing few fossils, but with interstratified shales at the base of the subdivision, which contain the remains of plants. Thickness, 400 feet.

The total thickness of these four subdivisions, forming the carboniferous limestone of the north of Flintshire, is 1,700 feet, which is much greater than anywhere else in North Wales.

Although the line of the section is nearly north and south, the average dip of the strata is about 14° to the E.N.E. at Coed-yr-Esgob, N.W. at Bryniau, and N.E.N. at Moel Hiraddug, so that it is greater than it appears to be in the section. The highest subdivision, the Upper Black Limestone, occurs at the north end, and the Upper Grey Limestone crops out from under it and extends to Nant-yr-Ogof, where there is a considerable fault, which brings up the top of the Lower Brown and the base of the Middle White Limestone. From the fault the Middle White extends three-quarters of a mile, when the Lower Brown Limestone crops out, continues some distance and forms the conspicuous hill, Moel Hiraddug, on the top of which the lower beds of the Middle White Limestone are again exposed.

Along the west and parallel with the section there are two great faults, known as the Prestatyn fault and the Vale of Clwyd fault, and on the western side of the former a bare limestone hill, Graig-fawr, rises to an elevation of 500 feet and presents a grand exposure of the Middle White Limestone, which is 600 feet in thickness. Numerous fossils occur at the north end of Graig-fawr, and a greater number has been obtained there than from the Middle White Limestone anywhere else.

On the west of the carboniferous limestone shown along the line of section several faults, including the two already referred to, have thrown down the limestone beneath the level of the sea, and the Lower Coal-measures have been proved to occur at Meliden and Dyserth, beneath a covering of drift. In one of the recent 'Memoirs of the Geological Survey,' by Mr. A. Strahan, M.A., F.G.S., a full description of the geology—*Explanation of Quarter-sheet* 79 *N.W.*—will be found, with all the details of the drift and underlying strata.

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7. *On the Classification of the Carboniferous Limestone Series: Northumbrian Type. By* HUGH MILLER, *F.R.S.E., F.G.S.*

It is now twenty years since the late George Tate, of Alnwick, published a completed classification for the Carboniferous Limestone Series of North Northumberland. For more than half that period this classification has been set aside as of a merely local value. It will be the endeavour of this paper to claim for it its true place.

Tate's classification may be summarised as in the following table:—

CARBONIFEROUS LIMESTONE SERIES OF NORTH NORTHUMBERLAND: TATE'S CLASSIFICATION, 1856–1868.

Upper or Calcareous group:—From the base of the Millstone Grit to the Dun Limestone—'the lowest limestone of any value.' Good workable limestones, interstratified with alternations of sandstone, shale, and coal; large numbers of marine organisms connected with the calcareous strata. Thickness, about 1,700 feet.

Lower or Carbonaceous group:—From the base of the Dun Limestone to the top of the Tuedian group. Marked by the number, thickness, and quality of its coal seams; limestones thin and generally impure; marine organisms in fewer numbers. Thickness, 900 feet.

Tuedian group:—Beds intermediate between the productal and encrinital limestones and the Upper Old Red Sandstone. Distinguished by coloured shales, by thin, argillaceous and cherty or magnesian limestones, and by the rarity of encrinites and Brachiopoda; some Stigmarian layers, but no beds of coal. Thickness, about 1,000 feet. In one of his papers Tate distinguishes an upper group of 'Tuedian grits.'

[*Upper Old Red Sandstone.* Local conglomerates, 'more connected with the Carboniferous than with the Devonian.' No *Stigmaria.*]

In 1875, Tate's classification of the upper divisions of the series was set aside by Professor Lebour in favour of an arrangement more 'natural and convenient.' Professor Lebour abolished the distinction between the *Calcareous* and *Carbonaceous* groups, and threw them together—along with the Tuedian grits of some parts of the county—into a single large series, to which he applied the term *Bernician.* It is based on the assumption that Tate's two divisions either do not exist in nature or do not persist throughout the county.

CARBONIFEROUS LIMESTONE SERIES IN NORTHUMBERLAND: LEBOUR'S CLASSIFICATION, 1875–1886.

Bernician	A large group—which 'cannot be divided in any natural manner'—of limestones, grits and sandstones, shales, and coals; lower limit, 'a variable one,' not keeping to any one horizon; thickness, in North Northumberland, 2,600 feet (after Tate); in Mid Northumberland, a maximum of 'at least 8,000 feet'; in South Northumberland, 2,500 feet (after Westgarth Foster).
Tuedian	As in Tate's classification, but without definition at its upper limit.
Basement Conglomerates	Local.

It has never been contended, the author believes, that Tate's prior classification is not applicable to North Northumberland. It is now, as a result of the labours of the Geological Survey, found to be equally applicable to South Northumberland, and to the whole of what deserves to be distinguished as the *Northumbrian Type* of the Carboniferous Limestone series—in contrast with the Yorkshire type and Scottish type. It is amplified in some not very important details, as set forth in the following table:—

CARBONIFEROUS LIMESTONE SERIES—NORTHUMBRIAN TYPE (Northumberland, East Cumberland, and Liddisdale.

		Feet
Upper Limestone Series.	*Felltop or Upper Calcareous Division:—From the Millstone Grit to the zone of the Great Limestone.* Sandstones and shales; one or more beds of marine limestone, including the Felltop Limestone; some coals	350–1,200
	Calcareous Division:—From the great Limestone to the bottom of the Dun or Redesdale Limestone. Many beds of good marine limestone; sandstones and shales; coals	1,300–2,500
Lower Limestone Series.	*Carbonaceous Division (Scremerston Beds of North Northumberland:—From the Dun or Redesdale Limestone to Tate's 'Tuedian Grits.'* Strata prevalently carbonaceous; limestones chiefly thin, many of them containing vegetable matter; coals	800–2,500
	Tuedian Division:—Upper Tuedian or Fell Sandstone Group, the 'Tuedian Grits' of Tate:—From the Carbonaceous Group to the Cement-Limestones. Great belt of massive grits (Tweedmouth, Chillingham, the Simonside and Harbottle Hills, the Peel and the Bewcastle Fells). Shales greenish and reddish as well as carbonaceous-grey; coals rare, thin, or absent .	500–1,600
	Lower Tuedian or Cement-Limestone Group:—From the base of the grits downwards. Cement-stone bands passing (Rothbury, Bewcastle) into limestones; coals very rare; generally some coloration of the shales and sandstones	500–1,500
	Basement Conglomerates (Upper Old Red Sandstone); local	—

In conclusion, Tate's admirable classification presents us with well-defined types, generally recognisable almost at a glance by the practised eye, and bounded by lines as good probably as from the complications of the structure (faults, obscurities, &c.) could be expected. His names, if not high-sounding, are at least sufficiently expressive.

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8. *The Culm Measures of Devonshire.*[1] *By* W. A. E. USSHER, *F.G.S.*

The late Professor Phillips contributed the most considerable and important part of the literature of this subject in 'The Palæozoic Fossils of Somerset, Devon, and Cornwall,' a work from which several quotations are given; Mr. T. M. Hall and other writers are cited as to the occurrence of anthracite in the neighbourhood of Bideford, &c.

After having observed the Culm Measures on the borders of the Triassic area for some years, the author was enabled to study them in detail during the years 1876 and 1877, his researches being confined to the area east of a line between Hartland Point and Okehampton. In this area he discovered that the Culm Measures were broadly divisible into three groups, which, however, owing to the passage of one group into another, to local intercalations, and to the innumerable flexures and disturbances by which the main synclinal structure is obscured, cannot be separated by hard and fast lines—at least, on the one-inch scale.

The following is the general classification given:—

Culm Measures.	Upper.	Eggesford type	Hard, rather thick, even bedded grey grits, and dark grey shales and slaty beds.
	Middle.	Morchard type	Thick-bedded, grey, greenish, and reddish sandy grits, associated with marly splitting shales in places; irregular grits, slates, and shales.
	Lower.		Dark grey shales with grit-beds, generally thin and even, slaty and splintery shales (St. David's, Exeter, type), even-bedded cherty shales and grits (Coddon Hill type), limestones and dark grey shales.

Some leading characters in each group are then pointed out. The Lower Culm Measures are assigned a breadth of from two to three miles on their northern outcrop, and of about fifteen miles in the southern area on each side of Dartmoor. The impersistent character of the limestones of this series, and the frequent absence of their most marked characters from the beds on the Coddon Hill horizon, is also mentioned. The apparent passage of the Culm Measures into Devonian in the north is contrasted with the seeming unconformity between these strata in the south.

The Middle Culm Measures attain a breadth of about four miles in their northern, and from four to five in their southern outcrop. Some structural peculiarities in this series, and a part of the coast section between Portledge Mouth and Westward Ho, are briefly described.

The Upper Culm Measures are said to form a band of from six to seven miles in width. The even character of the bedding and the interstratifications of dark grey shales render the contortions of this series on the coast between Portledge Mouth and Clovelly very apparent.

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9. *Denudation and Deposition by the Agency of Waves experimentally considered.—By* A. R. HUNT, *F.G.S.*

The author, after referring to the importance of waves as agents of denudation, said that endless cases might be cited in proof of the conflict of authority as to the depth at which wave-action practically affected the sea-bottom. Until this

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[1] Printed in full in the *Geol. Mag.* Dec. 3, vol. iv. p. 10, 1887.

question be settled, no progress can be made in assigning to waves their proper position among agents of denudation and deposition.

The author said that much of the prevailing uncertainty arose from the fact that waves of oscillation have not been studied experimentally, and that Mr. Scott Russell's waves of translation, created by admitting a fresh volume of water into a tank, are not analogous to sea waves in any part of the passage of the latter from deep water to the shore. One proof of this is that the ordinary sea wave of oscillation is always preceded by a depression, and plunges seaward of the margin of repose of the water; whereas one characteristic of Mr. Russell's wave of translation is that its surface is wholly raised above the level of repose of the fluid.

The author showed by diagrams that experimental oscillating waves plunged further and further from the margin of repose as the incline of the beach was reduced, and that they showed no tendency to turn into waves of translation.

The subject was then considered from four points of view, viz., observation, direct and indirect; experiment; and theory.

(1) *Direct Observation.*—As one of innumerable instances of bottom disturbance, the author referred to slate shingle dredged 2,600 yards east of Hope's Nose in Torbay (in 14 fathoms), together with a specimen of the sluggish and helpless mollusc *Pleurobranchus membranaceus.* The shingle was derived from the northern shores of Torbay, and proved that in heavy weather the shingle occasionally travelled into deep water. The mollusc proved that in ordinary weather the tidal currents exerted no appreciable disturbing action.

(2) *Indirect Observation.*—The forms of marine fauna exposed to wave currents are specially adapted to withstand such action.

(3) *Experimental.*—Artificial oscillating waves made to roll over glass plates disturb flocculent matter on the plates at a depth approaching half the wave-length.

(4) *Theoretical.*—According to theory the disturbance in deep water is very slight at half the wave-length, but rapidly increases on approaching the surface. The evidence of rolling action at forty fathoms on the bottom of the English Channel, based on the condition of a soda-water bottle and its contents (exhibited to Section C at Southampton, 'Rep. B. A.,' 1883, p. 535), was afterwards fully confirmed on mathematical grounds by Professor G. G. Stokes, Pres.R.S. (' Journal Linnean Soc. Zoology,' vol. xviii. p. 263).

After describing the complexity of the currents set up in front of plunging waves, the author pointed out that behind the plunging point the waves stir up the sand by symmetrical oscillating currents, which keep it in motion and place it at the disposal of any passing continuous current, whether derived from tide, wind, or even earthquake. Of these currents perhaps those raised by wind are of most importance, as they are most intense when the waves themselves are highest. The water propelled by the wind shorewards (independently of any wave motion) escapes seaward as an under-current, or side-current along shore. Thus in wind and wave combined we have a most efficient excavating tool—a tool which not only cuts well, but which clears itself well.

The waves cut the land, the wind-raised currents remove the *débris,* and this frequently in the teeth of both wind and wave.

If waves can disturb sand and shingle at a depth of forty fathoms, as the triple cord of evidence relied on seems to prove, and if these waves are accompanied by wind-formed currents, as they often are, then waves supplemented by wind-currents are agents of denudation and deposition which no geologist can afford to neglect, except at the risk of seriously misinterpreting the records of the sedimentary rocks.

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10. *Third Report on the Rate of Erosion of the Sea Coasts of England and Wales.*—See Appendix, p. 847.

11. *On Deposits of Diatomite in Skye.*[1] *By* W. IVISON MACADAM, *F.C.S.*, *and* J. S. GRANT WILSON, *F.G.S.*

This newly discovered deposit occurs in several places in the north-east part of the island, and, in all, extends over an area of about 58 square miles. The two places especially described are: (*a*) Loch Cuithir, where the diatomite lies under 3 feet 8 inches of turf and peat. It has been proved in 19 bore-holes to a depth of 8 feet 4 inches, the bottom not reached. It probably extends to a depth of at least 14 feet. This deposit is very pure, containing in a calcined sample 99·20 per cent. of diatomaceous matter. (*b*) Loch Monkstadt. Here the deposit is somewhat irregular in its thickness and in the thickness of the overlying peat, &c. The diatomite is rather less pure than in Loch Cuithir, but it contains 93·55 per cent. of diatomaceous matter.

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[1] For fuller details, see papers by the authors, in *Min. Mag.*, vol. vii. (No. 32), p. 35, 1886; and *Trans. Geol. Soc. Edinb.*, vol. v. (Part 2), p. 318, 1887.

SECTION D.—BIOLOGY.

PRESIDENT OF THE SECTION.—WILLIAM CARRUTHERS, Pres.L.S., F.R.S., F.G.S.

THURSDAY, SEPTEMBER 2.

The PRESIDENT delivered the following Address:—

IN detaining you a few minutes from the proper work of the Section, I propose to ask your attention to what is known of the past history of the species of plants which still form a portion of the existing flora. The relation of our existing vegetation to preceding floras is beyond the scope of our present inquiry: it has been frequently made the subject of exposition, but to handle it requires a more lively imagination than I can lay claim to, or, perhaps, than it is desirable to employ in any strictly scientific investigation.

The literature of science is of little, if any, value in tracing the history of species, and in determining the modification or the persistency of characters which may be essential or accidental to them. If help could be obtained from this quarter, botanical inquiry would be specially favoured, for the literature of botany is earlier and its terms have all along been more exact than in any of her sister sciences. But even the latest descriptions, incorporating as they do the most advanced observations of science, and expressed in the most exact terminology, fail to supply the data on which a minute comparison of plants can be instituted. Any attempt to compare the descriptions of Linnæus and the earlier systematists who, under his influence, introduced greater precision into their language, with the standard authors of our own day, would be of no value. The short, vague, and insufficient descriptions of the still earlier botanists cannot even be taken into consideration.

Greater precision might be expected from the illustrations that have been in use in botanical literature from the earliest times; but these really supply no better help in the minute study of species than the descriptions which they are intended to aid. The earliest illustrations are extremely rude: many of them are misplaced; some are made to do duty for several species, and not a few are purely fictitious. The careful and minutely exact illustrations which are to be found in many modern systematic works are too recent to supply materials for detecting any changes that may have taken place in the elements of a flora.

But the means of comparison which we look for in vain in the published literature of science may be found in the collections of dried plants which botanists have formed for several generations. The local herbaria of our own day represent not only the different species found in a country, but the various forms which occur, together with their distribution. They must supply the most certain materials for the minute comparison at any future epoch of the then existing vegetation with that of our own day.

The preservation of dried plants as a help in the study of systematic botany was first employed in the middle of the sixteenth century. The earliest herbarium of which we have any record is that of John Falconer, an Englishman who travelled in Italy between 1540 and 1547, and who brought with him to England a collection of dried plants fastened in a book. This was seen by William Turner, our first British botanist, who refers to it in his 'Herbal,' published in 1551. Turner may have been already acquainted with this method of preserving plants, for in his enforced absence from England he studied at Bologna under Luca Ghini, the first professor of Botany in Europe, who, there is reason to believe, originated the practice of making herbaria. Ghini's pupils, Aldrovandus and Cæsalpinus, formed extensive collections. Caspar Bauhin, whose 'Prodromus' was the first attempt to digest the literature of botany, left a considerable herbarium, still preserved at Basle. No collection of English plants is known to exist older than the middle of the seventeenth century; a volume containing some British and many exotic plants collected in the year 1647 was some years ago acquired by the British Museum. Towards the end of that century great activity was manifested in the collection of plants, not only in our own country, but in every district of the globe visited by travellers. The labours of Ray and Sloane, of Petiver and Plukenet are manifest not only in the works which they published, but in the collections that they made, which were purchased by the country in 1759 when the museum of Sir Hans Sloane became the nucleus of the now extensive collections of the British Museum. The most important of these collections in regard to British plants is the herbarium of Adam Buddle, collected nearly two hundred years ago, and containing an extensive series which formed the basis of a British Flora, that unhappily for science was never published, though it still exists in manuscript. Other collections of British plants of the same age, but less complete, supplement those of Buddle: these various materials are in such a state of preservation as to permit of the most careful comparison with living plants, and they show that the two centuries which have elapsed since their collection have not modified in any particular the species contained in them. The early collectors contemplated merely the preservation of a single specimen of each species; consequently the data for an exhaustive comparison of the indigenous flora of Britain at the beginning of last century with that of the present are very imperfect as compared with those which we shall hand down to our successors for their use.

The collections made in other regions of the world in the seventeenth century, and included in the extensive herbarium of Sir Hans Sloane, are frequently being examined side by side with plants of our own day, but they do not show any peculiarities that distinguish them from recent collections. If any changes are taking place in plants, it is certain that the three hundred years during which their dried remains have been preserved in herbaria have been too short to exhibit them.

Beyond the time of those early herbaria the materials which we owe in any way to the intervention of man have been preserved without any regard to their scientific interest. They consist mainly of materials used in building or for sepulture. The woods employed in mediæval buildings present no peculiarities by which they can be distinguished from existing woods; neither do the woods met with in Roman and British villages and burying-places. From a large series collected by General Pitt-Rivers in extensive explorations carried on by him on the site of a village which had been occupied by the British before and after the appearance of the Romans, we find that the woods chiefly used by them were oak, birch, hazel, and willow, and at the latter period of occupation of the village the wood of the Spanish chestnut (*Castanea vulgaris*, Lamk.) was so extensively employed that it must have been introduced and grown in the district. The gravel beds in the north of London, explored by Mr. W. G. Smith for the palæolithic implements in them, contained also fragments of willow and birch, and the rhizomes of *Osmunda regalis*, L.

The most important materials, however, for the comparison of former vegetation of a known age with that of our own day have been supplied by the specimens which have been obtained from the tombs of the ancient Egyptians. Until recently these consisted mainly of fruits and seeds. These were all more or less carbonised, because the former rifling of the tombs had exposed them to the air. Ehrenberg, who accompanied Von Minutoli in his Egyptian expedition, determined the seeds which he had collected, but as he himself doubted the antiquity of some of the materials on which he reported, the scientific value of his enumeration is destroyed.

Passalacqua in 1823 made considerable collections from tombs at Thebes, and these were carefully examined and described by the distinguished botanist Kunth. He pointed out, in a paper published sixty years ago, that these ancient seeds possessed the minute and apparently accidental peculiarities of their existing representatives. Unger, who visited Egypt, published in several papers identifications of the plant-remains from the tombs; and one of the latest labours of Alexander Braun was an examination of the vegetable remains in the Egyptian Museum at Berlin, which was published, after his death, from his manuscript, under the careful editorship of Ascherson and Magnus. In this, twenty-four species were determined, some from imperfect materials, and necessarily with some hesitation as to the accuracy of their determination.

The recent exploration of unopened tombs belonging to an early period in the history of the Egyptian people has permitted the examination of the plants in a condition which could not have been anticipated. And happily, the examination of these materials has been made by a botanist who is thoroughly acquainted with the existing flora of Egypt, for Dr. Schweinfurth has for a quarter of a century been exploring the plants of the Nile valley. The plant-remains were included within the mummy-wrappings, and being thus hermetically sealed, have been preserved with scarcely any change. By placing the plants in warm water, Dr. Schweinfurth has succeeded in preparing a series of specimens gathered four thousand years ago, which are as satisfactory for the purposes of science as any collected at the present day. These specimens consequently supply means for the closest examination and comparison with their living representatives. The colours of the flowers are still present, even the most evanescent, such as the violet of the larkspur and knapweed, and the scarlet of the poppy; the chlorophyll remains in the leaves, and the sugar in the pulp of the raisins. Dr. Schweinfurth has determined no less than fifty-nine species,[1] some of which are represented by the fruits employed as offerings to the dead, others by the flowers and leaves made into garlands, and the remainder by branches on which the body was placed, and which were enclosed within the wrappings.

The votive offerings consist of the fruits, seeds, or stems, of twenty-nine species of plants. Three palm fruits are common; the *Medemia Argun*, Würt., of the Nubian Desert, and the *Hyphæne thebaica*, Mart., of Upper Egypt, agreeing exactly with the fruits of these plants in our own day; also dates of different forms resembling exactly the varieties of dried dates found now in the markets of Egypt. Two figs are met with, *Ficus carica*, L., and *Ficus Sycomorus*, L., the latter exhibiting the incisions still employed by the inhabitants for the destruction of the Neuropterous insects which feed on them. The sycomore was one of the sacred trees of Egypt, and the branches used for the bier of a mummy found at

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[1] List of the species of ancient Egyptian plants determined by Dr. Schweinfurth. I am indebted to Dr. Schweinfurth for some species in this list, the discovery of which he has not yet published.

Delphinium orientale, Gay; *Cocculus Leæba*, DC.; *Nymphæa cærulea*, Sav.; *Nymphæa Lotus*, Hook.; *Papaver Rhœas*, L.; *Sinapis arvensis*, L., var. *Allionii*, Jacq.; *Mærua uniflora*, Vahl.; *Oncoba spinosa*, Forsk.; *Tamarix nilotica*, Ehrb.; *Alcea ficifolia*, L.; *Linum humile*, Mill.; *Balanites ægyptiaca*, Del.; *Vitis vinifera*, L.; *Moringa aptera*, Gærtn.; *Medicago denticulata*, Willd.; *Sesbania ægyptiaca*, Pers.; *Faba vulgaris*, Moench; *Lens esculenta*, Moench; *Lathyrus sativus*, L.; *Cajanus indicus*, L.; *Acacia nilotica*, Del.; *Lawsonia inermis*, Lamk.; *Punica Granatum*, L.; *Epilobium hirsutum*, L.; *Lagenaria vulgaris*, Ser.; *Citrullus vulgaris*, Schrad., var. *colocynthoides*, Schweinf.; *Apium graveolens*, L.; *Coriandrum sativum*, L.; *Ceruana pratensis*, Forsk.; *Sphæranthus suaveolens*, DC.; *Chrysanthemum coronarium*, L.; *Centaurea depressa*, M. Bieb.; *Carthamus tinctorius*, L.; *Picris coronopifolia*, Asch.; *Mimusops Schimperi*, Hochst.; *Jasminum Sambac*, L.; *Olea europæa*, L.; *Mentha piperita*, L.; *Rumex dentatus*, L.; *Ficus Sycomorus*, L.; *Ficus carica*, L.; *Salix Safsaf*, Forsk.; *Juniperus phœnicea*, L.; *Pinus Pinea*, L.; *Allium sativum*, L.; *Allium Cepa*, L.; *Phœnix dactylifera*, L.; *Calamus fasciculatus*, Roxb.; *Hyphæne thebaica*, Mart.; *Medemia Argun*, P. G. v. Würtemb.; *Cyperus Papyrus*, L.; *Cyperus esculentus*, L.; *Andropogon laniger*, Desf.; *Leptochloa bipinnata*, Retz.; *Triticum vulgare*, L.; *Hordeum vulgare*, L.; *Parmelia furfuracea*, Ach.; *Usnea plicata*, Hoffm.

Abd-el-Qurna, of the twentieth dynasty (a thousand years before the Christian era), were moistened and laid out by Dr. Schweinfurth, equalling, he says, the best specimens of this plant in our herbaria, and consequently permitting the most exact comparison with living sycomores, from which they differ in no respect. The fruit of the vine is common, and presents, besides some forms familiar to the modern grower, others which have been lost to cultivation. The leaves which have been obtained entire exactly agree in form with those cultivated at the present day, but the under surface is clothed with white hairs, a peculiarity Dr. Schweinfurth has not observed in any Egyptian vines of our time. A very large quantity of linseed was found in a tomb at Thebes of the twentieth dynasty, now three thousand years old, and a smaller quantity in a vase in another tomb of the twelfth dynasty, that is, one thousand years older. This belongs certainly to *Linum humile,* Mill., the species still cultivated in Egypt, from which the capsules do not differ in any respect. Braun had already determined this species preserved thus in the tombs, though he was not aware of its continued cultivation in Egypt. The berries of *Juniperus phœnicea,* L., are found in a perfect state of preservation, and present a somewhat larger average size than those obtained from this juniper at the present day. Grains of barley and wheat are of frequent occurrence in the tombs; M. Mariette has found barley in a grave at Sakhara of the fifth dynasty, five thousand four hundred years old.

The impurities found with the seeds of these cultivated plants show that the weeds which trouble the tillers of the soil at the present day in Egypt were equally the pests of their ancestors in those early ages. The barley fields were infested with the same spiny medick (*Medicago denticulata,* Willd.) which is still found in the grain crops of Egypt. The presence of the pods of *Sinapis arvensis,* L., among the flax seed testifies to the presence of this weed in the flax crops of the days of Pharaoh, as of our own time. There is not a single field of flax in Egypt where this charlock does not abound; and often in such quantity that its yellow flowers, just before the flax comes into bloom, present the appearance of a crop of mustard. The charlock is *Sinapis arvensis,* L., var. *Allionii,* Jacq., and is distinguished from the ordinary form by its globular and inflated silicules, which are as characteristically present in the ancient specimens from the tombs as in the living plants. *Rumex dentatus,* L., the dock of the Egyptian fields of to-day, has been found in graves of the Greek period at Dra-Abu-Negga.

It is difficult without the actual inspection of the specimens of plants employed as garlands, which have been prepared by Dr. Schweinfurth, to realise the wonderful condition of preservation in which they are. The colour of the petals of *Papaver Rhœas,* L., and the occasional presence of the dark patch at their bases, present the same peculiarities as are still found in this species growing in Egyptian fields. The petals of the larkspur (*Delphinium orientale,* Gay) not only retain their reddish-violet colour, but present the peculiar markings which are still found in the living plant. A garland composed of wild celery (*Apium graveolens,* L.) and small flowers of the blue lotus (*Nymphæa cœrulea,* Sav.), fastened together by fibres of papyrus, was found on a mummy of the twentieth dynasty, about three thousand years old. The leaves, flowers, and fruit of the wild celery have been examined with the greatest care by Dr. Schweinfurth, who has demonstrated in the clearest manner their absolute identity with the indigenous form of this species now abundant in moist places in Egypt. The same may be said of the other plants used for garlands, including two species of lichens.

It appears to have been a practice to lay out the dead bodies on a bier of fresh branches, and these were inclosed within the linen wrappings which enveloped the mummy. In this way there have been preserved branches of considerable size of *Ficus Sycomorus,* L., *Olea europæa,* L., *Mimusops Schimperi,* H., and *Tamarix nilotica,* Ehrb. The Mimusops is of frequent occurrence in the mural decorations of the ancient temples; its fruit had been detected amongst the offerings to the dead, and detached leaves had been found made up into garlands, but the discovery of branches with their leaves still attached, and in one case with the fruit adhering, has established that this plant is the Abyssinian species to which Schimper's name has been given, and which is characterised by the long and slender petiole of the leaf.

In none of the species, except the vine to which I have referred, which Dr. Schweinfurth has discovered, and of which he has made a careful study, has he been able to detect any peculiarities in the living plants which are absent in those obtained from the tombs.

Before passing from these Egyptian plants I would draw attention to the quality of the cereals. They are good specimens of the cereals still cultivated. This observation is true also of the cultivated grains which I have examined, belonging to prehistoric times. The wheat found in the purely British portion of the ancient village explored by General Pitt-Rivers is equal to the average of wheat cultivated at the present day. This is the more remarkable, because the two samples from the later Romano-British period obtained by General Pitt-Rivers are very much smaller, though they are not unlike the small hard grains of wheat still cultivated on thin chalk soils. The wheat-grains from lake dwellings in Switzerland, for which I am indebted to J. T. Lee, Esq., F.G.S., are fair samples. My colleague, Mr. W. Fawcett, has recently brought me from America grains of maize from the prehistoric mounds in the valley of the Mississippi, and from the tombs of the Incas of Peru, which represent also fair samples of this great food-substance of the New World. The early peoples of both worlds had then under cultivation productive varieties of these important food-plants, and it is remarkable that in our own country, with all the appliances of scientific cultivation and intelligent farming, we have not been able to appreciably surpass the grains which were harvested by our rude ancestors of two thousand years ago.

In taking a further step into the past, and tracing the remains of existing species of plants preserved in the strata of the earth's crust, we must necessarily leave behind all certain chronology. Without an intelligent observer and recorder there can be no definite determination of time. We can only speculate as to the period required for effecting the changes represented by the various deposits.

The peat-bogs are composed entirely of plant-remains belonging to the floras existing in the regions where they occur. They are mainly surface accumulations still being formed and going back to an unknown antiquity. They are subsequent to the last changes in the surface of the country, and represent the physical conditions still prevailing.

The period of great cold during which arctic ice extended far into temperate regions was not favourable to vegetable life. But in some localities we have stratified clays with plant-remains later than the Glacial Epoch, yet indicating that the great cold had not then entirely disappeared. In the lacustrine beds at Holderness is found a small birch (*Betula nana*, L.), now limited in Great Britain to some of the mountains of Scotland, but found in the Arctic regions of the Old and New World and on Alpine districts in Europe, and with it *Prunus Padus,* L., *Quercus Robur,* L., *Corylus Avellana,* L., *Alnus glutinosa,* L., and *Pinus sylvestris,* L. In the white clay beds at Bovey Tracey of the same age there occur the leaves of *Arctostaphylos Uva-Ursi,* L., three species of willow, viz., *Salix cinerea,* L., *S. myrtilloides,* L., and *S. polaris,* Wahl., and in addition to our alpine *Betula nana,* L., the more familiar *B. alba,* L. In beds of the same age in Sweden, Nathorst has found the leaves of *Dryas octopetala,* L., and *Salix herbacea,* L., this being associated with *S. polaris,* Wahl. Two of these plants have been lost to our flora from the change of climate that has taken place, viz., *Salix myrtilloides,* L., and *S. polaris,* Wahl.; and *Betula nana,* L., has retreated to the mountains of Scotland. Three others (*Dryas octopetala,* L., *Arctostaphylos Uva-Ursi,* L., and *Salix herbacea,* L.) have withdrawn to the mountains of northern England, Wales, and Scotland, while the remainder are still found scattered over the country. Notwithstanding the diverse physical conditions to which these plants have been subjected, the remains preserved in these beds present no characters by which they can be distinguished from the living representatives of the species.

We meet with no further materials for careful comparison with existing species until we get beyond the great period of intense cold which immediately preceded the present order of things. The Glacial Epoch includes four periods during which the cold was intense, separated by intervals of somewhat higher temperature which are represented by the intervening sedimentary deposits. During these alterations of temperature, extensive changes in the configuration of the land were taking place. The first great upheaval occurred in the early glacial period, and was followed by a considerable subsidence. A second upheaval took place late in the glacial epoch. Various estimates have been formed of the time required for this succession of climatic conditions and earth-movements. The moderate computation of Ramsay and Lyell gives to the boulder clay of the first glacial period an age of 250,000 years, estimating the time of the first upheaval as 200,000 years ago, while the subsidence took place 50,000 years later, and the second upheaval 92,000 years ago.

The sedimentary deposits later than the Pliocene strata, but older than the glacial drift, indicate an increasing severity in the climate, which reached its height in the first glacial period.

At Cromer, on the Norfolk coast, the newest of these deposits has supplied the remains of *Salix polaris*, Wahl., *S. cinerea*, L., and *Hypnum turgescens*, Schimp. This small group of plants is of great interest in connection with the history of existing species; their remains are preserved in such a manner as to permit the closest comparison with living plants. Such an examination shows that they differ from each other in no particular. In the post-glacial deposits in Sweden, *Salix herbacea*, L., is associated with *S. polaris*, Wahl., as I have already stated. These two willows are very closely related, having indeed been treated as the same species until Wahlenberg pointed out the characters which separated them when he established *Salix polaris* as a distinct species in 1812. One of the most obvious of the specific distinctions is the form and venation of the leaf, a character which is, however, easily overlooked, but when once detected is found to be so constant that it enables one to distinguish without hesitation the one species from the other. The leaves of the two willows in the Swedish bed present all the peculiarities which they possess at the present day, and the venation and form of the leaves of *S. polaris*, Wahl., from the preglacial beds of Cromer present no approach towards the peculiarities of its ally *S. herbacea*, L., but exhibit them exactly as they appear in the living plant. This is the more noteworthy as the vegetative organs supply, as a rule, the least stable of the characters employed in the diagnosis of species. The single moss (*Hypnum turgescens*, Schimp.) is no longer included in the British flora, but is still found as an arctic and alpine species in Europe, and the pre-glacial specimens of this cellular plant differ in no respect from their living representatives.

The older beds containing the remains of existing species, which are found also at Cromer, have recently been explored with unwearied diligence and great success by Mr. Clement Reid, F.G.S., an officer of the Geological Survey of England. To him I am indebted for the opportunity of examining the specimens which he has found, and I have been able to assist him in some of his determinations, and to accept all of them. His collections contain sixty-one species of plants belonging to forty-six different genera, and of these forty-seven species have been identified. Slabs of clay-ironstone from the beach at Happisburgh contain leaves of beech, elm, oak, and willow. The materials, however, which have enabled Mr. Reid to record so large a number of species are the fruits or seeds which occur chiefly in mud or clay, or in the peat of the forest-bed itself. The species consist mainly of water or marsh plants, and represent a somewhat colder temperature than we have in our own day, belonging as they do to the arctic facies of our existing flora.

Only one species (*Trapa natans*, L.) has disappeared from our islands; its fruits, which Mr. Reid found abundantly in one locality, agree with those of the plants found until recently in the lakes of Sweden. Four species (*Prunus spinosa*, L., *Œnanthe Lachenalii*, Gmel., *Potamogeton heterophyllus*, Schreb., and *Pinus Abies*, L.) are found at present only in Europe, and a fifth (*Potamogeton trichoides*, Cham.) extends also to North America; two species (*Peucedanum palustre*, Moench, and *Pinus sylvestris*, L.) are found also in Siberia, whilst six more (*Sanguisorba officinalis*, L., *Rubus fruticosus*, L., *Cornus sanguinea*, L., *Euphorbia amygdaloides*, L., *Quercus Robur*, L., and *Potamogeton crispus*, L.) extend into Western Asia, and two (*Fagus sylvatica*, L., and *Alnus glutinosa*, L.) are included in the Japanese flora. Seven species, while found with the others, enter also into the Mediterranean flora, extending to North Africa: these are *Thalictrum minus*, L., *Thalictrum flavum*, L., *Ranunculus repens*, L., *Stellaria aquatica*, Scop., *Corylus Avellana*, L., *Zannichellia palustris*, L., and *Cladium Mariscus*, Br. With a similar distribution in the Old World, eight species (*Bidens tripartita*, L., *Myosotis cæspitosa*, Schultz, *Suæda maritima*, Dum., *Ceratophyllum demersum*, L., *Sparganium ramosum*, Huds., *Potamogeton pectinatus*, L., *Carex paludosa*, Good., and *Osmunda regalis*, L.) are found also in North America. Of the remainder, ten species (*Nuphar luteum*, Sm., *Menyanthes trifoliata*, L., *Stachys palustris*, L., *Rumex maritimus*, L., *Rumex Acetosella*, L., *Betula alba*, L., *Scirpus pauciflorus*, Lightf., *Taxus baccata*, L., and *Isoetes lacustris*, L.) extend round the north temperate zone, while three (*Lycopus europæus*, L., *Alisma Plantago*, L., and *Phragmites communis*, Trin.), having the same distribution in the north, are found also in Australia, and one (*Hippuris vulgaris*, L.) in the south of South America. The list is completed by *Ranunculus aquatilis*, L., distributed over all the temperate regions of the globe, and *Scirpus lacustris*, L., which is found in many tropical regions as well.

The various physical conditions which necessarily affected these species in their diffusion over such large areas of the earth's surface in the course of, say, 250,000 years, should have led to the production of many varieties, but the uniform testimony of the remains of this considerable pre-glacial flora, as far as the materials admit of a comparison, is that no appreciable change has taken place.

I am unable to carry the history of any existing species of plant beyond the Cromer deposits. Some of the plant-remains from Tertiary strata have been referred to still living species, but the examination of the materials, as far as they have come before me, convince me that this has been done without sufficient evidence. The physical conditions existing during even the colder of the Tertiary periods were not suitable to a flora fitted to persist in these lands in our day, even if the period of great cold had not intervened to destroy them. And in no warmer region of the earth do these Tertiary species now exist, though floras of the same facies occur, containing closely allied species. The sedimentary beds at the base of the Glacial Epoch contain, as far as we at present know, the earliest remains of any existing species of plant.

It is not my purpose to point out the bearing of these facts on any theoretical views entertained at the present day: I wish merely to place them before the members of this Section as data which must be taken into account in constructing such theories, and as confirming the long-established axiom that by us, at least, as workers, species must be dealt with as fixed quantities.

The following Reports and Papers were read:—

1. *Report of the Committee for arranging for the Occupation of a Table at the Zoological Station at Naples.*—See Reports, p. 254.

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2. *Report of the Committee for continuing the Researches on Food-Fishes and Invertebrates at the St. Andrews Marine Laboratory.*—See Reports, p. 268.

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3. *On the Value of the 'Type System' in the Teaching of Botany.*

By Professor BAYLEY BALFOUR, *F.R.S.*

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4. *Remarks on Physiological Selection, an Additional Suggestion on the Origin of Species, by G. J. Romanes, F.R.S.* *By* HENRY SEEBOHM, *F.L.S.*

5. *On Provincial Museums, their Work and Value.*
By F. T. Mott, *F.R.G.S.*

Provincial museums are at present very unsatisfactory institutions, but there is an undeveloped capacity in them which, once recognised, would put them on a new footing. A provincial museum should be a complete monograph of its own particular district, illustrated throughout with actual specimens, and the preparation of it should be set about in a systematic manner and completed as rapidly as possible. The natural history, botany, and geology of the district should be first undertaken; then the antiquities, the agriculture, the manufactures, arts, and political history in succession as distinct departments, each worked out in the most complete manner.

The advantages would be—(1) that this is work which can never be done elsewhere, and would render the museum unique; (2) that it is work which can be made complete, whereas anything else will be fragmentary and imperfect; (3) that it will furnish information especially interesting to the inhabitants and of real value to science.

The staff required for the natural history will be two curators, one workman, and four paid collectors, and the expense will be about 1,000*l.* a year for two years, the building being otherwise provided. No reliance must be placed on amateur collecting—it is too slow and desultory. Every living creature, vertebrate and invertebrate, indigenous to the district must have its whole life-history illustrated. Labels must be plentiful with the English and local names prominent. A room 70 feet by 40 will take the whole of the local vertebrates in wall-cases, and the invertebrates in table-cases.

When the natural history is completed the annual expense for the botany and geology may be reduced to 700*l.* a year for two years more.

Each of the other departments may be completed in a single year, at the same annual cost, and when the whole ground is covered a permanent income of 600*l.* a year will be sufficient.

The curators' attention must then be continually directed to devising and carrying out plans for making the museum available in every possible way for reference and for education.

There is no town in England in which the inhabitants would grudge the halfpenny or penny rate for a museum so constructed and so worked.

FRIDAY, SEPTEMBER 3.

The following Papers were read:—

1. *On Some Points in the Development of Monotremes.*
By W. H. Caldwell, *M.A.*

2. *On the Morphology of the Mammalian Coracoid.*[1]
By Professor Howes, *F.L.S.*

The author shows that the importance of a third centre of ossification of the mammalian shoulder-girdle has been overlooked. He claims that it is homologous with the true coracoid bone of the lower vertebrata, basing his determination upon a study of the facts as they stand in the common rabbit; the coracoid process he holds to be the morphological equivalent of the monotreme epicoracoid. He further upholds the view that the mammalian coracoid has been derived from a primarily expanded sheet-like type; fenestration thereof, the rule among the lower amniota, being the exception among mammals. He describes the shoulder-girdle of the

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[1] Published in the *Journal of Anatomy and Physiology*, Jan. 1887.

youngest monotreme yet dissected, and concludes that the characters of the mammalian shoulder-girdle are constant throughout.

3. *On Rudimentary Structures relating to the Human Coracoid Process.* *By* Professor MACALISTER, *F.R.S.*

SUB-SECTION PHYSIOLOGY.

1. *Discussion on Cerebral Localisation.*

2. *On the Connection between Molecular Structure and Biological Action.* *By* JAMES BLAKE, *M.D., F.R.C.S., F.C.S.*

The paper contained the results of the author's researches on the connection between the molecular constitution of inorganic substances and their biological action, and is, in fact, a continuation of previous communications to the Association, the first of which was made at the meeting at Newcastle in 1838, followed by others in 1843, 1844, and 1846.

The author showed that these biological reactions are determined, in the case of compounds of all the more electro-positive elements, by the electro-positive element of the compound, and that they are closely connected with its isomorphous relations and atomic weight, and that when an element forms two classes of compounds which are members of two different isomorphous groups, as with the ferrous and ferric salts, the biological action of the salts in each class differs, and is analogous to that of the other members of the group to which it belongs, the salts in which the electro-positive element has the highest molecular weight being by far the most active.

In cases where an element forms a connecting link between two isomorphous groups its biological reactions are such as connect it with each group. Between the metals and metalloids differences exist as regards the connection of biological action with their atomic weights, although the general reaction is still determined by their isomorphous relations. In investigating the biological reactions of compounds of forty-two of the elements but two exceptions have been met with to the conclusions above stated connecting molecular constitution with biological action. One of these exceptions (beryllium) is associated with other anomalous molecular reactions of the element. The connection of these facts with the normal reactions of living matter will be considered, and also their bearing on investigations on the molecular structure of bodies.

In conclusion, the author shows that the objections that have been brought forward to his results have been founded either on imperfect methods of research or a false interpretation of facts.

3. *Supplement to the Paper 'On the Causes and Results of assumed Cycloidal Rotation in Arterial Red Discs.'*[1] *By* Surg.-Major R. W. WOOLLCOMBE.

The author wishes to record further, that although he then for illustration cited the fact of rotation about the shortest diameter being manifested by 'the rolling on their edges of irregularly shaped leaves, or of scraps of paper on the ground before the wind,' yet he has since found that the above law of rotation obtains even further than he supposed, and to such a degree that he considers it disposes of the objection that certain discs, as those of the 'Camelidæ' and 'Aves,'

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[1] Vide *British Association Report*, 1881, p. 722.

having peripheries not circular but more or less elliptical, would not be likely to rotate. The author has found that flat chips of wood, of even rhomboidal periphery, roll freely on the edge when impelled by sufficient wind along such a surface as the horizontal woodwork of a pier, the difference between the movement of such a departure from the circular, and that of a circular periphery, being less visible in the rotation than in the translation, the latter being of a proportionally interrupted kind. The difference between a rhomboidal and a circular periphery being so much greater than that between a circular and an elliptical, it appears to the author the objection referred to vanishes, viz. that the latter (in the 'Aves' and 'Camelidæ') would not be likely to have rotation. The author would suggest the possibility that in the 'Aves' and 'Camelidæ' a less continuous and more interrupted impingement of the red disc on the nervous and muscular tissue, for their due stimulation, may be in request. Referring again to the paper in the 'B. A. Report of 1881,' where the author points out that, if there be rotation of red discs it must be wholly suppressed when the capillaries are reached, and then and there appear as heat, he would venture to ask if this supposition does not offer a reasonable view that may account for the missing link in the otherwise accepted theory of animal heat? The unaccounted portion is alleged to be but small, and such only would probably be the increment from the suppression of the rotation by the capillaries—the locality where the wanting increment has to be looked for.

SATURDAY, SEPTEMBER 4.

The following Reports and Papers were read:—

1. *Report on the Migration of Birds*—See Reports, p. 264.

2. *Report of the Committee for promoting the Establishment of a Marine Biological Station at Granton.*—See Reports, p. 251.

3. *Report on the Record of Zoological Literature.*

4. *Report of the Committee for investigating the Mechanism of the Secretion of Urine.*—See Reports, p. 250.

5. *On the Flora of Ceylon. By* Dr. TRIMEN.

SUB-SECTION ANIMAL MORPHOLOGY.

1. *On Man's Lost Incisors.*[1]

By Professor WINDLE, *M.A.*, *M.D.*, *and* JOHN HUMPHREYS, *L.D.S.I.*

Teeth beyond the ordinary number may occur in the incisive portion of the dental series. Such teeth may fall into one of two categories—viz., *supplemental*, that is, incisiform though generally smaller than the ordinary incisors; and *supernumerary*, which are conical and do not conform to any human dental type. Similar teeth have been observed in other parts of the dental series also. Eustachius,

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[1] Published *in extenso* in the *Journal of Anatomy and Physiology*, vol. xxi. p. 84.

Hunter, Meckel, Owen, and others have mentioned the occurrence of these extranumerary teeth. Wedl ('Pathologie der Zähne') gives a good description of them, stating that whilst six incisors are very rare, five are of more common occurrence, the additional tooth, when of the supplemental group, being generally a lateral incisor. When supernumerary they are placed either amongst the permanent teeth or behind them within the alveolar arch. Their eruption takes place during the first or second dentition, or in the interval between the two; generally, however, they belong to the permanent series. Baume ('Odontologische Forschungen') states his belief that the archaic incisor dentition of man was In $\frac{6}{6}$, and that the missing teeth are the median In_1 in each case. This theory he bases upon the facts (1) that a separation may exist between the median incisors in man and the higher apes; and (2) that in this position superfluous teeth may exist. Dr. Edwards, of Madrid, shares his opinion for somewhat similar reasons. Professor Turner, from a study of a number of cases of alevolar cleft palate, believes the missing incisor to be the second, that is, In_2. This view is shared by Albrecht and Andrew Wilson.

The specimens upon which we base this communication may be arranged in eight groups. We have obtained most of the casts ourselves at the Birmingham Dental Hospital. Others we owe to the kindness of Messrs. Sims and Adams Parker, of this town; Dr. Crapper, of Hanley; Mr. Percy May, of London; and Mr. J. S. Amoore, of Edinburgh.

The groups which we describe are as follows:—

(Series i.) *Supplemental teeth.*—In this group we have one case of six separate incisors (sup. max.), and one of six, the two central being geminous, and seven in which there were five teeth. Of these seven three were on the right, four on the left side. In all the cases save one they were situated behind the true lateral, generally occasioning some displacement. In one case, however, the intruder was placed between the lateral and central. One case only belonged to the milk dentition, and all but one were found in the upper jaw.

(Series ii.) *Supernumerary teeth.*—We have four casts in which there are two of these teeth: in two they were situated behind the median incisors; in another one was posterior to the left lateral, and a second between the right median and lateral; and in the fourth one was posterior to the right central, and the second between the two median. In fifteen cases there was one supernumerary. These teeth were situated inside the alveolar arch posterior to the left median incisor in seven cases, the right in five, and in the middle line in three instances. They generally caused more or less displacement of the remaining teeth. All were found in the superior maxilla, and all belonged to the permanent series.

(Series iii.) *Coexistence of supplemental and supernumerary with the normal number of incisors.*—Of this we have one specimen, in which a properly formed though small incisor is placed behind the right lateral, and in series with it, and a blunt tooth posterior to the left median, which it displaces forward. This was in superior maxilla and permanent series.

(Series iv.) *Substitution of a supernumerary tooth for a normal incisor, the number of teeth remaining four.*—Of this we have four specimens. The substitution was once each for the right and left median, and twice for the left lateral. All the cases belonged to the superior maxilla and to the permanent series.

(Series v.) *Substitution of two supernumerary teeth for normal incisors, the number of teeth remaining four.*—Of this we have six cases, the two lateral superior incisors of the permanent series being those always to suffer.

(Series vi.) *Absence of one incisor, the number being three.*—In two cases the right lateral (superior) incisor was wanting, and in one the same tooth in the inferior maxilla. All three were of the permanent series.

(Series vii.) *Absence of one incisor, diminution or malformation of another, the number being three.*—Of this we have three cases. In two the right lateral was absent. The left lateral was conical in one of these, small but incisiform in the other. In the third case the left lateral was absent and the right lateral small though incisiform. All were of the superior maxilla and permanent series.

(Series viii.) *Absence of two incisors, the number being reduced to two.*—Of this we have seven cases, all belonging to the superior maxilla and permanent series.

In all the laterals are the missing teeth. The jaws are generally well formed, and there are often gaps between the teeth in the incisor region. The ages of four of these patients were 21, 22, 22, and 17 respectively; of the others we have no exact information, but they were adults.

The points which these cases illustrate are as follows:—

(i.) *Man's original dentition included six incisors.*—This thesis is already fairly generally admitted by odontologists. If supplemental and supernumerary teeth are to be regarded as reversions to the primitive dentition, then in two cases we have, so far as the superior maxilla is concerned, the complete series. Galton, Wilson, Flower, and Edwards also quote cases of six incisors in the upper jaw. Kirk describes one which occurred in the inferior maxilla and in the milk series. As Wedl remarks, however, the occurrence of six incisors is rare. That of five is, on the contrary, fairly common. What has just been said relates to supplemental teeth, but, as will be seen by a reference to the digest of the series above, a supplemental and supernumerary may coexist to increase the number of the dentition to six, or two or one supernumeraries may coexist with the normal four incisors. That a milk supplemental may be followed by a permanent successor is proved by a case for which we are indebted to Mr. Amoore. This is interesting as bearing on the development of these teeth. We may sum up by saying that man seldom attains to the archaic dentition of In $\frac{6}{6}$ in the upper jaw, still more rarely in the lower, never, so far as we are aware, in both simultaneously. On the other hand, in fairly numerous cases, he regains one of his lost teeth, either ill- or well-formed, or both, in an imperfectly formed condition.

(ii.) *Man's lost incisor is the lateral or In$_3$.*—Baume and Edwards consider the lost tooth to be In$_1$, mainly on account of a supposed separation existing between the two median. This separation is, in our experience at least, by no means common. Again, in all our cases, whatever teeth are added or suppressed, the medians remain typical in shape. We have also casts showing that the ordinary laterals may take up a position behind the median. This shows that teeth found in this position need not necessarily be abortive medians. These facts, we believe, dispose of the median theory. Two other arguments, shortly to be mentioned, also make against it. Turner and Wilson's theory, that the missing incisor is In$_2$, is much more tenable. We are unable at present to explain the facts quoted by the former authority, but would venture to put forward the following arguments in support of our position:—

1. Tomes bases his theory that the dentition of man was In $\frac{6}{6}$ on the fact that Homalodontotherium possessed that number of teeth, and that the transition from incisors to canine was thus rendered more gradual. Upon these grounds he believes that In$_3$ is the lost tooth. Now, if we suppose that In$_1$ or In$_2$ is missing the force of this argument falls to the ground, unless we believe that, *pari passu* with their suppression, the others became modified in shape, which there are not facts to prove.

2. It has long been held—and we have fresh facts to show its truth—that the present lateral incisor is now being suppressed. This being so, it seems more reasonable to suppose that the tooth already lost is that which lay behind the present lateral in the original series.

3. Finally—and this is the most important argument—wherever the dentition is increased by two or one incisors, the superadded teeth are behind the laterals, that is, are In$_3$. This is shown in the case where six are present, and still better in one case of five, where the superadded tooth is obviously In$_3$, has no fellow on the opposite side, and affords a perfect example of a tooth bridging over the gap between incisors and canine.

(iii.) *The loss of incisors is due to the contraction of the anterior parts of the jaw.*—It is well known that the jaws of civilised races are less well developed than those of uncivilised, and that amongst the former the lower have better shaped alveolar arches than the upper classes. These facts are dealt with by Darwin, Herbert Spencer, Oakley Coles, Cartwright, Coleman, Mummery, and Nicholls. We have not had an opportunity of working out the point satisfactorily, but believe this contraction to take place most markedly in the incisive region. Topinard states that of the various shapes of alveolar arch the elliptical is most commonly met with amongst inferior, the parabolic amongst superior races; and the former appears to us to afford a far more roomy incisive region than the latter. Callender, in a paper on the 'So-called Serpent Teeth,' has shown how the contraction of the incisive region may occur by arrested growth of the incisive process of the superior maxilla. We suggest that the diminished necessity for the incisors when food is eaten after having been cooked carefully may account for this suppression.

(iv.) *Suppression of the two present lateral incisors is taking place.*—Cope predicts that in the future civilised man's dentition will be—

$$\text{In}\,\tfrac{1}{2}\quad \text{C}\,\tfrac{1}{1}\quad \text{P}\,\tfrac{2}{2}\quad \text{M}\,\tfrac{3}{3},\quad \text{or}$$
$$\text{In}\,\tfrac{1}{1}\quad \text{C}\,\tfrac{1}{1}\quad \text{P}\,\tfrac{2}{2}\quad \text{M}\,\tfrac{2}{2},$$

and this view is shared by other authorities quoted above.

Our series iv.–viii. inclusive bear out this theory very strikingly. In iv. there are cases in which three well- and one ill-formed incisors are present. In v. two well- and two ill-formed coexist. In vi. one tooth has disappeared. In vii. one is missing, a second malformed, and finally, in viii., two are missing. It will be noticed that of twenty-three cases in these series two only affect the median incisors. Three of the cases are interesting as forming a family group: the eldest, F., æt. 22, has only the two medians; the second, F., æt. 20, has lost the right lateral; and the third, I., æt. 17, like the eldest, has no laterals.

(v.) *The conical teeth frequently observed are a reversion to the primitive type of tooth.*—It is interesting to note that in the cases of reversion to the archetype or of gradual suppression, a tooth unable to reach full development may remain of the conical form characteristic of lower dentitions than the human. This reversion is not peculiar to man, as we have a skull of a Midas Rosalia in which an additional premolar of a conical shape exists on one side.

To sum up, our conclusions are as follows:—

1. Man's original dentition included six incisors.
2. Man's lost incisor is the lateral or In_3.
3. The loss of these incisors is due to the contraction of the incisive region of the alveolar arch.
4. Suppression of the two present lateral incisors, in the upper jaw at least, is at present taking place.
5. The conical teeth, supernumerary (Wedl, 'Dutten-oder Zapfenzähne'), frequently observed, may be looked upon as a reversion to the primitive type of tooth.

2. *On the Nervous System of Myxine and Petromyzon.*
By Professor D'Arcy Thompson.

3. *On the Vestigial Structures of the Reproductive Apparatus in the Male of the Green Lizard.*[1] *By* Professor Howes, *F.L.S.*

The author describes in detail a specimen in which the two oviducts were fully developed. He demonstrates for the species a series of stages in the development of the same identical with those recorded for the male toads and frogs by Van Wittich, Marshall, and others. He claims that the constant tendency towards the fuller development of the oviducts on the part of the male—so prevalent among the higher vertebrata—points not towards an ancestrally hermaphroditic condition, but rather towards one most nearly represented in the adult males of the living Ganoids and Dipnoi.

4. *On the Development of the Skull in Cetacea.*
By Professor D'Arcy Thompson.

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[1] Published in the *Journal of Anatomy and Physiology*, Jan. 1887.

5. *On some Abnormalities of the Frog's Vertebral Column.*[1] *By* Professor HOWES, *F.L.S.*

Two cases were described. In one a supernumerary (Xth) vertebra was developed, which had usurped the function of the true sacral one; the latter had established its customary connections on one side only, and the accessory processes to be accounted for were shown to be the resultants of an attempt to make good the loss by failure to do so on the other. In the second case the urostyle had 'slipped' and was displaced dorsally. Instead of becoming buried in the adjacent soft tissues, or ankylosed to the neighbouring bony ones, it had entered into a new connection with the sacrum—the body of which was prolonged upwardly into two new articular facets. The process was held to be tantamount to that of reproduction of a lost part so familiar among invertebrates.

MONDAY, SEPTEMBER 6.

The following Papers were read:—

1. *On the Brain of an Aboriginal Australian.* *By* Professor MACALISTER, *F.R.S.*

2. *On Heredity in Cats with an Extra Number of Toes.*[2] *By* E. B. POULTON, *M.A.*

Observations on this subject were brought before the notice of the British Association in 1883, the complete account being published in 'Nature' for November 1 in that year (p. 20). The abnormality had been then traced through six generations, and the stock in which it appeared through two earlier generations. The observations have been continued from 1883 until the present time, resulting in a large addition to the eighth generation, which now contains five families, and in the appearance of one family in a ninth generation. A very high proportion of abnormality continues in the recent families, and in the latest of all there are two kittens with seven toes on the forepaws and six on the hind; while in the last family of the eighth generation one kitten possessed seven toes on each forefoot and seven on one hind foot, with six on the other—the greatest abnormality which has come under my observation, although an even larger amount (seven on *both* hind feet) is on record in the same stock.

3. *On the Artificial Production of a Gilded Appearance in certain Lepidopterous Pupæ.* *By* E. B. POULTON, *M.A.*

A few years ago Mr. T. W. Wood brought before the notice of the Entomological Society of London some proofs that certain pupæ resemble the colour of the surface upon which pupation takes place. This conclusion was received with some incredulity by many leading entomologists, but without sufficient reason. For the last few years I have been working upon the colour of larvæ in relation to the colour of their surroundings, and I have shown that the colour may be modified in one generation (in certain species) by an appropriate alteration of the surroundings. It seemed very probable from these experiments that the larvæ were affected by their surroundings through some sensory surface, and that by means of a nervous circle a corresponding colour effect was wrought. It appeared to be very likely that Mr. Wood's observations were but a special case of those general methods of protection which I had been investigating. Mr. Wood explained his observations by supposing that the moist surface of a freshly exposed pupa was photographically

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[1] Published in the *Anatomischer Anzeiger*, vol. i. Part XI. 1886.

[2] The complete account of all the families, with figures of the abnormal paws, is published in *Nature* for the week ending Nov. 13, 1886.

sensitive to the colour of surrounding surfaces. Such an explanation appears to be merely a metaphor borrowed from photography, and it is furthermore unsupported by any proofs. There is, in fact, much *à priori* exception to be taken to it, inasmuch as it implies that all those pupæ which throw off the larval skin on a dark night must lose the advantages of this form of protective resemblance. It is much more probable that the effect is produced by the action of surrounding colours upon the larva during the time (long enough to include many hours of daylight) in which the latter rests upon the surface where pupation will take place. In the first place, I made many experiments in order to test the accuracy of Mr. Wood's observations, resulting, as I had anticipated, in the most complete confirmation. Among the pupæ experimented upon was that of the common tortoiseshell butterfly (*Vanessa urticæ*). It was found that by causing pupation to take place upon a white or black screen very different results could be produced. The pupæ upon the white screen were often brilliantly golden, and quite unlike all the ordinary forms assumed by this species, and well known to entomologists. Curiously enough, however, the pupæ of this and other species, which are full of parasitic larvæ of ichneumons, and which can never produce butterflies, are often as brightly gilded as those upon which I experimented. But my pupæ were perfectly healthy and produced normal butterflies. Considering the effects of my first experiments, it appeared probable that an artificially gilded surface would produce even stronger results than a white screen, and experiment soon confirmed this prediction. Such a result seems to imply that the metallic lustre of many exposed pupæ harmonised with equally brilliant objects among the vegetal or, more probably, the mineral surroundings.

The next point was to ascertain the period during which the larva was sensitive, and incidentally to confirm in the most complete way my suggestion that these effects are due to the larva itself, and not to the freshly formed pupa. These objects were achieved by transplanting the larva at various periods before pupation from one surface to another, which was known to produce an opposite effect. It was thus found that the larvæ are sensitive for many hours—even more than a day—before pupation takes place. It was then necessary to ascertain if possible the nature of the larval sensory surface which is affected by surrounding colours; and, first of all, the ocelli were eliminated by covering them with an opaque varnish (renewed if necessary), but this treatment did not affect the result. Equally ineffectual was the result of snipping off the larval bristles, which it was thought might possibly contain the desired sense-organ. Then another method was adopted: as soon as the larvæ suspended themselves head downwards (many hours before the change takes place), they were surrounded by tubes so constructed that the head and anterior part of the larva were contained in a gilt chamber, while the rest of the body was surrounded by black walls, tending to produce an opposite effect, the two compartments being separated by a perforated disc which just allowed the larval body to pass through. The head in the lower chamber was always turned on one side, so that the colour of the upper compartment could not possibly affect it. In other cases the colours of the compartments were reversed. When I first looked at the pupæ in these tubes I fully believed that the colours followed those of the chamber in which the larval head had been, and I was much puzzled by this, inasmuch as the only likely sense-organ—the ocelli—had been already eliminated by previous experiments. But when the pupæ were taken out of the tubes, and placed side by side upon white paper, I found that the effects I have described were entirely misleading, being due to reflection from the walls of the lower chamber when gilt, and to a dark appearance due to the surrounding black surface in the other cases. The negative result obtained seems to indicate that the sense organ exists in the skin, or that possibly the light acts in a more direct way upon the larval skin without the intervention of the nervous system. The full results of the investigation will not, however, be obtained until an immense amount of work has been bestowed upon the notes made during these experiments, in which many hundreds of individuals have been employed.[1]

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[1] See *Proc. Roy. Soc.* No. 237, 1885, and No. 243, 1886, and *Trans. Ent. Soc.* London, Pt. I. 1884, Pt. II. 1885, and Pt. II. 1886 for the experiments and observations upon larval colours alluded to above.

4. *Some Experiments upon the Protection of Insects from their Enemies by means of an unpleasant taste or smell.* By E. B. POULTON, *M.A.*

When working up the historical side of this question my attention was directed towards the necessity for further experiments. Wallace had predicted that brilliantly coloured and conspicuous insects would be refused by the ordinary vertebrate enemies of their class—that, in fact, the gaudy colouring acts as a warning of the existence of something unpleasant about its possessor. Conversely, Wallace argued that insects which were protectively coloured, resembling their surroundings, would be eaten when detected. It appeared that experiments (conducted by Mr. Jenner Weir and others) yielded the most complete proof of the existence of these sharp distinctions. But on thinking the whole subject over it seemed to me that the acquisition of an unpleasant taste or smell, together with a conspicuous appearance, was so simple a mode of protection and yet, *ex hypothesi*, so absolutely complete, that it is remarkable that more species have not availed themselves of this means of defence. What could be the principle which worked in antagonism to this mode of protection? For in Wallace's theory no suggestion of a true counterbalancing limit appeared, *i.e.*, one which increased with the increasing application of this method of defence until the latter was checked, or for the time being rendered of no avail, or even turned into an absolute danger. But if a very common insect, constituting the chief food of one or more vertebrates, gained an unpleasant taste, the latter animals might be forced to devour the disagreeable objects in order to avoid starvation. And the same thing might readily happen if a scarce and hard-pressed form adopted the same line and so became dominant, after ousting many species which were much eaten by vertebrates. If once the vertebrate enemies were driven to eat such an insect in spite of the unpleasant taste, they would certainly soon acquire a relish for what was previously disagreeable, and then the insects would be in great danger of extermination if in the meantime they had become conspicuous by gaining warning colours. If this reasoning be correct it follows that this mode of defence is not necessarily perfect, and that it depends for its apparently complete success upon the existence of relatively abundant palatable forms. In other words, its employment must be strictly limited. In order to test my argument I determined to experiment with a view to ascertain whether hunger would drive a vertebrate to eat an insect which was evidently unpleasant to it. I obtained a few different species of Italian lizards and some tree-frogs, and very soon found that I had reasoned correctly. The lizards would often refuse a conspicuous insect at first, with all the signs of repugnance, but would afterwards make the best of it, when they were not supplied with other food which they liked better. I sometimes found this to be the case with species (*e.g.*, larva *P. Bucephalus*) to which other observers have ascribed the most complete immunity. I should add that it has been always recognised that an insect may be distasteful to one vertebrate enemy but palatable to another, and to this extent Wallace admits a limit to the application of his principle of defence. But the limit which I have proved is of course entirely different, for I have shown that the vertebrate may be forced to eat the insect, *although unpalatable* to it. Although the latter limit is thus quite distinct, it would certainly in time become identical with the former, for, as I have argued above, the unpalatable forms when eaten would soon become palatable. I have, in fact, shown how the limit which Wallace himself admits has grown up, and how it may become a counterbalancing principle, working against and perhaps reversing the principle which he was the first to point out as of general application in insects. Some quite new modes of defence came out during the inquiry. Thus size alone seems to act as a protection: a large moth (*S. ligustri*), evidently palatable and quite harmless, was untouched by small lizards, but eaten by larger ones. Again, it is probable that a species may acquire protection by causing digestive troubles after being eaten, rather than by having an unpleasant taste, and it may be that the former effect would leave an even more indelible effect than the latter upon the memory of the captor. Some experiments with the frogs rendered this conclusion probable (*E. Jacobææ* imago being used).

Another result at first surprised me very much; it was a limitation to the universal application of Wallace's second prediction. I found that certain species which are well protected by resembling their surroundings, were nevertheless also protected by an unpleasant taste (*e.g.*, larva of *M. Typica*, imago of *P. Bucephalus*) and were only eaten with reluctance in the absence of other food.

I have given a brief abstract of the results of my experiments, which on the whole confirm the general principles which Wallace laid down, but show that there are other principles which may work in antagonism and prevent the application of the former, or may even reverse their action. I have also shown that these two methods of protection are not always sharply demarcated or mutually exclusive, as was previously believed to be the case.

5. *On the Nature and Causes of Variation in Plants.*[1] *By* PATRICK GEDDES.

In this paper (a preliminary outline of a more extended analysis underlying the writer's essay on 'Variation and Selection,' in preparation for a forthcoming volume of the 'Encyclopædia Britannica') it was first pointed out that while the fact of the origin of species by evolution was no longer disputed, nor the operation of natural selection upon organic forms any longer denied, the absence of any general theory or *rationale* of variation in either the animal or the vegetable world was not only generally admitted, but often regarded as inevitable or even hopeless: variation to some writers being simply 'spontaneous' or 'accidental;' to others, if not fortuitous, at least dependent upon causes lying beyond our present powers of analysis.

A theory of variation must deal alike with the origin of specific distinctions or those vaster differences which characterise the larger groups. To commence, then, with the latter, we may propose such questions as, *e.g.*—(1) How comes an axis to be arrested to form a flower? (2) How is the evolution of the forms of inflorescence to be accounted for? (3) How does perigyny or epigyny arise from hypogyny? (4) How is the reduction of the oophore and differentiation of the sporophore to be explained among cryptogams and phanerogams, and why should the moss type be so aberrant and so comparatively arrested? (5) How do angiosperms arise from gymnosperms? (6) How are the forms of fungi, algæ, &c., to be accounted for? and so on. The explanation was shown to lie not in the operation of natural selection upon accidental variation, requiring separate explanation in every case, but upon that general and familiar antagonism between reproduction and vegetative growth further analysed (in the writer's subsequent paper 'On the Theory of Sex and Reproduction,' and 'Encyclopædia Britannica' article SEX) to its basis in the constructive and destructive metabolism of protoplasm. It was shown by the aid of diagrams that in all such cases as those above mentioned, the reproductive axis, organ, tissue, &c., in every case tended to become more and more shortened, depressed, or hollowed in proportion to the vegetative. This conception was further developed, and shown to apply alike to the construction of the general genealogical tree, and in particular to the affinities of the flowering plants; and very frequently to the interpretation of minute details of floral structure usually regarded as the product of natural selection on spontaneous local variations, the common Geranium sylvaticum being selected as a case in point.

6. *The Honey Bee* versus *Darwinism.* *By the* Rev. T. MILES.

7. *On the Biological Relations of Bugio, an Atlantic Rock in the Madeira Group.* *By* Dr. GRABHAM.

Reasons for Writing.—Because seldom visited though possessing special interest, and because considered typical of insular flora distribution and variation by Lyall and others.

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[1] See writer's paper bearing same title as the above in *Trans. Bot. Soc. Edin.* 1885–6

Author proposed to illustrate recent accumulation of facts and variations by reference to prominent instances of distribution, &c., from one of the smallest and most inaccessible rocks of the group.

Physical Characters of Dezertas Origin.—Foundation on a narrow ledge, dimensions not much changed, no evidence of contact or union, not survivals of an ancient continent. Islands in a Miocene sea, deriving their colonists from Miocene Europe.

Description of Bugio.—Dimensions, formation, central volcanic dike, difficulty of access, large proportion of tufas; no sections of old river-beds or surface obliterations.

Summit showed deep clay-beds and surface deposits of calcareous earth and sands, with 'fossils,' so called, of Madeira.

Flora.—Relation to Madeiran, arbitrary distribution, absence of easily wafted forms.

Senecio incrassatus, form of, how related to Madeira and Canary Islands.

Echium fastuosum, maritime form of; relations to other Madeiran Echia. Hybrid with E. simplex, deriving perennial characters and change of colour and habit.

Jasminum oderatissimum, Mesembrianthema, as instances of fitful distribution.

Chrysanthemum hæmatominmata, a distinct and only species, description of, and remarks on cognate Madeira forms.

Monizia edulis, Dezertan, Salvagic and Madeiran examples and varieties. Description of, Miocene origin of.

Fauna.—Mischievous presence of goat and rabbit.

Feral character of rabbit, reference to Darwin's description of, identical with that of Porto-santo, description of.

Sea Birds.—Sternus hirundo. Thallassidroma Bulwerii and many other Petrels; existing confusion of species in Loudon. Procellaria Anglorum dominant at Bugio, excluding P. major and P. obscura. Influence of, on migration of plant-species; size of egg and form.

Testacea.—Helix crystallina, affinities; H. leonina, distribution; H. erubescens, distribution; H. punctata, modification of; H. vulgata, dwarfed sub-fossil; H. polymorpha, Bugian form; H. coronata, description of, and affinities to H. Grabhami and others.

Coleopterous Deucalion, species of, how related to Salvagic form.

Short Summary.—The above instances show the difficulties attending studies of the presence, origin, and variation of fauna and flora from a single point, to be equally great locally as between the archipelago itself and an ancient continent.

Agency of Man, ancient and modern. Destruction of cover and food in vegetation; contaminating introductions. Man obvious chiefly in extinction; instances from St. Helena as well as Madeira.

Ravages of Eupatoria and Phylloxera in Madeira, and of other species.

Surviving vigour of Miocene forms of plants.

Author's paper only meant to be indicative, and does not pursue any branch in detail, though the history of any variety would profitably occupy the time of the Section.

8. *On some new Points in the Physiology of the Tortoise.*
By Professor HAYCRAFT.

9. *Preliminary Account of the Parasite Larva of Halcampa.*
By Professor HADDON.

10. *Notes on Dredging off South-West of Ireland.* *By* Professor HADDON.

11. *Points in the Development of the Pectoral Fin and Girdle in Teleosteans.*

By EDWARD E. PRINCE.

At a very early stage, and long before liberation from the ovum, the pectoral fins can be distinguished in Osseous Fishes as a pair of flattened pads projecting horizontally from the trunk, some distance behind the otocysts. Their position seems to vary in different species,[1] but a considerable interval always separates the early fins from the auditory organs, or rather from the true pectoral region. They are differentiations of a continuous lateral expansion of epiblast passing along each side of the trunk, and are formed by the folding of this epiblastic layer upon itself at the point where the fins appear. Each fin consists therefore of two epiblastic lamellæ (separated by a fissure) lying flat upon the vitellus, and continuous with the extra-embryonic blastodermic membrane. The fins soon assume a denser appearance as mesoblastic cells push their way into the median fissure, separating the upper from the lower lamella of the fin. These mesoblastic cells are certainly not splanchnopleuric, but as no well-marked somatopleuric crest has been recognised in fishes comparable to the Wolffian ridge of higher forms, they seem to be derived from the intermediate cell-mass in close proximity to the Wolffian ducts.

As the fin becomes stouter its position alters, its lengthy lateral attachment to the trunk diminishes, while it becomes pedunculate and stands erect, though not quite vertically. The distal portion of the fin is very thin and transparent, save at the periphery, where, at the junction of the upper and lower lamellæ, the epiblast cells are approximated so as to form a marginal ridge probably connected with the subsequent development of dermal fin-rays.

Meanwhile the fin progresses over the interval before mentioned to a point immediately behind the auditory organs, and the well-known rotation of the fin is accomplished, so that it now projects obliquely in a dorso-ventral direction almost parallel to the plane of the branchial arches in front.

The gradual shifting of the fin from its original place brings it into close relation with a band of mesoblastic cells, which passes obliquely behind the otocysts, and is called by Ryder the 'oblique or vertical pectoral fold.' In this fold cartilage-cells appear, and extend dorsally and ventrally. To the cartilaginous pectoral bar, thus formed, the fin-plate becomes attached, and simultaneously a median stratum of mesoblast in the latter is converted into cartilage, which, by its basal portion, articulates with the girdle. It is noteworthy that each half of the pectoral arch originates independently, nor do they approach each other in the middle ventral line until a much later stage. A strong plate of translucent ectochondral bone, like a curved bar of chitin, develops and becomes attached to the scapulo-coracoid rod, and the subsequent reduction of the latter (the primary cartilaginous girdle) produces much complication in the adult structure.

Without desiring to lay undue stress upon the suggestions afforded by the development of the anterior limb and its girdle in forms so highly specialised as the Osseous Fishes, it is still of interest to note their bearing upon accepted theories as to the true nature of the fin and its related arch.

Support is thus certainly given to the continuous lateral-fin theory of Balfour, for the fins arise in connection with longitudinal epiblastic ridges extending in a horizontal plane[2] from the trunk of the embryo, while their independent origin is adverse to Gegenbaur's view that they spring from a branchial arch and are modified gill-arch elements. Owen, more than a quarter of a century ago, compared the branchiostegal rays springing from the hyoid arch to the 'pectoral fin diverging from the hæmal arch' (*i.e.*, the pectoral girdle); but Balfour's view (which is also that of Dohrn and Mivart) receives more countenance from Teleostean embryology. Dohrn, however, not only regards the fins as aggregations of a long lateral fin; but supposes that the coalesced fins became connected with underlying gill-arches which ancestrally extended beyond their present limits. Gegenbaur

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[1] The forms especially referred to by the writer are certain species of *Gadus*, *Pleuronectes*, *Cottus*, &c., studied at the Marine Laboratory, St. Andrews.

[2] This position is, according to Gegenbaur's view, secondary, whereas in Teleosteans it seems to be primary, and the vertical position is assumed secondarily.

also derives the pectoral girdle from a branchial arch, and, according to both authorities, this arch must have shifted to the surface from a deeper plane of origin, for the girdle is essentially a superficially placed structure. The visceral cleft system arises more deeply, and is hypoblastic, the gill-arches being developed in the splanchnopleure, whereas the cartilaginous pectoral girdle is somatopleuric, if the cells, from which it originates, are to be distinguished from the adjacent intermediate-cell mass. There are many difficulties in deriving the fin from branchial arch appendages, even so primitive a girdle as that of Ceratodus having no directly articulating rays, comparable to branchiostegal elements, and there are difficulties no less in assigning a branchial origin to the shoulder-girdle itself. The girdle arises as two separate rods, external to the heart and the alimentary tube, and passing dorso-ventrally. Its two elements originate, indeed, precisely like a pair of strongly developed ribs, for the ribs begin as ossifications at independent centres in the intermuscular septa, and grow both ways, dorsally to unite with the vertebral bodies, and ventrally to meet or remain separate, as the case may be. In exactly the same way the scapular and coracoidal halves of the pectoral bars develop to subserve the same function—viz., that of providing a support in connection with the movements of the body.

The attachment of the pectoral girdle to the skull recalls the connection of undoubted rib-elements with the skull in Carps and Siluroids. Can we not refer the two halves of the pectoral girdle to the axial skeleton as strengthened and modified costal rods,[1] possibly equivalent to many coalesced ribs, to which the fins, originating independently, become secondarily attached? It is significant that the Cyclostomes are destitute of ribs, and they possess no limbs; and this accords with the above suggestion, for if no ribs exist, no limb-girdle could be developed from them. In the Selachians it is noteworthy that the ribs seem to have suffered great degeneration. Whether a costal or branchial origin be attributed to the pectoral girdle, the appended limbs are wholly separate structures, and only become related to it after changes in shape, position, and function of the most remarkable character.

12. *Some Remarks on the Egg-Membranes of Osseous Fishes.*
By Robert Scharff, *Ph.D., B.Sc.*

It is no doubt due to the transparence and the extreme smallness of the objects that so many different opinions prevail on the structure of the Teleostean ovum. All authors, however, agree that a membrane surrounds the egg, which in many if not in all cases, is pierced by minute canals or pores. The name most generally adopted by zoologists for this membrane is 'zona radiata,' which I think is a much more suitable one than 'vitelline membrane,' or 'yolk sac,' for reasons which I shall give presently.

In the ovum of the gurnard (*Trigla gurnardus*) I could distinctly see with a high power a very delicate homogeneous membrane internally to the 'zona radiata.' In the ripe egg, or rather in the fully-grown intra-ovarian egg, it covers the protoplasmic layer known as the 'Rindenschicht,' or 'periblast,' which is one of the later modifications of the yolk. Ransom was the first observer who not only saw a similar membrane in various Teleostean eggs, but also isolated it. Some of the later observers failed to make it out; others, again, confirm Ransom's observations. As long as any doubts exist as to presence or absence of this inner 'yolk sac' of Ransom, the 'zona radiata' should not be called a vitelline membrane. The latter term, however, might very well be applied to the inner membrane which I have just mentioned. It corresponds to a cell-membrane, and is, therefore to be considered as a vitelline membrane.

In the gurnard as well as in the cat-fish (*Anarrhichas lupus*) the zona radiata showed an external portion which stained darker, and through which the pores piercing the inner part were apparently continued. This outer part was sometimes

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[1] Prof. Humphry, of Cambridge, hinted at a connection of certain elements in the coalesced lateral fins (that is to say, the median longitudinal fins) and the ribs, in the *Journ. of Anat. and Phys.* vol. x. p. 671.

separated from the inner in cross-sections, and the pores were frequently obliterated by numerous very fine granules contained in it. In the ripe egg of the cod (*Gadus morrhua*) only one thin membrane is visible, which, as far as I could ascertain, is not porous. I am not quite convinced that the pores are really absent in this case, as I only examined spirit specimens, but it occurred to me that what we see here is really only the outer denser part of the zona radiata, the inner portion having become absorbed during development. That such a thing might happen has been fully demonstrated by Balfour in the egg of Scyllium. Balfour's vitelline membrane is equivalent to the outer part of the zona just mentioned. Both of these seem to become absorbed in some of the Elasmobranch eggs during later development.

With regard to the Teleosteans I might mention that, in case the presence of a true vitelline membrane should be definitely established in all intra-ovarian eggs, the zona radiata is to be regarded as a cuticular formation of the ovum.

Every intra-ovarian egg is surrounded by the follicle or granulosa, which is a cellular layer. In a paper which I propose to publish shortly, the formation of the yolk will be fully considered along with some remarkable changes which take place in the nucleus of the growing egg.

TUESDAY, SEPTEMBER 7.

The following Papers were read:—

1. *On* Humboldtia laurifolia *as a Myrinekophilous Plant.*
By Professor F. O. Bower.

It is already well known that the hollowed and swollen internodes of *Humboldtia laurifolia* are inhabited by small black ants. The questions which present themselves with regard to this symbiosis are—1st, How do the hollows originate? 2nd, Is the presence of the ants of any advantage to the plant? An investigation of young shoots shows that the opening, through which the ants enter, is formed by rupture of the superficial tissues, owing apparently to pressure from within, and that the ants thus gain access to and hollow out the pith which had previously begun to decay. Thus the plants take the initiative, and the ants are not slow to avail themselves of the opportunity offered. Further, from the numerous glands on the leaves it is probable that they derive food, and are thus supplied with both nourishment and lodging. No evidence is forthcoming, however, that the symbiosis is of any advantage to the plant. The stipules in this plant are of a peculiar form; a study of their development shows that a peculiar auricle-like outgrowth is formed at the base of the simple, young stipule, subsequently to the origin of the latter. Though this assumes a peculiar, almost sagittate form, still in its real nature it is similar to those auricles which are formed at the base of the stipules of *Viola tricolor*.

2. *On Positively Geotropic Shoots in* Cordyline australis.
By Professor F. O. Bower.

It was noticed in Peradeniya Gardens that when, by reason of the weight of the head of leaves, stems of *Cordyline australis* assumed an oblique or horizontal position, shoots were formed from the lower side pointing directly downwards. It was ascertained that these were in their origin axillary. By hanging pots of soil in such a position as to immerse the tips of these shoots, an elaborate root system was soon formed, the roots arising in the usual manner. In the cases observed the apex of the shoots remained covered with scale leaves, and the ultimate fate of it is uncertain. It is clear that here we have a special adaptation for mechanical and physiological support of a weakly axis, and in this respect we may compare the cases of *Ficus* and *Pandanus*, and also of *Rhizophora*, though it is to be noted that in *Cordyline* shoots are the members employed, while roots are used in the other cases named.

3. *Note on Apospores in* Polystichum angulare, *var.* pulcherrimum.
By Professor F. O. Bower.

Specimens were shown illustrating the above peculiarity, which has been recently observed in a plant from a locality quite distinct from that where the original plant was taken some twenty years ago.

4. *On the Formation and Escape of the Zoospores in Saprolegniæ.*
By Professor Hartog.

5. *On the Germination of the Spores of* Phytophthora infestans.
By Professor Marshall Ward, *M.A.*

6. *Two Fungous Diseases of Plants.* *By* W. B. Grove, *B.A.*

The first was the 'Eucharis disease,' which has been shown by the author to be due to the fungus, *Saccharomyces glutinis.* It attacks other bulbs besides Eucharis, and may be known by producing reddish spots. It can be killed by growing the bulbs in a considerable heat, or by sulphide of potassium.

The second was a 'Viola disease,' attacking cultivated species of Viola. It is due to an Œcidium and its accompanying Puccinia, known respectively as *Œcidium depauperans* and *Puccinia ægra.* It has only been observed in two or three districts, as yet; and does considerably more harm to its hosts than the similar disease which is common on *Viola canina.*

7. *Preliminary Notes on the Autumnal Fall of Leaves.*
By Professor W. Hillhouse, *M.A., F.L.S.*

So far as these experimental investigations—commenced in the autumn of 1882 and still in progress—are concerned, the question of the autumnal fall of leaves has been approached from two standpoints.

(1) The mechanism of leaf-fall.

(2) The transfer of the cell-contents from the leaf.

(1) *The Mechanism of Leaf-fall.*—It appears to be certain that the dissociation of leaf and branch takes place by the formation, by means of renewed cell-division in the basal plane of the leaf-stalk, of a layer of cells, which the author proposes to call the *absciss-layer.* The absciss-layer is produced by new dividing walls being formed across the cellular tissue of the base of the leaf-stalk. It is clearly recognisable, not merely by means of these walls, but also by its marked quantity of protoplasm, and the presence usually of numerous small grains of starch. The exact position of the absciss-layer slightly varies, always outside the periderm line of the branch, and usually sloping inwards and upwards. It is formed usually very shortly before the fall of the leaf. In some cases no absciss-layer is formed, and the leaf does not fall normally. The formation of the absciss-layer may be either preceded, sometimes by a fair interval of time, or succeeded by the formation, on the stem side of it, of a periderm; this likewise by new dividing cells being formed in a pre-existing cellular tissue. This periderm lies usually more or less in the line of that of the branch, and becomes continuous with it. The cells outside the periderm shrivel.

The author's experiments tend to show that the fall of the leaf arises from the increased turgescence of the cells of the absciss-layer, owing to their osmotic activity. These become strongly rounded; their adhesion equally diminishes.

This turgescence appears to arise from root-activity continuing, after the transpiration, or rather conducting, power of the leaf, for reasons hereafter noted, has been in the main lost. The presence of water in the living cells of the absciss-layer is so much the greater from their being bounded by cells which are practically dead; and whereas the rounding of two living cells in contact need not destroy their power of cohesion, the rounding of a living cell in contact with one which is dead would probably cause complete separation.

The soft elements of the vascular bundles are either pinched, or else cell-division takes place in them also. The lignified elements undergo changes, the nature of which I am not yet able to explain satisfactorily, and then rupture with the strain.

(2) *The transfer of the cell-contents from the leaf.*—In leaves about to fall, starch is always found in the sieve-tubes, mainly collected in cloudy, granular-looking masses in the neighbourhood of the sieve-plates. With iodine these grains do not stain violet, but brown or reddish-brown. The accumulation is commonly greatest on the leaf side of the sieve-plate. To be devoid of starch is usually the first sign of a leaf being ready to fall. In all cases where tannin is present in the leaf, it is present, and with the same distribution, in the fallen leaf. Tannin and starch are especially abundant in what I will call the food-layer at the base of the leaf-stalk, in which the absciss-layer and cork-layer are formed. In naturally fallen leaves starch is rarely found, except right at the very base of the stalk, and then in very small grains. Taking in all cases precautions against prematurely fallen leaves, perfect nuclei are comparatively rare in fallen leaves, though in some cases (*e.g.*, *Salisburia adiantifolia*, *Acer platanoides*, *Catalpa bignonioides*, *Quercus pedunculata*, and *Ficus Carica*) perfect nuclei are general in blade and petiole. Cells containing no nuclei have, however, very commonly a number of larger or smaller irregular fragments of proteid matter, staining deeply with ammonia-carmine or methyl-green. In many cases, where the nuclei are apparently perfect, they show manifest granularity, and often irregularity of outline. The evidence tends thus to show that the nucleus, or at least the chromatin, is left behind in the empty cell, the nucleus tending to what we will call 'disintegration,' as distinguished from 'fragmentation' or direct division, this latter being by no means a sign of the death of the cell. Nor does disintegration bear any relation with the fragments of nuclear substance found in many pollen-tubes which show no nucleus, nor with the scattered small grains, which perhaps replace the nucleus in many Chroococcaceæ, Nostocaceæ, &c. Perhaps a strict classification would require to divide the terms 'direct division' from 'fragmentation,' both possible in living cells.

It is interesting to note in this connection that from the leaves of the few evergreens that I have thoroughly studied, starch is likewise usually absent in winter, being transferred to the stem, the tannin, on the other hand, remaining behind.

8. *On an Apparatus for Determining the Rate of Transpiration.*
By Professor W. Hillhouse, *M.A.*, *F.L.S.*

9. *On the Cultivation of* Beggiatoa alba.
By Professor W. Hillhouse, *M.A.*, *F.L.S.*

This bacteriad is especially found on decaying algæ, &c., in sulphur springs and waters receiving the refuse of factories. It is comparatively large, the threads varying in thickness from 0·001 to 0·005 mm., and hence is very suited for laboratory purposes in teaching. Though normally in the form of segmented threads, attached to a substratum, it illustrates the most modern conceptions of bacteriologists (Cohn, Zopf), showing, in various stages of its existence, coccus forms, rodlets, spirals, swarming movements, and even creeping movements, which much resemble those of the oscillarians. For laboratory work it can be kept growing continuously and with certainty upon fragments of india-rubber tubing in water, upon which it will usually appear spontaneously after the lapse of a few months.

10. *On Heterangium Tilioides.*

By Professor W. C. WILLIAMSON, *LL.D., F.R.S.*

In part iv. of my series of memoirs in the 'Philosophical Transactions' I published a description of a remarkable stem from Burntisland, to which I gave the name of Heterangium Grievii. More recently we have obtained a second and yet more interesting species of the same genus from Halifax. In many respects it agrees closely with H. Grievii, especially in the structure of its central axis and its exogenous zylem-zone. Its distinctive features are chiefly confined to the bark and phloem-zone. In H. Grievii I found no traces of a true phloem, but such a zone is fully developed in the new species, to which I propose to give the name of Heterangium Tilioides. The vascular zone is abundantly furnished with medullary rays of various sizes. The largest primary ones are not only prolonged into the bark as phloem-rays, but as they pass outwards their section assumes the trumpet shape seen in those of the common Lime, the large square, parenchymatous cells of which they are composed being arranged in irregularly parallel, arched lines, the concavities of which face the zylem. Between each pair of these primary phloem-rays is a mass of true phloem, through which the numerous narrow secondary medullary rays are also prolonged outwards to the cortex. Longitudinal sections show the phloem to consist of much parenchyma, through which numerous elongated, thin-walled, narrow tubes pass vertically. In tangential sections these tubes are seen to follow an irregular, wavy course, reminding us of the bands of hard bast in the lime. I detect no evidence of the presence of true sieve-tubes in this phloem, though some of the numerous thin-walled tubes may represent those tissues.

External to the phloem-zone are two very distinct zones of cortical parenchyma, in which we discover twin pairs of large vascular bundles passing outwards to what I presume have been foliar organs; and in the outermost cortical zone we discover large, defined masses of sclerous parenchyma. The plant also exhibits proofs that it also gave off true branches of larger size than mere foliar appendages.

The vessels vary, from small ones with reticulated semi-scalariform walls in the young foliar (?) bundles, to others of intermediate size in the exogenous zone; whilst the latter conduct to the very much larger ones, which, intermixed with the medullary parenchyma, constitute the medullary axis of the plant. Those of the exogenous medullary regions are unquestionably vessels exhibiting modified conditions of bordered pits. The zylem, phloem, and cortical zones of this plant unquestionably suggest Gymnospermous relationships; but the structure of the centre or medullary axis has nothing analogous to it among known Gymnospermous plants, recent or fossil. It approaches much more nearly to what we find in the corresponding axis of Lepidodendron selaginoides.

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11. *The Multiplication and Vitality of certain Micro-organisms, Pathogenic and otherwise.* *By* PERCY F. FRANKLAND, *Ph.D., B.Sc., F.C.S.*

In this paper the author records a number of experiments which he has carried out on the multiplication of the micro-organisms present in natural waters, and also on the vitality of certain pathogenic organisms when purposely introduced into similar media.

These phenomena have been studied by aid of the method of gelatine-plate cultivation, originally devised by Koch. The first part of the paper treats of the influence of storage in sterilised vessels, upon the number of micro-organisms present in the unfiltered water of the rivers Thames and Lea, in the waters of these rivers after sand-filtration by the companies supplying the metropolis, and in deep-well water obtained from the chalk. Of these three different kinds of water, at the time of collection the unfiltered river-waters are the richest in micro-organisms, containing, as they do, several thousand microbes, capable of being revealed by plate-cultivation, in one cubic centimetre of water, whilst the filtered river-water have this number generally reduced by about 95 per cent., and the number present in the deep-well water rarely exceeds 10 per cubic centimetre.

On storage in sterilised vessels at 20° C., however, a great change in the relationship of these numbers soon takes place, for whilst the number of organisms in the crude river-water undergoes but little change or even suffers diminution, that in the filtered river-water exhibits very rapid multiplication, and this increase is even still more marked in the case of the deep-well water. The author suggests that the differences in the rate of multiplication exhibited by these three kinds of water is dependent upon the number of different varieties of micro-organisms which they contain. Thus in the unfiltered river-waters the organisms belong to a number of different kinds; the filtered river-waters exhibit fewer varieties; whilst in the deep-well water the number of varieties is still more limited, the gelatine-plates having generally the appearance of almost pure cultivations. The microbes in the deep-well water will thus be less hampered in their multiplication by hostile competitors than those in the filtered river-waters, and these again less than those in the crude river-waters, in which an equilibrium must have already been established between the various competitors.

When the waters were exposed to a temperature of 35° C. the multiplication was in all cases very much more rapid, but both at 20° C. as well as at 35° C. the multiplication was, on prolonged storage, followed by reduction.

The pathogenic forms which have been studied by the author are (1) Koch's '*Comma*' *spirillum* of Asiatic cholera, (2) Finkler-Prior's '*Comma*' *spirillum* of European cholera, and (3) the *Bacillus pyocyaneus*, which produces the greenish-blue colouring-matter frequently present in abscesses. The vitality of these organisms has been studied by introducing minute quantities of their cultivations into sterilised distilled water, deep-well water, filtered Thames water, and London sewage. In these media they present some very striking differences. Thus the Bacillus pyocyaneus was found to flourish in all; even in distilled water it was present in largely multiplied numbers after fifty-three days. Koch's 'Comma' spirillum, on the other hand, when introduced into deep-well water was no longer demonstrable after the ninth day, whilst in sewage it was still found in enormously multiplied numbers after twenty-nine days.

Finkler-Prior's 'Comma' spirillum, although showing such far greater vital activity than Koch's in gelatine cultures, possesses far less vitality than the latter when introduced into water. Thus in the above-mentioned media it was in no case demonstrable after the first day.

A curious phenomenon was observed in the case of the Bacillus pyocyaneus and Koch's 'Comma' spirillum, viz. that when introduced into water a large proportion of these organisms at first perish, the numbers often becoming greatly reduced, the survivors subsequently, having apparently adapted themselves to the new medium, multiplying to a greater or less extent.

The author points out how necessary it is that each pathogenic organism should be made the subject of separate investigation, and how fallacious must be any generalisations concerning the vitality of pathogenic microbes which are based upon the study of a single form.

The more important results referred to above are summarised in the following table:—

BACILLUS PYOCYANEUS IN DISTILLED, DEEP WELL, FILTERED THAMES WATER, AND SEWAGE.

Number of Colonies obtained from 1 *cc.*

—		Day of Preparation	2nd	3rd	5th	8th	18th	20th	53rd day
Distilled Water	1	6,100	203	—	—	—	—	276	100,000
	2	6,800	368 (Incub.)	—	—	—	—	13,400 Incub.	69,000
Deep-well Water	5	262,000	—	—	851 (Incub.)	87 (Incub.)			
	6	262,000	—	—	195,000	227,000			

BACILLUS PYOCYANEUS, &c.—*continued.*

Number of Colonies obtained from 1 *cc.*

—		Day of Preparation	2nd	3rd	5th	8th	18th	20th	53rd day
Filtered Thames Water	1	3,900	—	Innum.					
	2	3,900	—	Innum. (Incub.)					
Sewage	1	29,000	—	Innum. (Incub.)	—	Innum. (Incub.)	547,000 (Incub.)		
	2	29,000	—	90,500	—	Innum.	Innum.		
	3	29,000	—	116,500	—	Innum.	Innum.		

KOCH'S 'COMMA' SPIRILLUM IN DEEP-WELL WATER, SEWAGE, AND FILTERED THAMES WATER.

Number of Colonies obtained from 1 *cc.*

—		Day of Preparation	2nd	5th	6th	9th	11th	17th	29th
Deep Well	1	5,750	0 (Incub.)	0	0	—	0		
	2	5,750	0	0	0	—	0		
Sewage	3	4,750	Innum. (Incub.)	Innum.	Innum.	—	96,000		
	4	4,750	60,000 (20°C.)	Innum.	Innum.	—	Innum.		
Deep Well	5	456	18 (Incub.)	1,225	—	147	—	0	0
	6	456	57 (20°C.)	3,834	—	1,232	—	0	0
Sewage	7	300	Innum. (Incub.)	Innum.	—	Innum.	—	128,000	56,000
	8	300	19,000	Innum.	—	Innum.	—	Innum.	Innum.
Filtered Thames Water	9	—	188 (Incub.)	0	0	0			
	10	—	63	313	480	173			

12. *The Distribution of Micro-organisms in the Air of Town, Country, and Buildings.* *By* PERCY F. FRANKLAND, *Ph.D., B.Sc., F.C.S.*

This paper contains the results of a number of experiments which the author has made on the relative abundance of micro-organisms in the air of different places, and of the same place at different times. In these experiments the number of microbes contained in a given volume of air has been supplemented by the determination of the number falling upon a unit of horizontal surface (1 sq. foot) in a unit of time (1 minute).

The determinations of the number of organisms in a given volume have been made by means of the apparatus originally devised by Hesse, which consists in slowly aspirating a known volume of air through a wide glass tube coated internally with sterilised nutrient gelatine. The author confirms the observations of Hesse, that, when the current of air is not too rapid, practically the whole of the organisms present in the air are deposited within the first half or two-thirds of the tube. That this deposition is due to gravity alone is shown by the fact that the organisms, or rather the visible colonies which result from them, are all found upon the bottom of the tube. The organisms which, in general, exhibit least tendency to subsidence, and which are sometimes carried nearer the further extremity of the tube, are moulds.

The number of organisms falling on a given area has been determined by exposing for a definite time small glass dishes filled with sterile nutrient gelatine.

The greater part of the experiments have been made on the roof of the Science Schools, South Kensington, whilst comparative determinations have been made in various places both in town and country.

A number of experiments were made with a view to determining the effect of altitude upon the abundance of microbes in the air. These experiments were carried out at various stages on the dome of St. Paul's and on the spire of Norwich Cathedral. The air in buildings has also been submitted to examination, and the fact established that, whilst in enclosed spaces in which the air is at rest the number of microbes in suspension may be very small, yet when aërial disturbance is occasioned, *e.g.*, by persons moving about, the number is enormously increased.

Some of the more important results are summarised in the following table:—

Place		Number of Organisms in ten litres of air	Number of Organisms falling per square foot per minute
Roof of Science Schools, South Kensington (average)		35	279
Country Places (average)		14	79
Open Places in London (Kensington Gardens, Hyde Park, Primrose Hill) (average)		24	85
St. Paul's	Golden Gallery	11	115
	Stone Gallery	34	125
	Churchyard	70	188
Norwich Cathedral	Spire (300 feet)	7	49
	Tower (180 feet)	9	107
	Close	18	354
Kensington Museum (Friday)		18	20
Ditto (Saturday) free day		73	87
Natural History Museum (morning)		50	136
Ditto (afternoon) (number of visitors more numerous)		70	255
Railway Carriage, four passengers, window open		—	395
Ditto, ten passengers, window almost closed		—	3,120
Ward in Brompton Hospital for Consumption (8 beds) morning		43	11
Ditto, afternoon		130	130
Ditto, night		42	44

The figures given in the above table show that the air on the roof of the Science Schools is very considerably richer in micro-organisms than that collected in the London parks, and this again than that of the country.

The gradual attenuation of the microbes in ascending St. Paul's and the spire of Norwich Cathedral is also very striking.

The figures obtained in the museums, railway carriage, and Hospital for Consumption speak for themselves, and show how in confined spaces the number of micro-organisms present in the air is influenced by the number of persons moving about.

13. *Note on the Floral Symmetry of the Genus Cypripedium.*
By Dr. MAXWELL T. MASTERS, *F.R.S.*

In this note the author adverted to so much of the normal structure of Orchids in general, and of Cypripedium in particular, as is necessary for the elucidation of his subject, and proceeded to describe a case of regular peloria in Cypripedium caudatum, which shows a reversion to the typical form of Orchids, and goes to prove that the so-called genus Uropedium was only a pelorian form of Cypripedium.

The construction of the andrœcium in these plants is then alluded to, and illustrations given of all intermediate stages from monandry to hexandry.

The frequently observed tendencies to a dimerous condition, and to the development of the inner row of stamens, was alluded to, and the significance of these changes pointed out.

The morphological changes consequent upon hybridisation, and the inferences to be derived from them, were passed under review. The paper concluded with a general summary of the teratological changes observed in the tribe Cypripedieæ.

14. *On the Culture of usually aerobic Bacteria under anaerobic conditions.*
By Professor MARCUS M. HARTOG *and* ALLAN P. SWAN.

Bacillus subtilis, regarded as a most typically aerobic bacterium, will germinate in appropriate nutritive solutions, form its 'Kahmhaut' and spores, when oxygen is excluded from the space not occupied by the liquid and replaced by carbon dioxide. Under these circumstances pressure rises in the closed apparatus employed, and bubbles of CO_2 raise the Kahmhaut in parts, leading to the inference that the vital energy of *B. subtilis* is, under these conditions, derived from true fermentation, not oxidation.

The lactic organism of Pasteur, usually aerobic, will develope and grow in suitable solutions during or after alcoholic fermentation induced by Saccharomyces, as in Kephir and other forms of Koumiss, and after the oxygen *must* be used up and replaced by carbon dioxide.

15. *On Cortical Fibrovascular Bundles in some species of* Lecythideæ *and* Barringtonieæ. *By* Professor MARCUS M. HARTOG.

Accessory fibrovascular bundles are usually connected with abnormalities of vegetation; and probably serve chiefly to assure continuity of the phloem under pressure; hence it is interesting to note their occurrence where this explanation is inadmissible. In *Gustavia* and *Lecythis,* belonging to the sub-order Lecythideæ of Myrtaceæ, there is a complete system of cortical bundles, external to the pericycle, anastomosing with the leaf-tracks at the nodes. These bundles have often a complete circle of exogenous wood, without pith, and a crescent of phloem on the outer side; they are all but concentric; in the petiole it is impossible to distinguish the bundles belonging to the common bundles from the cortical set, owing to the anastomoses in the nodes. The section of the petiole with its scattered bundles recalls that of a monocotyledonous stem, but there is no pericycle.

In *Stravadium racemosum,* belonging to the closely allied *Barringtonieæ,* there are similar bundles, but the orientation of the liber is reversed, and the common bundle retains its distinctness in the petiole.

The explanation seems suggested by the following facts. The cataphyllary first leaves of the seedlings of *Gustavia* are decurrent to the node below, so that the stem is winged and the wings contain one or two pairs of accessory common bundles. Higher up the wings are lost, but their vascular bundles remain to give rise to this system of accessory bundles.

Napoleona has a similar system of cortical bundles.

16. *On the Growing Point of Phanerogams.*[1] *By* PERCY GROOM.

These investigations were undertaken to test the accuracy of those of Dingler and Korschelt, who had found that phanerogams grow by means of a single apical cell. The author investigated many rapidly growing buds, and invariably found no apical cell, but an apical meristem.

In Gymnosperms a companion type is a growing point in which there is no distinct dermatogen, periblem, or plerome. In Angiosperms there is invariably a distinct and regular dermatogen, which covers tissue the fate of which the author did not follow out, but which in some cases appeared to be only indistinctly, if at all, differentiated into periblem and plerome. The author finally endeavoured to trace roughly the evolution of the growing point from the typical vascular Cryptogam, with one apical cell, to the Angiosperm, with a distinct dermatogen. He regards the Gymnosperms as intermediate types.

17. *On the Cultivation of Fern prothallia for Laboratory purposes.*
By J. MORLEY.

In botanical studies it is now the custom to examine fully the life-history of specially selected plants, and as far as possible to cultivate them under conditions in which they can be at all times available for examination. It may not be uninteresting to teaching botanists therefore to bring together the ways in which the spores of ferns can be grown, or at least such ways as are applicable to the laboratory.

Amongst British ferns spores of Osmunda and Lastrea Filix-mas are the most easy to grow, rather less easy Polystichums and Athyriums; the most difficult I have found to be Blechnum and Polypodium.

If ferns are to be grown from spores, the spores must be obtained in a condition fit for growing. If the sori are examined by the aid of a magnifying-glass and the sporangia are found to be of a dark-brown colour, and some of them have already split, a frond or part of a frond should be wrapped in unglazed paper and kept in a dry place until required. If any one of the pinnæ or the apex of any one of the fronds is forked or in any way abnormal, the spores obtained from those parts of the fronds will very likely reproduce the abnormality on every frond of some of the young plants.

I generally grow them in a 12-inch fern-pan covered with a round, flat-topped glass (confectioner's cake-glass). This pan will hold eight tree-pots, called sixties, seven round the edge and one in the centre; the pots are prepared for the reception of the spores in the following way: first a quantity of waste pots, bricks, or sandstone are broken up into different sized pieces from three-quarters of an inch to a quarter; with these the pots are filled to within one inch of the top, beginning with the largest pieces and finishing off with the smallest; this ensures perfect drainage, and at the same time prevents the soil from being washed down amongst the crocks. The pots with the drainage should now be placed in a vessel and covered with boiling water; this will kill all germs of animal or vegetable life that may be adhering to them. Next pass some cocoa-fibre refuse through a riddle with a quarter-inch mesh, and add one-third silver sand. This also must be covered with boiling water, and after the water is poured off the sand and fibre must be well mixed. For spores of the strong-growing ferns, such as the Lastreas, Polystichums, Osmundas, &c., the pots must be nearly filled, rather firmly, with the mixture; but for wall or rock ferns, such as the Aspleniums, Woodsias, Cystopteris, &c., merely sprinkle on about a quarter of an inch thick, and for these it will be better to fill up the pots with drainage nearer to the top. They are now ready to receive the spores, which can be sown by first unwrapping the paper in which the fronds have been placed to dry, when it will be found to contain thousands of dark-brown dust-like spores far too numerous for sowing. To obviate this the paper should be held at an angle of about 45° and gently shaken over another piece of paper, when all the super-

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[1] *Berichte d. deutschen bot. Gesellschaft*, Bd. III.

fluous spores will roll off, still leaving hundreds in the interstices of the first unglazed paper. This should now be turned over on to the top of a pot, and rapped two or three times with the end of a lead-pencil or the thumb-nail, when the spores will be shaken off on to the fibre. The pot is now ready to be placed in the pan, and when all the others have been prepared in the same way with the same or different kinds of spores, the pan can be placed on a level shelf in a window facing the south, and water that has been boiled poured in to the depth of half an inch; if the pots contain spores of rock ferns only a quarter of an inch will do, but if there are pots in the same pan some of which contain spores of the strong-growing kinds, and some of the rock-growing kinds, place the pots containing the latter on pieces of slate. This will prevent them from getting too wet. If the cover-glass is now put on, all that will be required for the next three weeks or a month will be to place a sheet of tissue paper before the glass during the midday sun, and if the bottom of the pan becomes dry by evaporation add more water; the water need not be boiled after the spores have germinated. After the spores have been sown from six to twelve days, if the weather should be warm and bright, each pot can be examined with a magnifying-glass, and in those containing spores of Osmunda, or Lastrea Filix-mas, hundreds of small green specks will probably be seen, which from day to day will increase in size until they meet and cover the surface with green leaf-like prothalli. If they come in contact before each one has attained at least a quarter of an inch in diameter the spores have been too thickly sewn and must be thinned out. Fronds will soon begin to appear, and will increase in number and size, each successive frond larger and perhaps more complex than its predecessor.

Sometimes a fungus attacks the prothalli in a pot. It first appears as a dark spot, and gradually spreads until they are all destroyed. If seen in time it can be stopped by heating some sand in an iron spoon and pouring some on the part affected, but should the fungus pass through the soil and kill all the prothalli there may still be some spores left that were unable to germinate in the first instance on account of being too thickly sown; these will soon make their appearance, and the fungus will not attack the pot a second time.

At any time in their development the prothalli can be lifted for examination, for this purpose preference being given to a fine ivory paper-knife.

The necessary conditions for the growth of spores are light and heat without direct sunshine, moisture without stagnation, and the absence of competition from plants of a stronger growth; provided these conditions be present, ferns and other spores can be grown in various ways for laboratory purposes.

They can be grown on a thin piece of sandstone, a piece of slate, a lump of peat, or a piece of glass.

18. *Life Cycles of Organisms represented diagrammatically and comparatively.* *By* D. McAlpine.

19. *A Re-arrangement of the Divisions of Biology.* *By* D. McAlpine.

Sub-Section ANIMAL MORPHOLOGY.

1. *On the Theory of Sex, Heredity, and Reproduction.* *By* Patrick Geddes.

In dealing with a subject naturally so obscure and so confused by conflicting hypotheses as that of the nature and origin of sex, it is necessary to start with a clear understanding that the required explanation must be not only in terms of structure but of function, and must be satisfactory from the point of view of each school of morphologists and physiologists in turn. Thus in any organism we must not only note the general outward characters which may distinguish the sexes, and correlate these with their habits of life, but follow them into the structures and functions of the internal organs, and thence through the tissues to the egg-cells and sperm-cells which respectively characterise the male and female. Below this, however, a new problem arises; it does not suffice to observe these characteristic forms; they need explanation in terms of the structural, and yet more of the functional, properties of protoplasm itself. Were this once done, it would actually be possible to retrace the progress of the science, and in the same way interpret, in terms of the functions of protoplasm, the forms and functions of tissues and organs—nay, even the facts of aspect, habit, and temperament themselves—thus reaching the *rationale* of what had hitherto been matter of empirical observation only.

The functions of protoplasm are essentially two: first that of constructive or synthetic change or metabolism (assimilation or *anabolism*), contrasted with that of destructive or analytic change (disassimilation or *katabolism*), and these two sets of changes never absolutely balance, as all the phenomena of rest and motion, growth and diminution, nutrition and reproduction clearly show. During life neither process can completely stop, but their algebraic sum varies within wide limits. Starting from the undifferentiated amœboid cell, a surplus of anabolism over katabolism involves not only a growth in size, but a gain in potential energy, and a reduction of kinetic, *i.e.*, a diminution of movement. Irregularities thus tend to disappear; surface-tension, too, may aid; and the cell acquires a spheroidal form. Again, starting from the amœboid cell, if the katabolic tendency be in excess, the increasing liberation of kinetic energy thus implied must be expressed in increased activity with diminished size. The form of the ovum and spermatozoon are thus explained as the outcome of protoplasmic activities of a respectively preponderating constructive and destructive kind.

This conception of sex at once leads to the hoped-for abundance of interpretation; thus the gradual differentiation of the two sexes becomes intelligible, since necessitated by the accumulation of one or other of these two great tendencies with advancing age, and (passing over the endless application of the theory to such problems as those of the alternation of generations, hermaphroditism, parthenogenesis, &c.), it affords us an explanation of the differences and habits, and even of the determination of the sexes in plants and animals. Thus the degenerate male rotifer is no mere exceptional curiosity, but the extreme development of a tendency visible everywhere, for (save among those higher animals where the strain of reproduction on the female necessitates the doubled activity of the male), females tend on the average to show better growth or larger size. In plants or tadpoles alike the determination of sex has been shown to be effected by nutrition, and to be female when this is abundant, male when it is checked. The phenomena of sex, then, are no isolated ones, but express the highest outcome of the whole activities of the organism—the literal blossoming of the individual life.

The preceding argument will also be found somewhat more fully in the writer's article on Sex in the 'Encyclopædia Britannica,' and in extended form in a paper of similar title to the present in the 'Proceedings of the Royal Society of Edinburgh,' 1886.

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2. *Notes on Australian Cœlenterates.* *By* Dr. R. VON LENDENFELD.

The author describes the extraordinary mode of development of Phyllorhiza punctata, a rhizostomous Medusa discovered by him in Port Jackson. The Ephyra has eight, the next stage twenty-four, the next sixteen, and the adult again eight marginal bodies. If the umbrella margin is injured and newly formed, marginal bodies appear between *all* the newly formed flaps.

Further, the migrations of Crambessa mosaica at the breeding time are described. This and other species of that genus of rhizostomous Medusæ migrate far up the rivers, like the salmon, to deposit their young.

A remarkable change in the colour of Crambessa mosaica which has taken place in Port Jackson since the observations of Huxley about forty years ago, is described. A new variety, which is brown, seems to have been produced or to have immigrated and superseded the *blue* form, which was observed by Huxley and others in that locality. In Port Phillip the blue variety is still exclusively found.

The author has found, in examining the lower freshwater animals, that the freshwater Hydroids and Sponges, as also the freshwater Rhizopoda of Australia, are very similar to the European, whilst the *marine* species of these groups differ very much in the two localities. He concludes that these freshwater forms are very old and conservative, and may be supposed to be the unchanged offspring of old ancestral forms, as such possessing particular systematic importance.

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3. *On a Sponge possessing Tetragonal Symmetry, with Observations on the Minute Structure of the Tetractinellidæ. By* Professor SOLLAS, *LL.D.*

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4. *The Anatomy of Neæra. By* Professor HADDON.

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5. *The Nervous System of Sponges. By* Dr. R. VON LENDENFELD.

The author gives an account of his discoveries on this subject up to date. Sensitive and ganglia cells have been observed by him in a number of sponges. Their locality varies, their shape is constant. They are mesodermal, and appear to preside over the movements of the membranes and pore-sieves, and so regulate the water-current. The great difference between sponges and higher cœlenterates is, that in the former the most important organs are mesodermal, whilst in the latter they are ecto- or ento-dermal. He divides the type Cœlenterata accordingly into Cœlenterata mesodermalia, or sponges, and Cœlenterata epithelaria or Cnidaria, as sub-types.

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6. *The Function of Nettle-cells. By* Dr. R. VON LENDENFELD.

The author gives a detailed account of the structure of the nettle-cells, or cnidoblasts, and discusses some biological facts regarding their function. He comes to the conclusion that the nettle-cells are exploded by direct reflex action when the cnidocil is touched; but that the animal can counteract this reflex action by a centrifugally acting nervous irritation, in the same way as reflex actions are controlled by higher nervous centres in man.

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7. *Note on a peculiar Medusa from St. Andrew's Bay. By* Professor MCINTOSH, *M.D., LL.D., F.R.S.*

When using the large net (with the fine mesh) attached to the triangle of wood, as described in the Report of the Marine Laboratory, presented to the Association, one of the earliest sweeps (August 9), north of the pier at the depth of 3 fathoms, in 5 fathoms' water, brought in a Medusa hitherto unknown to me. It occurred amidst swarms of *Thaumantias, Bougainvillea, Oceania, Turris, Cyanea, Aurelia, Pleurobrachia* and *Beroë*, but was readily distinguished by the presence of a simple pale cross on the translucent hyaline disc. The same form was again met with about a fortnight later off the East Rocks.

It is of considerable size, its disc measuring about five inches in diameter. It has the ordinary shape, viz., moderately convex dorsally, somewhat flattened ventrally, and presents no novelty in the microscopic structure of its hyaline tissue. The margin is surrounded by a closely arranged series of tentacles of considerable length. These taper from base to apex, each moreover having a single small black pigment-speck at the base. The latter shows no special differentiation, only a group of simple pigment-granules. Within the bases of the tentacles is a narrow frilled membrane, apparently the velum, and this is especially distinct during the contractions of the disc.

The reproductive bands begin a short distance within the margin, and extend along the representatives of the radiating tubes right across the disc in each case, thus forming a conspicuous cross. These bands are somewhat regularly folded or lobulated at the margin, and have a pale grey or dull whitish colour. The elements do not seem to be much developed, the minute cells which distend the frills being finely granular.

The reproductive bands join each other in the middle of the disc, which presents no trace of a mouth or of a manubrium, and in this respect it differs from any ordinary form.

It is premature to speak decisively as to the precise nature of the form, which has certain resemblances to an abnormal example of Forbes's *Thaumantias melanops*, from Shetland. The latter, however, was only half an inch in diameter, and had the usual manubrium.

8. *Note on* Helopeltis Antonii, Sign., *in Ceylon.*

By HENRY TRIMEN, *M.B.*, *F.L.S.*

I have brought for exhibition some specimens of this species of plant-bug, in consequence of its having attracted a good deal of attention in the East, as a pest of tropical agriculture, and also because there has been some confusion as to its identification.

Two or three years ago some of the growers of cacao (*Theobroma Cacao*) in Ceylon became alarmed at the prevalence of a 'disease' in their trees affecting especially the young twigs and young fruits; the former were spotted, then began to shrivel, and finally died off, and the latter became black and dry, and failed to arrive at maturity.

At the request of the Government of the Colony I made an investigation of, and reported upon, this state of things, and satisfied myself that the main cause of the damage to the trees was due to the effects of the punctures and suction of the juices effected by the insect now shown. As I am, however, not enough of an entomologist to be acquainted with the insects of Ceylon specifically, I should have been unable to determine the present one further than to refer it to its group, had I not possessed specimens from Java of the bug there identified as *Helopeltis Antonii*, with which our insect apparently agreed. In Java this insect has been very destructive to the cinchona plantations, affecting the young shoots of the trees in a very similar way to that noticed in cacao in Ceylon; and it was always a matter of surprise to me that our cinchona was not attacked also.

Since my visit to England I have had the advantage of submitting specimens of the Ceylon insect to Mr. Waterhouse, of the British Museum. The collection there, though it possessed specimens of the Java *Helopeltis*, had not any from Ceylon; and the result of comparison has convinced Mr. Waterhouse that the two are not identical. The Ceylon insect agrees completely with Signoret's original description of *H. Antonii*, which was made (in 1858) from Ceylon specimens; whilst the Java insect, which has hitherto passed under the same name, differs in several particulars, and is, perhaps, undescribed.[1]

There remains another closely-allied *Helopeltis* which is most destructive to the tea-plantations in Assam, where it is known under the name of 'Mosquito-blight.' This has been named *H. theivora*, and has recently formed the subject of an illustrated memoir by Mr. Wood-Mason, of Calcutta. I had hitherto supposed that this also was identical with the *H. Antonii* of Ceylon, but the tea-plants there have scarcely been touched (if at all) by that insect, and in view of the above facts with regard to the Java *Helopeltis*, it is quite possible that the Assam one may also be a distinct species and restricted to different plants.

It is remarkable that species of one genus of Heteropterous insects should be serious pests to three of the most important products of planters in the East.

9. *On Marsupial Bones.* *By* Professor THOMPSON.

10. *On the Sense of Smell.* *By* Professor HAYCRAFT.

11. *On Young Cod, &c.*

By Professor MCINTOSH, *M.D.*, *LL.D.*, *F.R.S.*

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[1] This has, since the above note was read, been figured and described by Mr. Waterhouse as *H. Bradyi* (*Trans. Ent. Soc.* Lond. 1886, p. 458).

SECTION E.—GEOGRAPHY.

PRESIDENT OF THE SECTION—Major-General Sir F. J. GOLDSMID, K.C.S.I., C.B., F.R.G.S.

THURSDAY, SEPTEMBER 2.

The PRESIDENT delivered the following Address:—

HOWEVER diffident I may feel in undertaking the duties of President of the very important Section of Geography at this anniversary, I have no right to take shelter under that diffidence for any shortcoming in the fulfilment of my task. All I would seek at your hands is indulgence for one whose training and antecedents have scarcely fitted him for appearing before you in a quasi-professorial capacity, and whose brief tenure of a Presidential chair at a meeting such as this must be regarded as rather an incidental passage in the annals of the British Association than a fair illustration of its *modus operandi*, or principle of selection in respect to its officers.

As to the subject of my opening address, I know none more befitting the occasion than the means of popularising the branch of science to which the meetings in this Section will be devoted, and thus attracting towards it that attention which it merits—nay which, in this our country if anywhere, it demands and necessitates.

The question is a wide one, but I will endeavour to narrow the field of its discussion to suit our purpose of to-day, and keep within reasonable limits. A few words will suffice to lay before you the programme. It embraces: first, the uses of geography, an exposition of which should prove, and a due apprehension of which should admit, the necessity of its inclusion among the special studies of public schools; secondly, the mode of imparting a knowledge of geography so as to render it at once practical and engaging; and finally, such illustrations of modern travel and research as may serve to demonstrate how urgent is the study of geography to all classes in this country.

Before closing the subject, I shall endeavour to draw your attention directly, if somewhat cursorily, to the progress made by travellers and geographers in furthering what I may for the nonce describe as the objects of their profession during the past year, or since the last Annual Meeting of the British Association at Aberdeen. But I shall only dwell upon such instances of geographical progress as from their character and locality come within the range of my personal experience, and serve to illustrate the main argument of this address.

To begin then with the uses of geography. There are doubtless many who will say demonstration here is superfluous, and that if its use was not admitted it would find no place in school studies, which is contrary to fact in many instances; there would be no primers or elementary works on the subject, whereas they may be reckoned by the score; books of travel would be rather entertaining than instructive, a charge which many recently published volumes would disprove; and so forth.

Some again will argue that its uses, such as they are, must be restricted to the few specialists who aspire to be geographers, and that for the million it is enough to carry about a rough idea of the four quarters of the globe, the principal countries and capitals in them, and a sufficient amount of preliminary instruction to understand Bradshaw and Baedeker. A third, and perhaps the largest category among educated people, consists of those who are indifferent to the whole question, and are content to find in geography either an honoured branch of science, or a mere nominal study, according to the views of the latest speaker, or most plausible reasoner. If it be allowable to apply things holy to things profane, no truer illustration of this class can be given than the Scriptural definition of men who receive seed 'in stony places.'

To the first of the above I would say that the place which geography holds among school studies is not that which it ought to hold if its uses were understood and appreciated. Primers and elementary books already published are good enough in their way, but the instruction they contain is not seriously imparted; and it may be that something fitter and more attractive to the beginner could be produced. At present all school-books on geography may be said, as a rule, to be consigned to the shelf of secondary subjects; and this is not the treatment which should be reserved for a study of such real magnitude. By-and-by it will be my endeavour to establish by argument and example the indisputable character of its importance.

For those who look upon geography as a profession which needs rather separate training than general education, and would prefer to leave its acquirement to travellers aiming at distinction, specialists in Government employ, and the more zealous and scientific Fellows of the Royal or any other geographical society, I can only express my regret that the delusion under which they lie unfits them so thoroughly to understand and much less satisfy the wants of a rising generation. By denying the universal character of the study they clearly misapprehend its true scope, and are dwarfing it to within the narrow limits of a conventional school task.

As a matter of State or public school education the science of geography should in truth be elevated, not degraded. In my humble opinion it should be placed on a par with classics, mathematics, and history, with each and all of which it has affinity. Undoubtedly there are accomplishments which come, as it were, of themselves, or are the outcome of lightly-sown seeds in the home. These for the most part are rather mechanical than mental, though some may have advocates to claim for them intellectual honour. But a knowledge of geography is not to be so acquired: it will not come like handwriting with incidental practice, nor is it to be gained by mere travelling. To move from place to place, whether across seas or continents, or both, to go round the globe itself and visit every important country and capital in the track chosen, even to prefer byways to railways and search into obscure and hidden spots rather than those which are more generally frequented—all this process affords admirable matter for the note-book of the man of the world and observer, but will not educate in geography, unless the student himself has a serious purpose to turn his wanderings to the account of science. The cursory description which would apply to men and women, cattle and conveyances, hotels and caravansaries, restaurants, coffee-houses, and the like, in a moving panorama, is not always suited to bring out in bold relief the physical aspects of a country.

To the indifferent and wavering, to those who would wish to promote the study of geography if they could feel persuaded that it needs promotion, but who would leave to the better judgment and experience of others the decision on the whole question; to those who are content to accept the institution of a professorial chair in honour to the science, or to leave geographical study to the primitive teaching of their own childhood, whichever course be most in accordance with the temper or fashion of the times—I can perhaps do no better than appeal on the grounds of urgency—in other words, of the real importance of the cause for which, in common with abler and worthier advocates, I would now most earnestly plead. The opening verse of the Bible, in imparting to us the first great act of creation, at once establishes the high position, among the lessons to be taught mankind, of astronomy and geography; and the description of the garden of Eden, and the river dividing into four heads—two of which, the Hiddekel and the Euphrates, still mingle their waters in one, after a long separate course from the highlands of Armenia—is an illustration of pure geography conspicuous in the second chapter, immediately following the story of man's formation. To say that there is a special fascination in Biblical research, whether geographical or archæological, is to say what those alone know who have made such studies a labour of love as well as a part of duty. But those who *do* know this truth from experience are ready to assert it without reservation. I have myself heard the assertion from the lips of one of the most zealous and industrious contributors to Smith's 'Dictionary of the Bible'—one whose versatile talent and comprehensive intelligence have now called him to a different sphere of usefulness, but who is no less a sure and competent witness. And is there no fascination in contemplating the marvellous fact I have just cited? For assuredly it *is* a marvel that for nearly 6,000 years, or, so far as we can tell, from the creation of the world itself in which we live, and the bestowal of names upon things animate and inanimate up to the present day, we find two ancient rivers retaining their names unchanged—Euphrates and Hiddekel. There is no need to speculate here on the Aryan origin attributed to the first, nor upon any broader meaning implied by the latter. I can myself answer for the local name 'Farát' or 'Al-farát,' and 'Digla' or 'Dagla' (with the article, Al-dagla, Addagal, Addigal) in use between Baghdad and the Persian Gulf.

In touching upon Biblical research, I may be told that—according to hard thinkers at the present hour—I am taking a sentimental view of an argument which should be mainly practical. But the geography of Mesopotamia, as of Palestine, is to all intents and purposes a practical study, especially in these days of possible railways and new lines of intercommunication east and west; now, too, that Cyprus is ours, and the immense advantages of its occupation have been demonstrated by time and experience. Moreover, if any geography can be considered Biblical, it is that of Asiatic Turkey, both as regards the New Testament and the Old.

I am not, however, going to dwell upon this highest view of the subject. The connection of geography with Holy Writ is self-evident, and the twenty-one years' history of the Palestine Exploration Fund, only just written, affords an admirable instance how public interest may be aroused to support, and individual energy and intelligence may be exercised to prosecute, a work hallowed by association. Those who were present at this year's meeting at the Royal Institution will not soon forget the cordial manner in which the names of the foremost labourers in this area of usefulness were received by the crowded audience. And rightly so. They have been worthy labourers in a worthy cause, and merit the grateful honour of public recognition and approval.

Turning to secular things, I almost seem to be treading upon the threshold of platitudes when seeking to explain why geography should be useful to young men of ordinary culture, for whatever career they may be destined. In some cases it is naturally more urgent as a study than in others. The military man, for example, should be more or less a scientific geographer. His profession may require him to survey and describe new regions; and a campaign over a beaten track should find him acquainted with the minute topography and physical aspect of places, at least the names of which are familiar household words. The sailor should in like manner bear in mind the configuration and character of sea-coasts and carry about the landmarks of his own observation as well as those to which he may refer in books. To both must geography be eminently a professional study. But, considering the enormous extent of our Indian Empire and Colonies, and the many foreign States with which we must have intimate relations, is any Englishman, I would ask, competent to discuss, much less to serve, the interests of his country who knows nothing of the physical features, resources, products, population, and statistics of these? It seems to me to be the duty of every loyal subject and citizen, high or low, rich or poor, to seek information on these heads wherever it may be obtained.

But of all men who should realise geography in its broad, comprehensive sense—both as an aid to history, and as a science to which history may be subordinate—first in order is the statesman in whose province falls the disposal and partitioning of countries or regions. What should we say of the judge—we may be thankful there are none such on the English bench—who not only gave his decision without mastering the merits of the case before him, but who was also ignorant of the law and precedents which should guide him in the treatment of those merits? The argument might apply with equal force to other callings from the members of which professional opinions or decrees are required by their fellow-men. Why, the evil would be so great and so palpable that its existence would not be tolerated for a single day: and the only reason why it *is* allowed to prevail in matters geographical is that, though equally great in respect of these, it is not equally palpable. The statesman may not know the situation of this or that particular place, nor its products and resources, but neither does the public. One is not taught geography any more than the other; so that while ignorance and error are brought to bear on a spurious judgment, the critic is not in a position to point out the real flaw, and the blunderer escapes the scathing condemnation which would otherwise await him in the columns of the morning paper.

Let us suppose a case by way of illustration—a case which conveys no exaggerated idea of what happens, or may happen in the course of a year—a case which without being an actual occurrence has in it the flavour of actual occurrences. There is a large tract of land in the far West or far East, it matters not which. All that is known about it is that it is called Laputa or Barataria, and that it is situated in the central part of a region or continent so vast that it might be reasonably called the largest quarter of the globe. Well: it is encroached upon by a powerful neighbour, and England requires the preservation of that land's integrity and independence. Her best instructors on the matter have told her that such is her interest, and she believes them. Intervention, therefore, becomes necessary; negotiations ensue; and the whole question resolves itself into a partition of territory and demarcation of boundary—in other words, the question becomes one of geography—what I should call, for reasons to be explained hereafter—Political Geography. Who, if not the ruling statesman, should know the true principle on which to deal with a large settlement of this nature—one, it may be, involving ethnological, commercial, humanitarian quite as much as territorial considerations? Who, if not the agent on the spot, should know the details to regulate the application of the principle? But the statesman should be in full possession of his agent's details, and be capable of appreciating them not only from the latest reports supplied, but from a certain insight into the matter obtained from early study. He should have been coached in that comprehensive kind of geography which would have embraced the particular information required. Under present arrangements it is not so. The geography taught at schools is too simple or too scientific—too complex or too superficial; in any case it is not the geography which would benefit the cabinet minister in solving a territorial difficulty any more than would those 'ingenuæ artes' which have so strong a civilising influence on the natural man. Experience in classics may forestall the faulty quotation and false quantity, but fail to suspend the false move on the political board. And it need not be said that, while the first, in point of fact, affects the speaker only, the last concerns the happiness of the million.

We now reach the second consideration: the mode of imparting a knowledge of geography so as to render it at once practical and engaging; and I may be pardoned if I dwell upon this somewhat lengthily, for it involves the gist of the whole question before us. It is always easier to detect a flaw than to find a remedy, and in the present case the flaw is generally admitted by experts. There may be differences of opinion on its character and extent, but apparently there are none on its existence. I shall have to recur to the first, but would ask leave to dismiss the last as established. We are told on excellent authority that in our own country the elements of success in geography are wanting, and the conclusion has been practically accepted by the representative Society for this branch of knowledge. The remedy has been suggested, and in a certain sense partially applied, but a great deal more remains to be done, and the many views entertained and expressed by competent men on the claims and requirements of geography in England render necessary a short review of what may be called the 'situation,' including notice of work achieved in the direction of reform.

In the first place let us examine into the work done and doing by the Royal Geographical Society. What the objects of this Society are, and what have been its operations for half a century, may be gathered by a perusal of Mr. Clements Markham's interesting record published on the occasion of its completing the fiftieth year of its existence on July 16, 1880. I quote two passages which bear upon our present lines of thought. One recites the propositions, 'unanimously accepted as sound and true,' which are in truth the basis on which this now flourishing institution was originally formed. They are thus expressed:

'That a Society was needed whose sole object should be the promotion and diffusion of that most important and entertaining branch of knowledge, geography; and that a useful Society might therefore be formed under the name of the GEOGRAPHICAL SOCIETY OF LONDON; that the interest excited by this department of science is universally felt, that its advantages are of the first importance to mankind in general, and paramount to the welfare of a maritime nation like Great Britain, with its numerous and extensive foreign possessions; that its decided utility in conferring just and distinct notions of the physical and political relations of our globe must be obvious to everyone, and is the more enhanced by this species of knowledge being obtainable without much difficulty, while at the same time it affords a copious source of rational amusement, and finally that, although there is a vast store of geographical information existing in Great Britain, yet it is so scattered and dispersed, either in large books that are not generally accessible, or in the bureaus of public departments, or in the possession of private individuals, as to be nearly unavailable to the public.'

There is perhaps a quaint boldness discernible in coupling the adjectives 'important and entertaining,' and introducing the word 'amusement,' but these verbal expressions are unquestionably appropriate, and may suggest an explanation of much of the Society's popularity at the present time—a popularity exemplified in the large and increasing number of its fellows.

The second passage from Mr. Markham's report is the author's own estimate of geographical work—an estimate supported by a wide and varied personal experience:—

'Geography is a progressive science. Every year, with its discoveries and novelties, also brings forth a large crop of corrections and of information which modifies preconceived theories and opinions. It is this freshness, this constant supply of new material, which constitutes one of the many charms of geographical research.'

Let us add a hope that when its real scope becomes known and its uses more patent to our masters in education, efficient advocates will not be wanting to secure its acknowledgment in England as a study of absolute necessity.

Of late years the Royal Geographical Society, in pursuance of its originally expressed aims and objects, and strong in the experience of a long and prosperous career, has endeavoured to arouse the rising generation to a sense of their short-comings as regards the particular science in the promotion of which it has its own *raison d'être.* It granted prizes to such public schools as chose to compete for them, and after sixteen years' trial discontinued the grant, owing to unsatisfactory results. It opened correspondence with schools and colleges, and made other judicious and laudable attempts to evoke sympathy and support. But all its proceedings have been as it were preliminary, and may be considered rather as foundation-stones of a temple of success than the outer walls or any visible part of the building itself. A more recent attempt to reach the masses was the Exhibition of Educational Appliances. Objects used in geographical instruction at home and abroad were collected and arranged in galleries hired for the occasion, and the public were invited to inspect them. At the same time appropriate lectures were periodically delivered, by competent and experienced men, to the visitors, many of whom were not merely interested amateurs, but persons actually engaged in school teaching. Attention was called to the fact that the exhibition was purely educational; that there were in it specimens of German, Austrian, and Swiss maps, executed with a finish and detail unusual in our school maps at home; but that as the Society's inquiry embraced universities as well as schools, part of the appliances exhibited were used in Continental universities, though in reality some of the finest maps shown were found also in the higher schools of Germany and Austria.[1] Besides maps, there were in the collection globes, models, and text-books, the presentations not being confined to countries visited by the inspector, to whom the task of collection had been entrusted, but from others also; and these were further supplemented by contributions from British publishers.

The result of this new departure—if the term be allowable—was pronounced very satisfactory, and at the close of the exhibition, or in the spring of the present year, the council considered what would be the next best step to take in furtherance of their desire to raise the character of geographical study. At a later date, on the recommendation of their Educational Committee, they resolved on addressing the universities to the effect that chairs or readerships be instituted similar to those which were at that time filled in Germany by Carl Ritter at Berlin and Professor Peschel and Richthofen at Leipsic. In carrying out the resolution alternative schemes were submitted. The council would appoint, under approval of the university authorities, a lecturer or reader in geography, paid out of the Society's funds, he being accorded a fitting local status; or each university might join with the council in the matter of payment, and a reader be appointed by a committee in which the Society should be represented.

Thus far I have referred to the proceedings of the Royal Geographical Society, and I think you will allow to those responsible for them the credit of moving in the right direction, with a genuine desire to promote a good cause. But the new Geographical Societies have not been idle: Edinburgh and Manchester have shown an intelligent vigour in seeking to popularise the study of geography, and much has been done in both places within the past few months only, which is worthy of permanent record. Of Manchester I can speak with a certain amount of personal knowledge, having read two papers there, and had the advantage of making the acquaintance of the more prominent members of the Society. The movement in a great commercial city such as this may well aid in strengthening the hands of the London Society; for nothing could more faithfully demonstrate the practical uses of the science under consideration than the fact that it had a centre in Manchester. As to the nature of the recent work there, I need refer only to the Exhibition of Geographical Appliances which followed that in London—arranged by the mayor at an art gallery lent for the purpose. We are told in the published reports that space could not be found for showing all the specimens sent, but that a selection was made, and that maps were the main feature. These were of many countries—English, German, Dutch, French, Italian, Norwegian, Swedish, Russian, American, and Canadian—among the Norwegian being a fine series presented to the Manchester Society by the Royal Institute of Christiania. During the exhibition, seventeen addresses were delivered in the building on subjects connected with geographical education. Every day lectures were given of about three-quarters of an hour each, on the contents of the rooms, to audiences ranging from ten to a hundred and fifty persons. The special Education Committee, appointed with reference to the Exhibition of Geographical Educational Appliances, were enabled, at the close of their work, to report to the Council that in their opinion the object of the Society had been accomplished, and expressed a hope that the impression produced might not be allowed to evaporate, but should rather be 'fostered to more definite results in this extensive branch of human knowledge.' From Manchester the London Society's collection of Geographical Appliances was transferred to Edinburgh, where an address was delivered by Mr. Ravenstein at the opening meeting in the Museum on June 14.

It will thus be seen that special efforts have been made and continue to be made to popularise a science which has never, so far as can be ascertained, held its proper place in the educational programme of our schools or universities. We must not, however, lose sight of one important consideration. More remains to be done than to institute a chair, a professorship, a readership. It must be clearly understood on what general lines of study we are about to proceed. Is geography

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[1] See Preface to Catalogue of Exhibition.

to be taught in its full, comprehensive sense as something involving a knowledge, more or less, of mathematics and astronomy, of ancient and modern history, of ethnology, zoology, botany, geology, of men and manners, laws of nations, modes of government, statistics and politics, something requiring in the disciple a quick ear, a searching eye, an appreciation of scenery and outer subjects as well as physical aspects of country, a power of picturesque but an adherence to accurate description? If so—and I believe I have only stated the qualifications of the travelled and finished geographer—would it not be well to inquire whether the component parts of the science should not be reconsidered, and a subdivision effected which would make it easier to deal with than geography as now understood, under the terms physical, political, and perhaps commercial?

It must be borne in mind that our governments or geographical societies, our boards or our Universities—whichever distinguished body takes the matter in hand, separately, it may be, or in concert—will have to cater for a multitude of pupils, and that, whatever change eventually takes place in programmes of study, the division of school teaching into two great representative branches, classics and mathematics, is a practice which has hitherto, at most public schools, resisted the shock of innovation. The maintenance of this time-honoured custom is not so much, to my mind, an illustration of conservative principle—*that*, we all know, is powerless against national progress—as the assertion of a profound truth, similar to that which in the region of language separates the Semitic from the Aryan category of tongues. It is a recognition of the distinction which exists in the human organisation between mind and mind—a distinction apparent in the boy as in the man, at school as at college—in the battle of life itself as in the period of preparation for battle. I do not mean to imply that all school studies fall essentially under one or other of these divisions; but I do believe that the student's progress will be in accordance with his idiosyncrasies; that the student's taste should be considered in the master's system; and that, in dealing with geography, we ought not to throw it wholesale into the hands of the professor or reader, but, as a primary measure, separate it to suit the capacity of the classical as of the mathematical intelligence, so that the one part comes within the province of history and art, the other within the limits of unadulterated science. Attention to both sections should be imperative, so far as attention to classics and mathematics is imperative, but the standard of competence attained in either must depend on the mind and bent of the pupil, who might readily excel in one but fall short in the other, not being even distinguished if the subject of study were undivided.

Not six months ago I wrote as follows:—'We are authoritatively told that, at one of our greatest public schools, which may be fairly taken as representative of its class, there is no systematic teaching of geography at all, but "that in the history lessons, as well as in the classical lessons, a certain amount of geography is introduced incidentally." Again, if we look at the Universities abroad, it has been found the custom, until quite lately, both in France and Germany, to combine the chairs of geography and history under one professor. Now the "incidental" character of geographical instruction is a tacit declaration of its unimportance, which every day's experience shows to be without warrant; and its combination with history may be an expedient to render it less distasteful than it appears as a separate study. But a useful hint may be taken from the Continental practice, and a partial fusion of two departments effected, which would commend itself to common sense, and, to judge from the recorded opinions of certain of our educational experts, might not be objected to by head-masters in England collectively. Let us, then, endeavour to extract from the lessons of conventional geography that part which is inseparable from the study of nations and people, and place it under a new and more appropriate head. In this view, so-called "political geography," stripped of its purely scientific belongings, would be taught in connection with history, and made an essential ingredient in the early training of British statesmen, whose after-reputation should be more or less the outcome of a University career, the grounding of a public or grammar school, or private tuition. It is difficult to reconcile the amalgamation of what may be considered "scientific" geography with history. One is as thoroughly apart from the other as geology is from astronomy.'

The meaning of the verbal combination 'political geography' requires some kind of analysis. Conventionally, and in an educational sense, it is the description of the political or arbitrary divisions and limits of empires, kingdoms, and states; their inhabitants, towns, natural productions, agriculture, manufactures, and commerce, as well as laws, modes of government and social organisation—everything being viewed with reference to the artificial divisions and works made by man. Accepting this interpretation of its objects, who can hesitate to admit its palpable and immediate relation to history? The mathematical science which investigates the physical character of territory and territorial boundaries is in this case but a secondary requirement and can be always fairly disposed of in the recognition of results. Otherwise, we have simply commercial geography with ethnography, and considerations which we may call political in the present but which are undoubtedly historical in the past. Surely, then, it would be wise and reasonable to combine the studies of history and political geography—putting a wider interpretation than the conventional one upon the latter designation in such a manner that the two together should be just the sort of *pabulum* dispensed to the rising generation of statesmen, diplomatists, and all who aspire to the name of politician, in its higher sense of capability to promote as well as to discuss the national welfare.

An admirable lecture on 'Geography in its Relation to History' was delivered by Mr. James Bryce—the late Under Secretary for Foreign Affairs—in connection with the recent London Exhibition of Geographical Appliances. Those who are acquainted with it will readily understand why I pause to remark on its enlightened teaching; to those who have not that advantage I would explain that it seems to embody the arguments of Modern Thought on the important question we are now considering, and that a brief allusion to it is therefore no irrelevant introduction here. The lecturer, seeking to demonstrate that history and geography touch one another in certain relations and interests, laid down the proposition that man is, in history, more or less 'the creature of his environment;' that 'on one side, at all events, he is largely determined and influenced by the environment of nature;' and that 'it is in discovering the different effects produced on the growth of man as a political and State-forming creature by the geographical surroundings in which he is placed' that one point of contact is found. He, moreover, maintained that man, 'although he may lift himself above his environment, cannot altogether escape from its power.' Dividing the influences thus exercised into three classes, he showed that those arising from the configuration of the earth's surface affected movements of races, intercommunications, and barriers of separation; that those belonging to climate affected the occupation or abandonment of particular localities on the score of health, fertility, or non-fertility of soil, and consequently commerce and cultivation; and that those which owed their existence to natural products unmistakably directed the energies of peasantry and people into certain fixed channels of enterprise—a result which applies to the zoology as well as to the mineral and agricultural resources of a country. He made the very true observation that the 'animals affect man in his early state in respect to the enemies he has to face, in respect to his power of living by the chase, in respect to the clothing which their furs and skins offer to him, and in respect to the use he is enabled to make of them as beasts of burden or of food'; and he, therefore, concluded that 'zoology comes to form a very important part of the environment out of which historical man springs.' A volume might well be written on this suggestive theme alone; and if, as I believe, the proposition of a human being's dependence on environment be admissible in its entirety, what a field of speculation is open to the inquirer! A condition held applicable to the unreckoned millions of to-day must have had a marvellous effect in giving character to original Man!

This conception of man's environment supposed heads or branches of geography, all bearing upon history, which might be distinguished by names such as ethnological, sanitary, commercial, linguistic, political and military, legal—the last leading to the consideration of the Suez Canal and sea-channels in which several States have interests. As time, however, will not allow me to quote the lecturer's apt and well-put illustrations which followed, I may mention that the express object with which they were introduced was to show how 'the possession of geographical knowledge, and a full grasp of the geographical conditions' with regard to some of the leading countries of the world, 'will enable a person studying their history to make the history more intelligible and real.' In strict conformity with this opinion, and in the conviction that the want of geographical knowledge and 'full grasp' of geographical conditions will betray men in power to commit dangerous mistakes, calculated to injure the national prestige and credit, and men out of power to become their upholders in error, I would express the hope that, in any future arrangements which may be perfected for the better education of our countrymen, while physical and scientific geography are invested with a degree of prominence and honour to which they have hitherto never attained, that branch of study which we have been accustomed to call political will be reconsidered and, if necessary, newly defined by competent men. The conclusion at which I have myself arrived —one which I am quite ready to abandon before the arguments of sounder reason—is that we have here something which belongs mainly to history, and, in such light, its scientific should be separated from its non-scientific elements. A partition should be made which would equally suit the mind of the student whose tendencies are rather towards metaphysics than mathematics, as of him who is a votary of practical science only. I do not presume to touch upon the action of Universities, except to say that I can conceive no better example could be afforded that the intellect of England had due regard for the material interests of England than by the creation of a chair for scientific geography and the relegation of that which is non-scientific to the chair of history. I now turn to the third, or illustrative portion of the subject under discussion.

To illustrate, by instances of modern travel and research, the urgency of geographical study to young Englishmen, especially those who from adventitious position, ambition, or ability are likely to hold the helm in any department of State, I see no fitter way than, by a retrospect of the work done, to come to the conclusion whether we, as a nation, would have participated more directly in that work, or derived more legitimate benefit from it, had we been better instructed. Now this is a delicate question to put, if applied to particular cases, because it involves matters of policy, and belongs to the domain of pure politics rather than to any form of political geography; but I shall not presume to ask whether we could, or could not, have acted more wisely in this or that diplomatic difficulty, only whether the solution of such a difficulty does not, in point of fact, depend upon a geographical experience which we do not always possess, and cannot always command from others. Having explained upon what particular instances of progress in the field of exploration or discovery I should dwell, at this stage of my address, I will now speak more definitely. Though my own personal experience of travel has been obtained, more or less, in the four quarters of the globe, I cannot but feel that Europe is more familiar to me in its chief cities and highways, and more popular social haunts, for the geography of which there is no demand—notwithstanding abundant and choice material—than as a subject for scientific description. So also with the United States. New York and Philadelphia, and the Hudson River, with all their recommendations, have certainly no gloss of novelty, and my personal knowledge is unfortunately restricted to these points. In Asia, I have a wider field—from the Canton River to the Bosphorus—but for obvious reasons a corner of this will suffice for present purposes. In Africa I have made quite recent acquaintance with the Congo—that great river whose introduction into our maps in its entirety is one of the most notable of geographical feats of modern times. My experience of it was brief and confined to its lower section, but the two months passed at Vivi and between Banana and Isanghila were not without instructive use. Plainly, then, after a retrospect of work lately achieved by travellers and explorers, I will limit such comments as I may have to offer to the Congo for Africa, and Eastern Persia for Asia.

Of the out-door operations of the past year those specially mentioned by the President of the Royal Geographical Society in London, in his address of May 24, are:—Prejevalsky's journey from Lob Nor to the populated districts of Eastern Turkistan, and from Khotan back to Russian territory *viâ* Aksu and the Tian-shan; Mr. Needham's expedition to the Za ul-chu; Colonel Woodthorpe's examination of the country between Assam and the Upper Irrawadi; the Anglo-Russian survey of the northern frontier of Afghanistan and Indian topographical survey in Burmah, the Kangra Hills and Panjab Native Hill States, the Andaman Islands and Baluchistan; and Colonel Tanner's exploration of the Tibetan frontier region. All these are in Asia. In Africa the Portuguese and German expeditions—the latter proving the Lualaba to be the true head-stream of the Congo; the travels of the Baptist missionaries; and Lieutenant Weissman's exploration of the Kasai were honourably referred to; and I may here mention that a highly interesting paper by Sir Francis De Winton has been since added to the reports of the officers of the Belgian International Association. The President further referred to work done in the east of Africa by Mr. Last, and Bishop Smythies of the Universities' Mission, as also by Major Serpa Pinto and his representative Lieutenant Cordozo in carrying out the Portuguese expedition organised from the Mozambique; to the proceedings of agents of German commercial societies; to the sad fate which befell Bishop Harrington at the hands of the King of Uganda; and to Dr. Fischer's adventurous but unsuccessful journey, with intent to reach the Russian traveller, Dr. Junker, by moving along the eastern shores of Victoria Nyanza—an attempt supported by Dr. Lenz (then at Stanley Falls) from the south-west. He also touched on Mr. Thomson's negotiations in the Central Sudan; Mr. Montagu Kerr's hazardous journey from the south across the Zambesi; Mr. Farini's passage through the Kalahari desert, and Sir Charles Warren's surveys in Bechuanaland. Besides Asia and Africa, public attention was drawn to Mr. Forbes' and other expeditions for the exploration of New Guinea; to the report of Mr. Simons on the Goajira Peninsula, and that of Mr. Wyse on the Columbian Isthmus and Panama Canal. South America, moreover, came in for a share of honour with respect to the ascent of Mount Roraima.

Among less known expeditions—of which something, however, has been heard in this country through the scientific periodicals—may be mentioned one undertaken by Dr. Bunge and Baron Toll for the Russian Imperial Geographical Society. These explorers have been occupied during the past year in examining the northern shores of the frozen sea and islands of New Siberia. The Upper Yana and its sea-mouth were the points to which the chief attention of one or other of the travellers was mainly directed, and the Baron explored three other rivers in the same locality. A highly favourable report of the results obtained has been received, and this last spring has probably witnessed a renewal of work. From the 'Proceedings of the French Geographical Society' we learn that in Eastern Siberia also the explorations of M. Martin last autumn between the Lena and Amoor were so carefully conducted that his itinerary has been accepted for adoption and publication by the Russian staff. Much might be said, too, about a recent scientific mission of M. Aubry to Shoa and the country of the Gallas; a journey by one of the missionary fathers to the plateau of Amboella east of the Portuguese territory of Mossamedes, and the active movement of the Government of the Argentine Republic and individual explorers on the Bolivian frontier and the Vennejo and Pilumayo Rivers: but time would fail me to repeat the nominal record only. With one exception I omit all reference to 'projected' expeditions, of which the number is unusually great.

The exception will be disposed of in very few words. It relates, perhaps, rather to a mooted subject than to a new project, the research of the Antarctic Polar Seas, on which a paper was read last year at the Aberdeen Meeting by Admiral Sir Erasmus Ommanney. Men's minds are so fully occupied at the present hour with the thousand and one practical interests which arise like sparks out of the fast-rolling wheel of Progress, that the theory of an unknown polar region may not possess the fascination which it exercised in days when steam power had been less developed, and electricity had not exhibited a tenth part of its now familiar uses and effects. Nevertheless, there is something to stir the imagination, even of this unimaginative age, in the theory of a South Polar Sea; and there is something practical in the proposition besides, for it tends to give substance and meaning to the unknown. If the object of exploring that comparatively neglected corner of the globe commend itself, as I know it does, to many; assuredly the project opens a worthy field of enterprise for this nation above all others. The perils may be, as stated on good authority, far greater than those of the Arctic Seas, but the conditions of the two poles greatly differ, and it is most desirable to find such a winter quarter within the Antarctic Circle as has never yet come within the experience of any human being. Those interested in this important question may remember that a Committee was appointed to report upon the advantages to be derived from further exploration of the immense region referred to—near which, some fifty years ago, James Ross made his famous discoveries. Hitherto, for reasons which might readily be explained, no report has been issued; and perhaps the wiser and the better preliminary step towards bringing matters to a successful issue would be to expand and strengthen the Committee by the accession of influential members. I now leave the subject in the hands of experts, who alone are qualified to deal with it in detail.

To return from this brief digression. There are two regions in which geographical activity has been evinced in a remarkable degree: both are in that large continent which one who knows it as well as any living man has qualified as 'dark'—the east and west coasts of Africa. It is really astonishing to trace the changes in a map of Africa during the last quarter of a century. Large spaces that were quite blank have been filled up with conspicuous delineations of mountains—fine lines representing rivers, crossed by or connected with finer lines of affluents or feeders—with names, circles, and dots for towns or villages. Yet as I now contemplate that map in its latest form, it seems to me that hundreds of spots visited have yet to be indicated, and that the coast lines of the Indian Ocean on the one side and the Atlantic on the other, are teeming with life imported, as it were, from Europe. Singly or collectively, emissaries and missionaries—would-be settlers or mere explorers—the number of these now in movement foretells in the course of time a change in the political divisions of the country, whatever the result for good or evil. For the sake of argument let us take the whole extent from 20° N. to 30° S., leaving out Morocco, Algeria, Tunis, Tripoli, and Egypt, as political considerations more or less understood in England. On the west, Germany has stepped in to hoist the flag of colonial power, and is to be recognised at the Cameroons. France has possessions and protectorates between Senegal and the mouths of the Niger, which promise development and consolidations such as it is now impossible to estimate. Below the Gold Coast she has just added to the Gaboon, by agreement with the Belgian-African International Association, an amount of territory which gives her, in place of a comparatively small settlement, a continuous coast line of more than 350 miles, touching inland a great portion of the right bank of the Congo. Those who would know how her agents work for her have only to read the narrative in the publications of her Government, her geographical society, or the records of her missionary fathers. They will there learn that if her soldiers find active service in Senegal, the Pères du Saint Esprit are not slack in peaceful attempts to educate and civilise the natives of the Gaboon. Spain and Portugal have also possessions which have been lately extended on the seaboard of West Africa; and the international partition effected at Berlin has confirmed to the latter her right to lands which had been denied on more than one distinct occasion during the last half-century. As to individual explorers of the west coast within the last year or two, I need only refer to the names mentioned in the address of the President of the Royal Geographical Society, and which I have just repeated. Others might be added were it necessary; but they would scarcely strengthen the case. For the east coast, again, Germany has annexed territory in the neighbourhood of the Sultan of Zanzibar; while the names of individual explorers and settlers are legion. Of these I will simply recapitulate some, without further comment. These are Major Serpa Pinto and Lieutenant Cardozo; Herr Colin and Captain Chaders; Messrs. Arnot and Giraud; Mr. Last, Mr. H. H. Johnston, Consul O'Neill, and Mr. Richards (of the American East Central African Mission); Bishop Harrington and Bishop Smythies; Governor Vieira Braza of Têtê and Padré Courtois; also Herr Reichard, who, by the death of his last remaining colleague, Dr. Böhm, has become the sole survivor of the German East African Expedition. The names are taken almost at random and include, besides our own countrymen, those of one or more representatives from France, Belgium, Germany, Portugal, and America.

This drawing within the pale of civilisation of semi-barbarous States, this inclusion among common things of the uncommon and strange by the independent or joint action of individual agents, is a matter which cannot fail to arouse a deep interest in those European Powers whose position is secured or prestige enhanced by the maintenance of empires, kingdoms, or colonies beyond the seas, over and above their home possessions. It has been seen that France and Germany have marked their sense of the situation by fresh annexations. The first, it is true, has made her West African gains a mere supplement to the more palpable advantages obtained under treaty with Madagascar and Annam; but M. de Brazza's exertions on her behalf have won the important line of the Ogowi river—the additional territory on the seaboard, to which we have referred, being a bargain of comparatively trivial cost. England, in the meanwhile, has refrained from active interference, further than reserving for herself certain rights connected with the Niger and Gold Coast, and entering into treaty with Portugal in respect to the Lower Congo. The reservation was a political fact to which we need not do more than allude; but the treaty calls for a word of remark. It was never ratified, and fell through in embryo. I do not say that a knowledge of Africa better and more comprehensive than that usually taught in English schools would have averted this result; but I do say that to treat so important a question a knowledge of geography, such as that which I would combine with history, would have been the best protective weapon. That low and uninviting mouth of the Congo—that unhappy birthplace of mangroves and of malaria—that much desired and yet most undesirable site of a few European factories, with enterprising but fever-stricken tenants—has a story of its own; and only those who know that story, in its geographical, ethnological, commercial, and political bearings, can understand why it is coveted by this or that European Power, and consequently what view England, when appealed to, should have taken regarding its disposal. All is now over; the Congo has been divided out under the Congress of Berlin.

From West Africa we turn to the East—to countries west of the northern frontier of India.

Three of these merit our serious attention, *i.e.*, Afghanistan, Baluchistan, and Persia, more particularly their history and geography, and full information on them is available in books. Nowhere is this to be found in the comprehensive form that would necessarily be adopted were geography honoured with professional chairs; but, in the absence of the appropriate manual, search must be made in encyclopædias, gazetteers, and volumes of history and travel. Afghanistan has been of late years so much the subject of official correspondence that the blue book is perhaps as useful a record as any other from which to draw the more important details on the character of the country and people. Baluchistan has a divided history. Her eastern half, contiguous to, and immediately connected with British India, is to all intents and purposes under the protection of that empire; her western half, till within the last fifteen years, encroached upon by Persia, is equally amenable to our influence, and should profit from English advice and help. Persia is never in lack of European travellers who delight to place on record their experiences of a country which with all its drawbacks has the immense advantages of grand associations and a charming climate. Nor are its people the effete race that some would suppose. Many of them, whether in the higher, middle, or peasant class, are endowed with energy and activity which need but occasion to draw out; and if cruelty on the part of governors and extortion and peculation on the part of high officials are painfully recognised native qualities, there is great kindliness and hospitality shown to strangers by the same classes, and, let me add, the love of poetry is universal. The servant who corrects his master's faulty poetical quotation from his humble post behind his master's chair can hardly be lost in Vandalism. I regret there is no paper to be read in our Section on Persian geography, but may incidentally mention that one of our latest travellers in that country, Mr. Rees, who will favour us with his impressions of Northern China, has published a graphic account of his recent journey, by a direct and little known route, from Kazvin to Hamadan.

It is a subject of much congratulation that Boundary Commissioners are now made the means of advancing the cause of Science as well as of political security. Their proceedings are no longer confined to the little-attractive blue book, nor doomed to the disguise and dilution essential to adapt them to the shelves of a circulating library. The progress of a mission may now be reported stage by stage for the public information, and fresh descriptions of fresh countries may be read in the daily prints, recorded with the minute accuracy of a photograph. Nor are the acts and words of the chief or members to be done and spoken in the interests of Government alone, registered in official foolscap, and marked confidential. Outdoor diplomacy, especially in Eastern countries, may have its occasional solemn aspect, but it is, in the main plain-spoken and Bohemian. The appearance of a Commissioner may be described, his official or general conduct discussed, his opinions and habits criticised, and his remarks, whether sober or facetious, given to the world—I might almost add the conferences in which he takes part, revealed—without let or hindrance of any kind. All this is a distinct gain to the public, and can be no cause of distress to the Commissioner, working in an honest and loyal spirit—though it may not always be politically expedient. In any case the information so imparted may be rendered invaluable, both in a patriotic and educational sense; for it is eminently calculated to elicit the views of competent men who have no other opportunity of acquiring the data on which to form them than that afforded by the Press. Whether these views would always be held acceptable is a separate question which need not here be considered. And now let me ask you to accompany me for a few moments to the camp of the Russo-Afghan Boundary Commission, of which we have telegraphic intelligence up to August 26, or only a week ago, and from which a letter in the 'Indian Pioneer' of July 18 brings full particulars under date Kham-i-Ab, June 15. For obvious reasons it would be out of place here to refer to the political knot which the Commissioners are seeking to untie. Had it been otherwise, I should have endeavoured to find a qualified exponent to admit us into the diplomatic secret, one which is so closely allied to geographical investigation. But the objection does not apply to the geography of the country traversed by the mission. 'Kham-i-Ab'—I have written it as printed in the 'Pioneer'—is a point near the Oxus, north of Andkúí. I shall not myself attempt to travel so far; but it affords me much pleasure to state that the actual scene of territorial demarcation and its immediate vicinity will be described by a gentleman who has made a professional study of this as well as of similar questions of political geography. In the meantime let us take a rapid glance at the tract between Quetta and the Helmand, a distance estimated at nearly 320 miles, of which Nushki is not quite third. I take my figures from Major Holdich's notes, in the 'Proceedings of the Geographical Society,' which include the stages and distances to Galicha; and from a letter in the 'Pioneer' of November 19, 1884, giving the distance from Galicha to Khwájah Ali on the Helmand at 53 miles—checked, moreover, by the above-named officer's statement that a place called Shah Ismaíl is halfway between Nushki and Khwájah Ali.

The country traversed was for the most part dreary and waste. Within 40 miles from Quetta the soil seemed 'poor,' and 'the cultivation scanty,' while it was not easy to obtain 'such necessary supplies as wood and chopped straw.' In 45 miles further it was 'difficult to describe the general appearance of poverty and desolation'; while for the next 31 miles water was only procurable at one place—'a narrow little oasis.' Then came a trying night march 'of 25 miles over ground always rough and stony, and occasionally steep for laden camels.' As for the climate, the sun was intensely hot in the daytime, the cold bitter at night, and a 'fine white dry dust' was blown about in constant clouds. The last 10 or 12 miles into Nushki was mainly along the bed of a stream. From Nushki to the Helmand there were three routes available, of which the Mission chose the most northerly, on account of its greater facilities for securing a sufficient supply of water. For nearly 80 miles of this distance—or to Gazchah—the characteristic of the ground was a flat, hard surface, commonly known in India and neighbouring countries as *put*, easy to cross, but monotonous to contemplate, and the writer's description of 'the same wide expanse of limitless plain, the same stunted undergrowth, and occasional sun-ridges (or drifts) of a few yards only in width, but deep and shifting, with an occasional hut or *ziyárat* (the dwelling of a desert *fakir*), like an inverted bird's nest of sticks adorned with quaint devices, leaves little wanting to complete an intelligible picture. From Gazchah onwards we are told that 'a marked geographical change occurs,' and that the line of march for about 90 miles further is 'a mere track, winding and twisting over the successive waves of rolling stone-covered plateau hills, with the line of distant rugged peaks to the south; a few scattered isolated hills on the northern horizon, and one or two remarkable conical peaks rising straight up from the plain, forming a peculiarly definite line of landmarks for the marching force. The direction at night was indicated by fires kept up at intervals of a few miles.' The last 50 miles or so to the river is 'a troublesome strip of waterless desert.' It should be noted that, with one exception, where it was reached at 25 or 30 feet below surface level, Major Holdich states that five to six feet is about the average depth at which water is found between Nushki and the Helmand.

Few can deny that all this is very useful and interesting information. So far back as the spring of 1808, Capt. Christie had made an adventurous journey to the left bank of the Great Afghan River, also from Nushki, whither he had proceeded from Kelat in company with Lieutenant Pottinger. He reckoned the distance at 191 miles, or somewhat less than the Mission's estimate. When Sir Charles MacGregor and Captain Lockwood passed through Western Baluchistan in 1877, they separated at a place called Lal Khan Chah, about 60 miles below the Helmand, to return, by different routes, to the Sind frontier post of Jacobabad, Captain Lockwood taking the upper route by Nushki and the Bolan, and Colonel MacGregor the lower by the Baila country; but they did not penetrate so far north as the Helmand itself. Nushki has, however, been more than once visited of late years by British officers from Kelat.

'Khwájah Ali,' writes Major Holdich, 'where the Boundary Commission first struck the Helmand, exists only in name.' Neither he nor the correspondents of the 'Pioneer' mention its distance from Rudbar, but it may fairly be concluded that it is not many miles to the eastward of that place. The river appears to have been forded at Chahár Burjak, whence the party moved up the right bank to Kala'i-Fath and Kohuk, passing on through Northern Sistan and its reed-beds to the Afghan territory of Lásh Juwain. Having myself visited the locality at which we have here arrived, it might naturally be inferred that I should pause to say something regarding it, but I will not weary you by recurring to narratives and descriptions published many years ago, reserving all personal experiences to guide me in the general conclusion to be submitted. How the British Commissioners for delimitation of the Russo-Afghan frontier proceeded from Lásh Juwain to the immediate vicinity of Herat, and on to the quasi-Mesopotamia of Badkhiz, I leave to be dealt with by the authority to whom I have already referred.

Time, too, warns me that I have detained you long enough, and that if my illustrations apply to the argument entrusted to your consideration, the application should at once be made evident. To my own mind the bearing is clear. A Boundary Commission represents the three branches of Science, Research, and Diplomacy—in other words, all that comes under scientific geography and political geography. The first, you will understand, comprises the survey of country, mapping, and determination of localities. The second has to do with the definition of territorial limits, and, in such sense, with history, ethnology, and laws of nations. That all this has been done, and well done, on the present occasion is not disputed, any more than that enlightened attention will be given to the due disposal of results. But are not these matters of sufficient importance to be taught as daily lessons in our schools, and presided over in university chairs? Even those barren and desolate lands of which we have now spoken—and I have myself traversed many miles of such, some, indeed, in the near vicinity of the Perso-Afghan frontier, between Herat and Farah—they may have a meaning which can only be understood by the initiated, by those who have made them a long and seriously-undertaken study. To the many they are but miserable deserts displayed in incomplete maps; to the few they may have a value far beyond their outer show. Were I asked to sketch out the kind of manual which might be useful in preparing officers for dealing with questions such as these, I would solicit reference to a late paper which I contributed to a quarterly journal, and which I have once before quoted. In it, I stated:—

'Asia itself is a stupendous study, but the difficulties may be smoothed to the learner by the judicious employment of method, which, after disposing of essential generalities, would naturally tend to division and subdivision. The first would imply a region such as Turkestan; the second, a group of States or single States only, such as Bukhára and Khiva. Given, then, a particular area, the next consideration should be to explain its physical geography. This should comprise the scientific description of its mountains, rivers, and valleys. Its orography should be comprehensive in respect of direction, elevation, watersheds, and connection with plains and plateaux; its hydrography should treat of sources and mouths, basins, drainage, and connection with lake and swamp. Climate and the more important forms of animal and vegetable life should succeed in due course; indeed, something of geology, zoology, and botany, and it may be more besides, might reasonably be added to satisfy the requirements of purely scientific teaching. After science, history would follow, and, joined to history, an account of the religion, manners, and customs of the people, as affected by the historical narrative; a statement of the artificial lines of separation which have replaced natural boundaries in consequence of the wars, revolutions, or arbitrary changes which have characterised certain reigns or epochs; an exposition of the form or forms of government in vogue at different periods; and, finally, a chapter on trade and commerce, including a notice of indigenous products and manufactures. Maps, applicable to relations of territorial changes, would be of immense value; and an historian's criticism on these relations, if offered in that fair spirit which alone is justified in composing history, would be an indispensable complement.'

But it is not the preparation of a manual which I have come before you to advocate. This would be one of the many fruits of a system now sorely needed for establishing at home the true position of geography as apprehended to a great extent abroad. I am one of those old-fashioned and perhaps obsolete persons who believe, not in the infallibility but in the ability of this country as a governing Power. If that ability is proved in the creation and growth of its colonies, it is no less distinguished by an unselfish tendency to lead those colonies to govern themselves. But the unselfishness would be selfish if confined to the action of Great Britain alone. It should be an example to other States and Powers to 'go and do likewise.' That example, rendered available in International arrangements by fitting action at fitting opportunities, can only be carried out by a knowledge of geography in its widest sense. As to questions of territorial boundary, in Asia or elsewhere, we may be fortunate in having able officers to decide, and wise Governments to scrutinise decisions: but one generation may not keep pace with another generation in the character of its Governments or agents, and the doctrine of chances is not a safe one in a matter of State urgency.

Plainly, let us not lose the immense advantage given to us by Providence owing to the want of systematic knowledge in a branch of science in which we are shown to have been outstripped by Continental nations, but which all historical precedent warns us that it is our duty to foster to the uttermost.

The following Papers were read:—

1. *Notes on the Extent, Topography, Climatic Peculiarities, Flora, and Agricultural Capabilities of the Canadian North-west. By* Professor JOHN MACOUN, *M.A.*

The author describes the geographical and topographical features of the North-west, and shows that its leading feature is that of a plane sloping to the north. From this results a nearly uniform climate. A uniform climate gives unity of natural productions, and cereals or other crops, if successful on one part, will therefore be equally so under the same conditions in another.

2. *The Canadian Pacific Railway.* *By* ALEXANDER BEGG.

The author explains the circumstances under which the federation of the British North American provinces was brought about, and gives some account of the acquisition by Canada of the north-west territories and the admission of British Columbia into the Dominion. He points out that the Transcontinental Railway through British territory was the very essence of the agreement between the different parts of Canada to unite under one system of government, and shows as a result of this the building of the Intercolonial and Canadian Pacific Railways, connecting the Atlantic and Pacific Oceans. He then proceeds to recount how the construction of the Canadian Pacific Railway, as a Government work, proved a failure, and that therefore the contract was entered into with the present Canadian Pacific Railway Company for the construction of the road. He next gives an outline of the progress of construction from the beginning of the work to its completion, and following this a description of the country traversed by the railway, at the same time showing the various sources of traffic upon which the line depends, and is likely to depend in the future, for its revenue. The condition of the north-west territories of Canada before and since the year 1881 is then described, showing that to the railway is due the rapid development which has taken place in so short a time. The author then goes on to say that a large traffic in cattle and grain from the Western States of America is certain to flow through the channel of the Canadian Pacific Railway to the seaboard, and that it will thus be an outlet for the produce, not only of North-western Canada and British Columbia, but also for a large portion of the United States.

Mr. Begg also demonstrates that the trade which has already commenced between Canada and Australia, China and Japan, *viâ* British Columbia, is likely to assume considerable dimensions, and to prove a very important source of revenue to the railway, and that the commerce also between Canada and the Australian Colonies is certain to be largely augmented by the Canadian Pacific connection with the British Columbia coast. In this respect the author points out that Canada is likely to prove a powerful rival to the United States. The imperial aspect of the enterprise is then dealt with, and shows how great an advantage it is to Great Britain to have an independent route through British territory for the protection of her possessions in the East. From a commercial standpoint the author maintains that the mother country cannot but derive very material benefit from this route in her trade relations with the Australian Colonies, China, and Japan. The paper concludes with a number of tables showing the mileage of the Canadian Pacific Railway lines operated by the company, the equipment of the road on December 31, 1885, comparative statements of the earnings, and a comparison of times and distances by the West to the East.

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3. *A new Trade Route between America and Europe.*
By HUGH SUTHERLAND.

The settlement and cultivation of the Canadian north-west have directed public attention in that country to the necessity of a new trade route to Europe. It has been found that a railway carriage of 1,800 miles before reaching a seaport is a serious drawback to the prosperity of that region, and places the settler at a great disadvantage in competing with the other wheat-producing countries of the world. With the object of getting on at least terms of equality with those rival countries an agitation was begun a few years ago to open up an outlet through Hudson Bay, and a railway has been projected from Winnipeg and Regina to Port Nelson, at the mouth of the Nelson River, which, when completed, will bring the north-west upwards of 1,000 miles nearer the seaboard than it is at present.

The Canadian Government, anxious to encourage the enterprise, fitted out an expedition to explore the strait and bay, with the view primarily of determining the practicability of the route for commercial purposes. The first expedition was sent out in 1884, and observing stations were established along the strait. These were relieved the following year, and the information thus obtained, together with the evidence of experienced navigators which was collected by a special committee of the Canadian Parliament, have satisfied the people of that country that the route is entirely feasible.

It is confidently expected that this new trade route, already in process of development, will create a revolution in the commercial traffic of the vast interior of that continent on both sides of the international boundary. Minnesota, Dakota, Montana, and Wyoming, with their immense productions of wheat and cattle, are naturally tributary to that route, as well as the whole of the Canadian possessions west of Ontario.

A reference to the map will show how far down into the heart of the continent Hudson Bay extends, and how favourably it is situated for commanding the entire trade of that vast territory. It would seem as if nature intended that it should be the outlet, offering as it does a seaboard within convenient reach of the districts named, and virtually placing them as near to European markets as Ontario, Western New York, and Ohio now are.

The attention which has been given to the bay in consequence of this new project has resulted in increased knowledge of the resources of that great inland sea. Salmon, seal, whale, and walrus abound in great numbers, while the coast regions of the bay and strait are rich in minerals. The region of country draining into James's Bay is covered with valuable timber. Besides offering a new and advantageous trade route between Europe and America, it is not improbable that the utilisation of those waters for such a purpose will soon be followed by the development of fish, timber, and mining industries of great and practically inexhaustible richness.

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4. *Proposed new Route to the Great Prairie Lands of North-west Canada, viâ Hudson's Strait and Bay.* *By* JOHN RAE, *M.D., LL.D., F.R.S., F.R.G.S.*

The project of opening a new route through Hudson's Strait and Bay by steamer, and from the west shore of the latter by railway to Manitoba, is being undertaken with the most praiseworthy motive of making a shorter and cheaper route for transmission of emigrants to, and for carrying grain and other produce from, the prairie lands of Canada than the present means of transport by lake and railway by the St. Lawrence river and Strait of Belle Isle to England.

Earnestly desiring that, if practicable, this great work should be carried out successfully, I fear, however, that failure is more probable than success, and a failure would be an immense misfortune. There are a number of adverse circumstances that have either been entirely overlooked or not taken sufficiently into consideration. These difficulties are wholly connected with the navigation of the Hudson's Strait, and have nothing whatever to do with the navigation of the Bay nor with the construction of the railway from thence to Manitoba, both of which are easy enough. This route, if established, would shorten the distance by 400 or 500 miles—more or less, according to the position on the prairies from which the measurements began—and would give about two days quicker time to a loaded steamer of ordinary speed; an advantage more than counterbalanced by a probable average detention by ice of three or four days on each voyage through the strait. The disadvantages are—

1. The short time—three or three and a half months (?)—during which the strait is sufficiently open each season to allow a steamer to get through without much hindrance by ice, whilst on the other hand the great Canadian lakes are perfectly open for fully six months, and the Strait of Belle Isle navigated for at least five months by the Allan steamers.

2. The danger to a large heavily laden steamer, whether of wood or iron, if caught in an ice-nip; also the higher rate of insurance consequent on such danger.

3. The uncertainty and rapidity of ice movements, which baffle the skill and experience of the oldest whaling captains, and are so well described by Lieutenant Gordon, who commanded the *Neptune* in 1884 and the *Alert* in 1885, on

voyages of inspection of the intended new route, whose opinion agrees closely with the far longer experience of the Hudson's Bay Company's captains *in sailing ships*, and of my own (much more limited) in the years 1833,[1] 1847, and 1854. Lieutenant Gordon says that in the first half of July a steamer would take ten days to pass through the strait—a distance of 500 miles—or fifty miles a day!

If this is correct the new route will occupy longer time, be more dangerous, and less favourable in every way than that by the St. Lawrence.

Up to the middle of July the ice-pack driving down Davis Strait fills up more or less closely the eastern entrance of the strait, whilst at its western end the same thing happens during a part of August or of September by the driving to the south of the 40,000 square miles of ice-floe from Fox's Channel.

At one part of Hudson's Strait the compasses used to be, and probably still are, useless, owing to some local attraction.

FRIDAY, SEPTEMBER 3.

The following Papers were read:—

1. *On the Place of Geography in National Education.* *By* DOUGLAS W. FRESHFIELD, *M.A., F.R.G.S.*

2. *Can Europeans become acclimatised in Tropical Africa?*[2] *By* ROBERT W. FELKIN, *M.D., F.R.S.E.*

With the exception of Cape Colony and a small portion of the north-west, the whole of Africa is in the tropical and sub-tropical zones.

This immense region is of great importance, and could it be colonised by Europeans it would be of great advantage to the civilised world.

Acclimatisation is the process, oftentimes slow, by which persons become adapted to, and so retain health in countries having a different climate from those in which they were born. This acclimatisation may be in part effected by changes taking place in the individual or in the race, and in part by hereditary modification of constitution. In some places real acclimatisation is impossible, but in nearly all a person may accommodate himself for a certain time to almost any climate.

Great changes have taken place in the location of different races, but these changes have taken place gradually. There is a marked difference in the possibility of withstanding climate in various races, and in each case we must examine the power of resistance possessed by any given national constitution, in order to decide whether it may successfully acclimatise itself in a tropical country when permanently colonised there. The difficulties with which Europeans have to contend in tropical Africa are heat, moisture, malaria, special diseases in special districts, &c.

It is probable that southern European nations could withstand these obnoxious influences best. In tropical Africa there are great differences of climate. (These differences, especially between the coast line and the interior, were next explained.) The coast line and the banks of rivers for the first 200 miles are most injurious to Europeans, and the difficulty of reaching the interior is the greatest hindrance to acclimatisation.

Next followed a description of the various comparatively healthy inland districts.

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[1] In this year both the ships to Hudson's Bay were shut in for about three weeks in close-packed ice near the east end of the strait in July. The ships were one and a-half mile apart, yet lady passengers walked easily over the floe from one to the other. On attempting to get home both ships were stopped by the Fox Channel ice early in October, and had to winter in the bay. Before giving up the attempt to force a passage through the pack two feet depth of ice was formed on the foredeck, and the ship was set down more than two feet by the head by the weight.

[2] Printed *in extenso* in the *Scottish Geographical Magazine*, Nov. 1886.

I think it is almost impossible for Europeans to do more than accommodate themselves to the coast climate for a short time (two or three years), but given some means of rapid transport, such as a railway, to carry them over the dangerous belt of malaria on the coast, it would be quite possible for them to thrive in the mountainous regions and high plateaux of Central Africa, with proper care and sanitary surroundings. The climate of Central Africa is not necessarily more fatal to life than that of India. We have now the advantage of greatly increased knowledge of tropical climates, so that precautions can be taken which were not dreamed of when India was added to our empire.

3. *Further Explorations in the Raian Basin and the Wadi Móileh.*
By COPE WHITEHOUSE.

The author exhibited maps, diagrams, and photographs showing the cartography of Middle Egypt and the Fayoum, from the papyrus map of Boulaq, completed by the fragments discovered by him, to the map of his expedition in February (1886), accompanied by a staff of engineers detailed by the Government, and in April with Col. Ardagh, C.B., R.E., and an admirable map of the Charaq basin, prepared expressly for this paper by Monsieur V. Giardini, of the Egyptian Cadastre. Diagrams of the Nile floods, sections of the Bahr Jousof, and photographs of this canal and the adjacent desert showed that a large volume of water (*circa*, a milliard of cubic metres) could be annually conducted into the Wadi Raian. The line of levels run with the aid of Mr. Stadler proves that there is a depth of from 100 to 250 feet below high Nile throughout an area of at least 400 square miles. Photographs and ancient maps show that the ruins in Móileh—never visited, with one possible exception, prior to the visits this year of Dr. Schweinforth and the author—are identical with Dionysias. Thus the Wadi Raian has been identified in position, shape, and depth with the *Lacus Meridis* of the Greeks and Romans. The project of its restoration is now actively occupying the attention of the proper authorities.

4. *Recent Exploration in New Guinea.*
By Captain HENRY CHARLES EVERILL.

The author of this paper commanded an expedition to New Guinea organised by the Geographical Society of Australasia. The expedition left Sydney in the steam launch *Bonito* in June 1885. The Hon. John Douglas and the Rev. S. MacFarline accompanied it to the entrance of the Fly River. For a long time nothing was heard of the explorers, but towards the end of October it was rumoured that they had met with a disaster, and the Rev. S. MacFarline was given a circumstantial account of their massacres when he visited the Fly River to make inquiries. This alarming news naturally caused much anxiety. A relief party left Thursday Island three days after its receipt, and the admiral in command of the station despatched well-found steam launches to the Fly River. However, three days after the search party had left Thursday Island the *Bonito* steamed quietly into port.

The expedition had gone up the river Fly for some distance beyond Ellangowane Island, and discovered a new river, which was named the Satrickland. It ascended that river as far as lat. 5° 30′ S., long. 142° 22′ E., a point near the boundary between British and German New Guinea. The last ninety miles of this voyage were made in a whale-boat, the *Bonito* having stranded on a shingle bank, where she remained high and dry for seven weeks. The journey proved very trying, owing to the strength of the current and the rapids which had to be surmounted, but was accomplished without loss of life. Several thousand objects illustrating the geology, botany, zoology, and ethnography of New Guinea were collected, and after having been exhibited in Sydney distributed among the Australian museums. Complications with the natives were avoided. Many of the party (twelve Europeans and twelve Malays) suffered from fever, but only one death was recorded, namely, that of a Malay, who died of lung disease.

5. *The Fiji Islands.* *By* JAMES E. MASON.

6. *New Britain.* *By* Rev. GEORGE BROWN.

7. *The Connection of the Trade Winds and the Gulf Stream with some West Indian Problems.*[1] *By* R. G. HALIBURTON.

SATURDAY, SEPTEMBER 4.

The Section did not meet.

MONDAY, SEPTEMBER 6.

The following Papers and Report were read:—

1. *Remarks on a Curious Album.* *By* H. BEAUGRAND.

2. *Report of the Committee for drawing attention to the desirability of further research in the Antarctic Regions.*—See Reports, p. 277.

3. *Telegraphic Enterprise and Deep Sea Research on the West Coast of Africa.* *By* J. Y. BUCHANAN.

4. *River Entrances.* *By* HUGH ROBERT MILL, *D.Sc., F.R.S.E., F.C.S.*

The entrances of rivers have hitherto been studied almost exclusively from the 'practical' point of view, and few facts concerning the mixture of sea and river water, except those ascertained incidentally by engineers, are known. The want of a proper geographical definition of a river leads to considerable difficulty in some cases, when it is of importance to know exactly where the river ends and the sea begins. This definition may be supplied by considering the physical conditions of the water. A preliminary classification of river entrances divides them into—

1. Those connected with inland seas, *e.g.*, the Caspian.
2. Those connected with tideless enclosed seas, *e.g.*, the Mediterranean.
3. Those connected with tidal seas.

River entrances of the third kind are of most interest in this country, and in order to class them naturally it is necessary to consider the physical conditions of the water as well as the topography of the shore.

A typical river system of the third class comprises a river gradually widening and deepening as it merges into a funnel-shaped sea-inlet, and such a system may be clearly divided into three parts:—

1. The *river* proper, a stream of fresh water with its connected tributaries and feeding lakes.
2. The *estuary*, where tidal mixture of fresh and salt water takes place, and along which there is a rapid change in salinity and temperature, while

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[1] Published in the *Proceedings of the Royal Geographical Society*, Nov. 1886.

there are considerable differences between bottom and surface conditions and between those found at high and at low tide.

3. The *firth*, where the rate of increase of salinity and of change of temperature, as the *sea* is approached, is small and progressively diminishing; and where there is little difference between bottom and surface conditions and between the state of matters at high and at low tide.

Some rivers have no firth, others have neither firth nor estuary; the size, position, and character of each region depending on the ratio between the volume and velocity of fresh water in the river to the size and configuration of the sea-inlet into which it falls, and also to some extent on the weather and on tides.

The only British river-system which has been pretty fully investigated physically is that of the Forth.[1] The Clyde,[2] Tay,[3] and Spey[4] have been examined in a preliminary manner, and the Thames[5] estuary to a slight extent. Attention may be specially drawn to the Thames, the Bristol Channel, the Wash, and the mouths of the Mersey, Ribble, Humber, and Shannon as worthy of special study in this respect.

The observations required in such researches as carried on by the Scottish Marine Station are the following, repeated monthly at intervals of a few miles along the river channel from fresh water to the sea:—

1. *Temperature* at surface, bottom, and intermediate depths.
2. *Density* of the water as a measure of salinity at the same places.
3. Amount of *suspended matter* and *transparency*.
4. *Alkalinity* as a measure of dissolved calcium carbonate.

Messrs. Negretti and Zambra's patent standard deep-sea thermometer, in the Scottish frame, and the Scottish slip water-bottle made by Mr. Frazer, Lothian Street, Edinburgh, are the most convenient and trustworthy instruments for ascertaining temperature beneath the surface, and for collecting samples of water in river entrances where depth is small and currents are rapid.

(The paper was illustrated by charts, diagrams, and by the exhibition of apparatus.)

5. *Configuration of the Clyde Water System.*[6]

By HUGH ROBERT MILL, *D.Sc., F.R.S.E., F.C.S.*

The Clyde runs westward for 25 miles from Glasgow, gradually widens to 2 miles at Cloch Point, where it turns abruptly southwards and pursues this course for 49 miles, rapidly attaining a width of 30 miles, which continues until it merges in the Irish Channel. The southern and eastern shores are unindented, but the northern is cut up by inlets averaging about three-quarters of a mile wide, and from 2½ to 16 miles long. Bute, Arran, and the Cumbraes give rise to narrow channels in the Firth; the largest, Kilbrennan Sound, runs up into Loch Fyne, the widest of the sea-lochs, and 40 miles long. This topographical description gives little idea of the natural divisions of the district or of the true relations in it of land and water.

The large bathymetrical chart exhibited, which was made for the author by Mr. Bartholomew, Edinburgh, is contoured and coloured to show the depths of water and the heights of land. It plainly indicates the following features. A broad plateau crosses the firth's mouth from the extremity of Cantyre, past the south end

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[1] Mill, 'Salinity of Firth of Forth,' and 'Temperature' of ditto, *Proc. R.S.E.* xiii. (1885) 29, 157.

[2] Macadam, *Brit. Assoc. Reps.* 1855, Part II. p. 61; Mill and Morrison, communicated to Sections A and B, this meeting.

[3] Mill, 'Salinity of Tay and of St. Andrew's Bay,' *Proc. R.S.E.* xiii. (1885) 347.

[4] Mill and Ritchie, 'Rivers directly entering a Tidal Sea,' *Proc. R.S.E.* xiii. (1886) 460.

[5] R. W. P. Birch, 'Passage of Upland Water through the Estuary of the Thames,' *Min. Proc. Inst. C.E.* lxxviii. 212; lxxxi. 295.

[6] Published in the *Scottish Geographical Magazine*, Jan. 1887.

of Arran to the Ayrshire cost, with a depth of about 25 fathoms. The 50-fathom line runs nearly from the Mull of Cantyre to the Mull of Galloway, and immediately beyond it the 80 fathom contour appears. Arran is surrounded, except on the south-west side, with water of over 30 fathoms, extending close to shore and deepening towards the centre to over 80 fathoms. The greatest depression runs N.W. from the Sound of Bute to beyond Tarbert, in Loch Fyne, near which the deepest point, 107 fathoms, occurs. This λ-shaped deep area is termed the Arran Basin. A narrow straight tract—the Dunoon Basin—runs N. by E. from Cumbrae into lower Loch Long. The estuary shoals rapidly; the 20-fathom line only reaches Greenock, and depths of 10 fathoms stop a little further up. Upper Loch Long, Loch Goil, Loch Strivan, and upper Loch Fyne, although very narrow, form abrupt troughs from 50 to 80 fathoms deep. These are surrounded by high hills, the 2,000 feet contour approaching the water's edge. Where flat land borders the shore depth, as a rule, is slight and increases gradually; a good example is seen along the Ayrshire coast. The occurrence of exceptional heights on land in connection with unusual depth of water is noticed at the Mull of Cantyre and the north of Arran.

A remarkable valley connects the Holy Loch through Loch Eck to Loch Fyne, and another through Loch Long to Loch Lomond. Both of these fresh lakes drain into the Clyde water system, and their configuration is exactly similar to that of the deep sea-lochs.

6. *British North Borneo.* *By* W. B. Pryer.

The author describes that part of the large island of Borneo recently ceded by native Sultans to the British North Borneo Company. This portion of the island he describes as being of about the same size as Scotland, mountainous on the western side, and with large slopes and flats on the eastern. Amongst the mountains is the celebrated Kina Balu, over 13,900 feet high. Many rivers have their sources near the west coast, and, following a very long and winding course, fall into the sea on the east. The junction of several of these rivers at a place called Penungah, about the centre of the territory, forms a noble stream, known as the Kina Batangan, which is traversable for most of its length by small steam launches, and up which even largish steamers can ascend for 150 miles. At various places below Penungah the Kina Batangan is joined by other large tributaries, up one of which, the Quarmote, are the Alexandra Falls, said to be a noble waterfall, but never yet seen by any European. The other rivers on the east coast are the Labuk, Sugut, Paitan, Segama, Benguya, Moanna, and others.

The author says that the non-existence of the Kina Balu Lake, still marked on many maps, was first proved by him in the year 1880. The theory, still existing, that the place where this lake was supposed to be is a large flat, subject to inundation in the wet season, he does not believe in, as he saw many hills and mountains in the part where this flat is supposed to be.

The rivers on the east coast, he says, run through uninhabited virgin forest, the population having been driven away, up to within very recent times, by the numerous pirates that infested the coast. On the west there is a fair sprinkling of people. The hills are for the most part sandstone, but here and there limestone and other formations occur. There are several fine harbours; Guya, on the west, Kudat, on the north, and Sandakan, on the east, being the principal. The author goes on to describe Sandakan Harbour, which, he says, is one of the finest in the world; easy of access even to steamers of the largest size, having behind it the trade of the two largest rivers in the territory, the Kina Batangan and the Labuk, almost on the track of the steamers between Australia and China, which sometimes call in, and commandingly situated as regards the trade and commerce of the surrounding seas and islands, which he thinks must ultimately concentrate there. He also calls attention to the immense importance in the future of Sandakan as a coaling station for our men-of-war and for docking purposes generally.

He then goes on to describe the resources of the country, which, he thinks, from the healthiness of its climate, the equableness and want of extreme heat of its temperature, the absence of physical disturbances, such as hurricanes, earthquakes, volcanoes, and the like; the fertility of its soil, and the prodigious quantity of natural wealth with which it abounds, including extremely rich birds'-nests, canes, beeswax, india-rubber, bêche de mer, pearls and pearl shells, fish, gold, &c., will support a very large population; and he even thinks that possibly in the future Europeans might work themselves on some of the higher slopes in the interior.

There is an absence of ferocious wild animals, though, from the list given, commencing with elephants, rhinoceroses, buffaloes, deer, &c., there would seem to be plenty of large game for the sportsman's rifle. To the European capitalist attraction is held out in the way of valuable timber, which exists in such quantity, and the facilities for bringing which to a shipping port are so great, that it is expected Sandakan will in time take rank as one of the largest timber-exporting places in the East; and after the wood has been cleared off, the ground will be available for planting tobacco, pepper, Manila hemp, Gambier sago, sugar-cane, and many other things. The lists of fruits and vegetables that thrive in the country are long ones, but the latter are described as more or less unsatisfactory. Reptiles, with the exception of crocodiles and a large species of chicken-eating lizard, are not common. The natives are courteous and pleasant, but lazy, and any real labour is usually undertaken by Chinese, of whom there are unlimited supplies to be had either in Hong Kong or Singapore.

7. *The River Systems of South India.*[1]
By General F. H. Rundall, *C.S.I., R.E.*

The paper commences with an account of the physical features of the peninsula, describing its several mountain ranges and plateaux, its general meteorological phenomena, and the effect which its peculiar configuration has on the quantity of rainfall and its distribution.

It next proceeds to enumerate the principal river-basins which serve to carry off that rainfall, distinguishing them in their respective types, indicating their relative positions, specifying their respective tributaries, and detailing particulars as to their areas, length of course, prevailing geological formation, and special characteristics.

After explaining that the four great delta rivers occupy about five-sixths of the eastern drainage area the paper enters on a detailed description of those rivers throughout their respective courses, the phenomena attending their floods, the measures adopted for keeping them under control in the lower or deltaic portions, the character of the estuaries, the formation of the delta, and the great systems of irrigation and navigation which have been constructed therein.

The paper concludes with a notice of the value of water in India generally, and in South India particularly, both for irrigation and navigation purposes, and enumerates the measures which have been adopted by the Indian Government for the promotion of such works, giving an outline of what has already been accomplished, and of what still remains to be done.

8. *On the Afghan Frontier.* *By* Charles Edward D. Black.

9. *On Preshevalski's Travels in Tibet.* *By* E. Delmar Morgan.

10. *North China and Corea.* *By* J. D. Rees.

The author gave an account of his journey from Taku to Peking, and, after noting briefly the most prominent sights and characteristics of the capital, described the route thence to the tombs of the Ming Emperors, and the Great Wall, and down the Peiho to Tientsin.

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[1] Printed *in extenso* in the *Proceedings of the Royal Geographical Society*, Nov. 1886.

The voyage thence to Chamalpu, in Corea, and a description of that place, and of Séul, the capital of the peninsula, next occupied his attention. The poverty of the inhabitants of Corea, and their character, were then referred to, and a contrast drawn between the high standard of administration aimed at in China and the absence of system that characterises the management of Corean affairs. The curious dress of the people was considered by the author to be worthy of note and of description.

The probability of the country being practically annexed by some energetic neighbour or foreigner was asserted, and the nature of the Chinese suzerainty discussed.

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11. *Universal Time: a System of Notation for the Twentieth Century.*
By SANDFORD F. FLEMING, *C.M.G., LL.D.*

TUESDAY, SEPTEMBER 7.

The following Papers were read:—

1. *A Journey in Western Algeria, May* 1886.
By Colonel Sir LAMBERT PLAYFAIR, *K.C.M.G.*

The author started from Beni Saf, the newest and most westerly harbour in the colony, which has lately been called into existence by the rich deposits of manganetic iron ore in the district. Whole mountains are being blasted and carried away; during 1885 more than 300,000 tons were exported, chiefly in British vessels; and so perfect are the loading arrangements that 1,600 tons are usually put on board daily.

Proceeding westward in an open boat, he visited the island of Rachgoun, the mouth of the Tafua, and the interesting Arab ruins of Hosn Honai. This city was founded about the middle of the twelfth century by Abd el-Moumen, the first sovereign of the Moahidin dynasty, whose government extended from Morocco to Tunis, and embraced the south of Spain, Granada, Cordova, and Murcia. He himself was born in the neighbourhood, and, as an act of royal favour, he exempted the city of his creation from imposts of every description. It became the port of Tlemçen, and was frequented by galleys from every port of Barbary as well as from Genoa and Venice. It was finally deserted on the occupation of Oran by the Spaniards in 1509.

The *frisé* walls are still standing, and enclose an area of 17 acres; now a beautiful tangle of fig-trees and flowering shrubs, with abundance of clear running water.

The author drew particular attention to the extraordinary and hardly fortuitous occurrence of Jewish names in the district. Procopius mentions that in his time two pillars existed at Tangier with the inscription, *We flee from the robber Joshua, the son of Nun.* Here we have Cape *Nun*, a marabout dedicated to *My Lord Nun*; another to *Our Lord Oucha,* a village of *Sidi Aissa,* and a tribe called *Oulad Ichou,* the last three being different forms of the word *Joshua.* A little further west is the tribe *Oulad Haouren,* or *Children of Aaron,* who are said to possess a distinctly Jewish type.

He landed at Nemours, the last town on the coast, and thence, proceeding south, he arrived at Lella Maghnia, an important frontier post. Close to Nemours may be seen a rude but interesting monument covering the remains of the column commanded by Colonel Montagnac, which was exterminated by Abd el-Kadir in 1845. At 16 kilomètres from the sea is the remarkable Berber city of Nedroma, surrounded with *frisé* walls exactly like Honai. Until the last few years it was inhabited exclusively by natives, but a few Europeans have lately settled there;

and it will probably soon lose its Berber character, which now makes it so interesting.

The author gave an account of the disturbances which have lately occurred within the frontier of Morocco and of his journey to Tlemçen by a new route only just opened to traffic.

From Tlemçen he visited Sebdou and the mountains of the Beni Snous, where he was hospitably entertained by *The Old Woman*, as she is affectionately called, the widow of Si Mohammed bin Abdulla, Agha of the Beni Snous, who was murdered by Captain Doineau, chief of the Bureau Arabe of Tlemçen in 1856. The affair created a great sensation at the time. Doineau was convicted and sentenced to death, a penalty commuted to perpetual exile from France.

2. *Recent French Explorations in the Ogowai-Congo Region.*[1]
By Major R. DE LANNOY DE BISSY.

3. *River Niger and Central Sudân Sketches.*[2] *By* JOSEPH THOMSON.

4. *Recent Explorations in the Southern Congo Basin.*[3]
By Lieutenant R. KÛND.

5. *A Trader on the West Coast of Africa and in the Interior.*
By ROBERT CAPPER, *F.R.G.S.*

6. *Bechuanaland.* *By* Captain CONDER, *R.E.*

7. *The Panama Canal.*[4] *By* F. DE LESSEPS.

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[1] Published in the *Proceedings of the Royal Geographical Society*, Dec. 1886.
[2] Published in the *Scottish Geographical Magazine*, Oct. 1886.
[3] Published in the *Proceedings of the Royal Geographical Society*, Nov. 1886.
[4] Published in the *Scottish Geographical Magazine*, Nov. 1886.

SECTION F.—ECONOMIC SCIENCE AND STATISTICS.

PRESIDENT OF THE SECTION—JOHN BIDDULPH MARTIN, M.A., F.S.S., F.Z.S.

THURSDAY, SEPTEMBER 2.

The PRESIDENT delivered the following Address:—

As the years succeed each other, and the roll of past Presidents lengthens, an ever-increasing burden of responsibility lies on the occupant of the chair which I am called upon to fill. For twenty-one years (1835-55) this Section existed as the Statistical Section; for thirty-one years more it has been known as the Economic and Statistical Section, and for the fourth time its meeting-place is Birmingham. Henry Hallam presided over this Section at the Birmingham meeting in 1839, the late Lord Lyttelton in 1849, the Earl of Derby, then Lord Stanley, in 1865; since the last-mentioned date the chair has been occupied by men distinguished by their knowledge and practice of public affairs—such as the late Mr. W. E. Forster, Lord Iddesleigh, and Mr. Shaw-Lefevre—or by their acquaintance with the theoretic aspect of economic questions, among whom may be mentioned Professor Ingram, Professor Jevons, Professor Thorold Rogers, and Professor Sidgwick, while the names of Mr. Palgrave and of the late Mr. Henry Fawcett recall men who in different careers of life have shown themselves conversant with matters theoretical and matters practical alike. It might have been assumed that under such guidance the position of this Section of the British Association would have been at all times amply secured; yet it is no secret that but a few years ago its efficiency was called in question, and its status as a scientific body was seriously challenged. The attack called forth an address that has been described by a subsequent President as 'the most elaborate and brilliant to which this Section has ever listened,' and since the delivery of this address at Dublin by Professor Ingram in 1878 the position of the Economic and Statistical Section has been, if not absolutely defined as a matter of form, yet practically secure as a matter of fact.

But it is not only before the followers of rival sciences in this many-sided British Association that economic research has had to stand on its defence. Almost at the same time that Professor Ingram was vindicating the proposition that economic phenomena were 'capable of' and 'proper subjects for' scientific treatment, Professor Bonamy Price, addressing a body[1] somewhat similar to our Section in its constitution, declared that 'political economy is in entire abeyance,' and concluded that 'political economy is not a science, in any strict sense, but a body of systematic knowledge gathered from the study of common processes, which have been practised all down the history of the human race in the production and distribution of wealth. Who,' he exclaims, 'sends for a professional economist in a strike?' and in despair at finding that 'in the war of classes political economy is absent,' and that he was unable to discover 'uniform sequences, general facts which can be described as laws because they ever recur in the same form,' decides that until the far-distant day shall come when the actions of man in his social relations shall be guided by a supreme governing science of society, 'for sociology we must substitute political philosophy in its broadest sense; or, better yet, the legislator himself.' But we

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[1] Department of Economy and Trade, *Social Science Congress*, Cheltenham, 1878.

should hardly look for such a legislator among the ranks of practical men, 'swarming with theories, with ideas built up with the greatest dogmatic confidence in his knowledge of business. His common sense is the very last authority to which the decision of what is right political economy ought to be referred.' From the guidance of such untrained empiricism, as obnoxious to Professor Bonamy Price as to Mr. Herbert Spencer, no right guidance is to be hoped, nothing but disaster can be expected. In point of form the controversy was obscured by the difficulty that exists in deciding the exact limits of art and science respectively, or of defining either the one or the other of these. It is not for one whose training has been strictly practical, whose conclusions have been derived rather from observation of contemporary facts than from academic teaching, and whose present object is not to weary you with dialectic subtilties, but to insist that true social science is nothing if not practical, to refine on the shades of meaning that attach to words and terms. It may be left to a more fitting time and place to reconcile or to decide between the dictum of Mill that 'art necessarily presupposes knowledge; art, in any but its infant state, presupposes scientific knowledge,'[1] and that of Dr. Guy:—'An art, so long as it continues to be a mere affair of skilful handiwork, remains an art; but directly it submits itself to the guidance of well-ascertained principles, it may claim to be a science;'[2] or to reconcile the saying of Sir John Herschel, that 'Science is the knowledge of many, orderly and methodically digested and arranged, so as to become attainable by one,'[3] with that of Professor Sedgwick, who understood science as 'the consideration of all subjects, whether of a pure or mixed nature, capable of being reduced to measurement and calculation.'[4] Within the bounds of one or other of these definitions we may arrive at the exclusion from the domain of science of all but the registration of immutable laws, and lay down as the *ne plus ultra* of science the statement of the simplest mathematical formula. In this showing there can be no experimental science, for there can be no science until the experimental process has evolved the knowledge of a law. Or, on the other hand, we may easily claim a place among sciences for the objects of this Section, namely, to investigate the laws which govern the individual and social life of man, to examine causes which seem to be accountable for exceptions, real or apparent, to such laws, and, in the words of Dr. George Mayr, 'from milliards of facts obtain the grand average of the world.'

It is perhaps in the sciences that have their origin in our knowledge of physiological law that we can find the closest parallel to the position of economics as a science. The sciences of medicine or of surgery are clearly based on our acquaintance with the growth, the nutrition, and the decay of the body, the structure and properties of its component tissues. We know that 'if the brain be out, the man will die'; that if we open an artery he will certainly bleed to death; that a given quantity of a certain drug will inevitably kill. But if medical science were no more than this, the physician would be no more than the veterinary, the surgeon nothing better than a joiner. In the application of medical knowledge, whether to a particular case or to an epidemic, previous history, immediate environment, even psychological considerations must certainly be taken into account. Mistakes have arisen, and still arise; we are amazed at the faulty inferences and analogies that have been drawn by medical experts in the past, and we may doubt whether finality has been in all cases attained even at the present; but the physical laws remain, and are not discredited by the faulty interpretation of them by their students.

We need not, then, despair of the future of political economy, and acquiesce in its relegation to a distant planet, because its teaching, based too often on *à priori* reasoning, and too little on the experience of history, does not always square with the actions of men, warped in their judgment of any particular problem of the day by prejudice or self-interest. May we not claim that political economy has rather taken up wider ground than, as has been said by a recent writer, that it has aban-

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[1] *Logic*, Introduction, § 2, cf. also § 6.

[2] 'Meaning of term Statistics,' *Journ. of Stat. Soc.*, Dec. 1865, p. 488.

[3] *Discourse on Natural Philosophy*, p. 18.

[4] Address to British Association, 1833.

doned many of its outworks: that it does not only concern itself with the production and distribution of wealth, regarding human beings as mere automata, or as parts of a machine, each fulfilling its assigned function with undeviating and passionless precision: but that rather

> Quidquid agunt homines, votum, timor, ira, voluptas,
> Gaudia, discursus,—[1]

must be taken into account in that true statecraft to which political economy should be our guide? If the parties to an impending civil war between labour and capital, to an international war of tariffs, or of arms, do not refer their differences to the arbitrament of a professional economist, is it not less because scientific opinion or expert common-sense could not be trusted to a sound and right decision, than because

> Faciunt homines plerumque cupidine cæci
> Et tribuunt ea quæ non sunt his commoda vere?[2]

It is no reproach to economic science to have taken up wider ground, to have recognised as matters within its proper scope considerations that the older economists, concerning themselves with wealth in its narrow sense as the *summum bonum*, and with the desire for its acquisition as the one mainspring of human action, would have rejected as sentimental or philanthropic. Humanity is many-sided, its units do not lend themselves to grouping or combination with the precision of mathematical symbols, and the experiments of the social philosopher are subject to disturbances unknown in the laboratory of the chemist. The experiments of physical science are difficult enough. 'In the spontaneous operation of nature there is generally such complication and such obscurity, they are mostly either on so overwhelmingly large or on so inaccessibly minute a scale, we are so ignorant of a great part of the facts which really take place, and even those of which we are not ignorant are so multitudinous, and therefore so seldom exactly alike in any two cases, that a spontaneous experiment is commonly not to be found.'[3]

But experiment on the body social is a matter of yet greater complexity; the very conditions of man's being, and the prerogative of independent action based on intelligent reasoning power, that form the basis of, and give rise to the study of social science, render all experiments tentative, and their result rather a calculation of grand average than an evolution of absolute law. Professor Marshall, in considering the functions and limits of the historic method, uses language similar to that applied by Mill to experiment in the physical sciences:—

'History never repeats itself. In economic or other social problems no event has ever been an exact precedent for another. The conditions of life are so various: every event is the complex result of so many causes, so closely interwoven that the past can never throw a simple and direct light on the future.'[4]

The attention of more than one ingenious inquirer has been occupied by the harmonies and antagonisms between economic and natural science, and the former may be shown to have its physical, its biological, and its psychological side.[5] It is no reproach to the latter studies if they, too, depend on the accurate observation and correct interpretation of facts for the determination of their truths and the establishment of their general laws. The discovery of a footprint in some primeval sandstone, of a flint weapon in the drift gravels of the Somme, of a human skull in the caverns of the Meuse Valley, or in the auriferous drifts of California, may set back the dial of geological time and revolutionise our conceptions of the duration of animal or human life on our planet. If, then, our inquiries into the physical phenomena that surround us compel us to admit that no finality has yet been reached, need the economist hesitate to allow that the bases of his sphere of observation are not immutably laid down, that his conclusions are not yet absolute?

The naturalist or biologist watches the infinite complexity of the opposing forces of construction and destruction that make up the balance of animal and

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[1] *Juv. Sat.* i. 85.

[2] *Lucretius*, iv. 1153-4.

[3] Mill, *Logic*, vol. i. Book iii., ch. viii.

[4] *Present Position of Economics*, 1885, p. 41.

[5] P. Geddes, 'Analysis of the Principles of Economics,' *Lond. and Edin.*, 1883.

vegetable life. All nature is incessantly at war with itself, and the battle is to the strong, the race to the swift; a sure instinct guides each individual, or each aggregation of individuals, in the path of unswerving selfishness that leads, in the great majority of cases, to the maintenance of the species. In the crowded communities of the lower animals all is order, regularity, and method; the sustenance of the community, the ventilation and sanitation of the common dwelling, and the disposal of its redundant population, all is provided for; and though pestilences occur, it is chiefly in the case of animals subject to man that they appear to have any sensible or permanent effect on the aggregate numbers of the species. With mankind it is different; his better and more amiable feelings no less than his self-interests, his virtues as well as his vices, tend ever towards results that are not in harmony with those that would ensue from the operation of natural law. The higher the civilisation of any community, the more does it tend to aggregation and concentration of its members; in large cities the forces that lead to the deterioration as well as those that promote the conservation of the race tend no less to destroy than to maintain the balance of nature. Sanitary science, even though its teaching be enforced by compulsory legislation, has a hard struggle to keep at bay the diseases that man, less well taught in this than are the lower animals, seems inevitably to invite to his crowded cities and insanitary dwellings. The resources of medicine and surgery ally themselves with the promptings of humanity or natural affection in promoting the survival of the least fit, and the perpetuation of a race too often inheriting the vices, no less than the diseases, of their predecessors. Nor is it in cities only that man's interference with natural forces reacts on the conditions of his life; the settlement and clearing of a new country, and in a minor degree even a change in agricultural methods in one already settled, affects the fauna, the flora, and even the climate and meteorology of the land, its power of production of food, and its salubrity for habitation.

It is something if we have learnt by the experience of time that social problems are not the mere calculation of man's actions as determined by motives of self-interest, and as measurable in money or its equivalents. Need we abandon all observation because we cannot conduct experiments with the precision of the chemist, weighing our ingredients in the balances of the laboratory? The land, as delimited by Adam Smith, by Ricardo, and even by Mill and Cairnes, has been found too narrow for us; the boundaries have been broken down and overpassed: is there no alternative between the despairing admission that all is barrenness before us, and the elaboration of such Utopian schemes of society as have been imagined by Rousseau, by Robert Owen, or by Comte and his disciples of the present day? One lesson at least we may learn and take to heart: whether, on the one hand, the problems of social science are capable of being stated and solved by a method towards which we are as yet but groping our way in semi-darkness, by some new organon yet to be formulated; or whether, on the other, we must depend on the promptings of well-balanced and trained common-sense for the explanation of every new combination of conditions: whether political economy consist in the discovery of truths, or merely in the recognition of facts, it must not be academic only. No community can be fed on dogma; an industrious and hard-working population, such as is that of our country, and of which the great city in which we are assembled furnishes the most conspicuous example; quick to appreciate the hardness of the struggle by which it maintains itself in existence, and eager to grasp at any prospect of alleviation, will not be convinced as to the universal applicability of formulæ of supply and demand, of entire freedom of contract, and unlimited competition in the circumstances of their particular case. Nor, on the other hand, will any credit accrue to the study of political economy if we abandon ourselves for all guidance to the untrained promptings of empiricism; the guidance of so-called common-sense, sometimes called into action by generous instincts, sometimes by mere impulse, is only too frequently misleading.

It is at this point that the statistical method comes in as an inseparable ally of economic speculation. If the latter has had from time to time, and still has, to assert its position among the sciences, what place shall be assigned to the method which is only too often assumed to be the mere massing and grouping of figures?

It has been said—and the saying is not altogether devoid either of truth or humour—that 'statisticians when they meet together devote half their time to discussing the status and dignity of their pursuit, and its precedence of, or subservience to, economics.'[1] The vulgar misuse of the word statistics has no doubt contributed, in many cases, to ambiguity in its use. The extreme instance need perhaps hardly be mentioned when 'statistics' are used simply as equivalent to 'figures'; one may read or hear even this expression, 'You can prove anything by statistics.' To say that you can prove anything by figures is intelligible; just so can you prove anything by a syllogism with a faulty premiss, or that might is right by the law of the stronger. But apart from cases in which false figures do not tell the truth—I do not say false statistics, for to speak of false statistics appears to me to be very nearly a contradiction in terms—there is the much more frequent class of cases in which they do not tell the whole truth. Examples of this class will readily occur to everyone; I may refer to one very happily chosen by the President of this Section in 1865 (Lord Derby), namely, the error that may be imported into the death-rate by a year of pestilence, not only by its effect on the mortality of the year of its occurrence, but by its clearing away feeble lives, and so lightening the death-rate in years immediately consequent. There is less to be feared from errors arising out of this source if we lay to heart the warning uttered by Mr. Goschen on a recent occasion, 'Beware of totals,'—if we recognise more fully than we are usually apt to do that a table of figures, even if it be absolutely correct as a statement of fact, is merely raw material, not a finished product. The misfortune is that it is only too frequently treated as the latter. Such a table usually sets forth what in the dialect of the produce-market is known as the 'statistical position' of some article of trade, or, in the language of Mr. Wynnard Hooper,[2] as the 'primary statistical quantity.' Mr. Hooper, while agreeing with Professor Ingram in denying to statistics any right to be described as a science, defines the Statistical Method as 'a scientific procedure involving the employment of statistics,' the intelligent compilation of these primary quantities, and the intelligent use of them when so compiled. This definition makes the statistical method applicable to the solution of the well-known problem, interesting, no doubt, to some in Birmingham, 'What becomes of all the pins?' no less than to the most complex economic questions. If the word 'statistics' were equivalent to 'figures,' there would be nothing to be said against this; but the history of the word shows that its connotation has always been in a condition of unstable equilibrium. The late Dr. Guy, one of the most ardent champions of the dignity as a science of the method for which he did so much, has traced for us the evolution of the word,[3] from the now almost extinct form 'statist,' as used by Shakespeare, Milton, and the dramatists of the Restoration, in the sense of economist, to the invention in 1749 by Achenwall of the singular form 'Die Statistik,' and the adoption of 'statistics' in this country at the beginning of the present century. Even since that recent period the wheel has come round full circle. In 1833 statistical inquiry was introduced to the notice of the British Association as one which should limit itself strictly to 'matters of fact' and 'numerical results,' eschewing altogether matters of opinion, even as deduced therefrom. A similar spirit seems to have been in the founders of the Statistical Society of London in 1834, who adopted as their motto 'aliis exterendum,' a phrase implying that their province was merely the harvesting of the above-defined primary statistical quantities, to be threshed and winnowed by the political economist. That this restricted scope was all that could be claimed by statistics was strongly held by some of its leading members; but the original motto of the Society has been abandoned, and the narrower view has been by no one more emphatically repudiated than by Sir Rawson Rawson, late President of the Society, in his opening address to its jubilee meeting in 1885:—'I am not prepared to make statistics the handmaid of social science, to degrade the parent into the position of a hewer of wood and a drawer of water in the service of its

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[1] *Times*, June 25, 1885.

[2] 'Method of Statistical Analysis,' *Journ. of Stat. Soc.*, March 1881, pp. 44–45.

[3] 'Meaning of the term Statistics,' &c., *Journ. of Stat. Soc.*, Dec. 1865, pp. 478–493.

own offspring.'[1] Nor have indications been wanting of a desire, still more recently expressed, to break down the wall of division between statistics as generally understood and political economy, and to treat the two, if not as identical, at least as so closely allied as to be capable of similar or simultaneous consideration.[2]

Enough has been said to show how very indeterminate have been the positions of economics and statistics from the time when they first obtained recognition as subjects of special study; how attempts have been made and resisted to restrict economics to the narrow circle of political arithmetic, or how statistical study has attempted, and that successfully, to vindicate for itself a more enlarged scope than the mere tabulation of figures. Dr. V. John of Berne, and Dr. Geo. Mayr of Strasburg, and among ourselves the late Dr. W. A. Guy, have amply summarised the history and terminology of this branch of inquiry. It would be superfluous to add to or to repeat what these and others have written; it is sufficient to insist—if indeed it be necessary to do so—that as in the debatable etymology of the word statistics we may find by implication the whole range of political economy, so in the word economy are included all things that pertain to the due regulation of the body corporate, whether State or household, and not those only that pass in the former as laws of the distribution of wealth, and in the latter as the keeping of accounts. But from whatever standpoint we may regard either economic or statistical study, whatever may be their mutual connection one with the other, and whatever affinities we may trace between either of them and the branches of knowledge which divide with them the attention of this Association, we must always bear in mind that we in this Section, though by no means utilitarian only, are yet pre-eminently liable to be called on to show how far our works have been of practical advantage to mankind. In other departments of inquiry, as in our own, science and art go hand in hand; astronomy depends not only on the interpretation of nature's laws reduced to mathematical formulæ, but on the art of the instrument-maker as taught by the science of optics: the microscope, the spectrum, the retort, and the blowpipe lend their assistance equally to the chemist, the geologist, and the physicist. So with us are figures, if not the slave or the handmaid, yet in any case an indispensable adjunct to and an inseparable companion of economic research. But while the word utilitarianism has an unpleasing sound to the majority of scientific ears, it is one by which ours need not be offended. The astronomer will be slow to admit that the knowledge of the causes that affect the tides and the better guidance of the adventurous navigator are the highest outcome of his science; the chemist or geologist alike will demur to the proposition that his proudest achievement has been the facilitation of gold-mining, or the improved application of artificial manure to the soil. The services of physical science to humanity have, indeed, been many and splendid; they have affected the conditions of man's existence all over the world, and have given rise to new problems for the economist; we cannot level at the man of science the reproach

nec quidquam tibi prodest
Aerias tentasse vias, animoque rotundum
Percurrisse polum, morituro.[3]

But we ourselves must be content to be judged directly by our works, to stand or fall as we can vindicate to ourselves that we have done, are doing, and shall continue to do work for the advantage of our fellows. 'Orthodox' political economy may be said to be the study of the laws which regulate the acquisition or distribution of wealth; the object of orthodox statistical inquiry to check, as in a balance-sheet, its concentration or diffusion: unless we enlarge the definition of wealth so as to make it include all things desirable by the well-balanced mind—a deliberate election of the good, under the guidance of rightly exercised reason, such as Aristotle defined virtue to be[4]—we shall be constrained to admit that the founders of the United States of America were better advised when they laid down as the

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[1] *Stat. Soc.*, Jubilee volume, p. 9.

[2] *Stat. Soc. Report*, 1886.

[3] Horace, *Carm.* i. 28, 4.

[4] Cf. definition of ἀρετή, Aristotle, *Ethics*, Book ii. § 6.

scope and object of their political system the assurance to every man of 'liberty and the pursuit of happiness.' If this be so, the 'unorthodox' economist of the present day will have to admit to himself that he has to address himself to the problem declared in a well-known passage of Carlyle[1] to be insoluble by 'the whole finance ministers and upholsterers and confectioners of modern Europe in joint stock company, to make one shoeblack HAPPY.' Nor will the disciples of the school of Humanity go far beyond us in declaring that 'we uphold as the true key-note of social reorganisation in the future the insisting on the moral law as supreme and paramount to interest.[2]

Our responsibilities are great, if our studies and labours are anything more than philosophic speculations, anything better than an Epicurean survey of causes and effects, which we are altogether powerless to direct or to influence. As we contemplate the changes that have taken place in the material conditions of man's life all over the civilised world during the past century, or in our own country during the period of fifty years, whose approaching completion under the sway of our Sovereign is giving a text to so many themes of self-gratulation, this responsibility is constantly forced on our attention. Has this vast increase of population, concomitant with a still more astonishing and ample store of the means of sustenance and of the collective wealth, been accompanied by an improvement in the average well-being of the individual? And if we are able to answer this question in the affirmative, and to justify our answer by figures, so far as figures will enable us to do so, can we claim that this general improvement is due in any degree to our right appreciation of economic laws, and to the right application of human control to them, so far as human agency is competent to interfere in their operation? Or has this progress been brought about by causes which we are impotent to control, and which it is therefore useless to examine? Or, on the other hand, is this apparent progress entirely illusory? is it true that the type must deteriorate in proportion as the individual multiplies? and must we admit that our researches have been either labour misapplied, or that they have been powerless to arrest the movement on the downward slope? These are questions to which it is not easy to give any answer that shall be beyond cavil or criticism, but they are always before us, and we may not decline to face their consideration. Most notably do they press themselves on our attention in such a place as Birmingham. Our overgrown inorganic metropolis is a thing apart, without cohesion or entity, not comparable with any other social unit; our large cities still have a life and individuality of their own. When we contemplate our busy ports, our fleets of ships, and the vast mass of foreign materials which a network of railways distributes to inland centres of manufacture; when we view the swarming streets, the splendid buildings, and teeming industrial population of such a city as Birmingham, we may point to evidence of material prosperity that cannot be gainsaid, and may challenge comparison in this respect with the world. But we pay a penalty for all this in a shape which is no less constantly forced on our notice; crowded lanes, noisome alleys, insanitary dwellings, stunted and unhealthy men and women, sickly children, bread hardly won by labour in factories or at occupations that no legislative interference can render wholly innoxious. 'The evils and the diminished vitality that are caused by poverty, crime, personal uncleanliness, drink, and excess of all kinds, as also by the close agglomeration of human beings in places that offer the best chance of lucrative employment, and especially by the unhealthiness of certain occupations, are such as can at best be mitigated by the sanitary authorities, and often lie entirely outside their power of interference.'[3] Hence arise misery and poverty, and thence discontent, contrasts between luxury or ease, and poverty or want. Hence, again, conflicts between capital and labour—a worse than civil, a fratricidal strife—between forces whose co-operation is essential to success, and an inclination to apply legislative remedies at every turn to each evil that strikes the imagination or the eye.

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[1] *Sartor Resartus*, Book ii. ch. ix.

[2] Mr. Frederic Harrison, *Times*, May 31, 1886.

[3] *Supplement to Report of Registrar-General*, 1885, Introduction p. xvii; see also *Report of Chief Inspector of Factories, &c.*, 1885, pp. 18–23.

It is not surprising that pessimist views should sometimes prevail, and that expressions should pass current such as the one which I quote from the public press: 'Some attempt should be made to strike at the over-pressure of population in London, which is, of course, the root of the evil. . . . It obviously is the evil which we have got to face. The tendency to drift into cities is one of the curses of all civilised communities, of whatever social stock they may be.'[1] For myself I am not prepared to admit that a tendency which is indisputable, and which is displayed in every nation in proportion to its enjoyment of peace at home and abroad, has laid the world under so widespread a curse. It is a tendency that is as well marked in nations that are among the least progressive in point of population as in those of most rapid growth. In France, whose population is practically stationary, the rural population, which forty years ago constituted three-fourths of the total inhabitants, is now but two-thirds of the whole, showing a transfer or balance of four million souls (including, however, one million of immigrant foreigners) from the country to the towns.[2] On the other hand, in the United States, whose population is expanding with a rapidity that is proverbial, and whose numbers are doubling themselves every twenty years, as against an estimated period of two hundred and seventy-one years in the case of France, the increase of urban population is still more strongly marked. The official figures of 1840 show that in the United States one-twelfth of the population lived in cities of 8,000 and over; in 1850, one-eighth; in 1860, one-sixth; in 1870, a little over one-fifth; in 1880, not much less than one-fourth.[3]

In England the same process has been going on simultaneously with the great stream of emigration which has transferred millions of our population to other countries. The phenomenon is too familiar to be insisted on, though the exact extent to which it has been displayed is less clear. The distinction between an 'urban' and a 'rural' district is, and perhaps must be, arbitrary, and in many cases unsatisfactory; it is not always easy to decide, officially or otherwise, who is a townsman, and who is a peasant. But it is roughly estimated[4] that whereas thirty years ago the population of England supported by agriculture was about equal in number to that supported by manufacturing industry, the proportions are now approximately as to two-thirds manufacturing, and as to the remaining one-third agricultural. Passing over the fact that in many cases a manufacturing population does not cease to be rural, and bearing in mind that the question is as to the comparative welfare of townsman and peasant respectively, a comparison of the birth-rate and death-rate in town and country does not show so preponderating a balance as is usually imagined to exist. A net normal increase in the English agricultural population of 14·135 per thousand as compared with an increase in the towns of 14·030, or a balance in favour of the former of one per thousand, is but a narrow margin of advantage. Nor is it the largest cities that are the most attractive to new immigrants, since we find that the rate of increase varies inversely with their size, and that during the last ten years the population of towns of under 20,000 inhabitants has increased almost exactly as fast again as that of towns of 50,000 and over. On the other hand, it is precisely during the evil

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[1] *Observer*, Feb. 7, 1886.

[2] *La question de la Population en France et à l'Étranger*, M. Cheysson, Paris, 1883.

[3] *Population of the United States: from Compendium of Tenth Census Report*, Introd. p. xxx., and Report p. 8:—

Year	Town Population 8,000 and over		Rural Population		Total	
1840	1,453,000	*8·5*	15,616,000	*91·5*	17,069,000	*100*
1850	2,897,000	*12·5*	20,294,000	*87·5*	23,191,000	*100*
1860	5,072,000	*16·1*	26,371,000	*83·9*	31,443,000	*100*
1870	8,071,000	*20·7*	30,487,000	*79·3*	38,558,000	*100*
1880	11,318,000	*22·5*	38,837,009	*77·5*	50,155,000	*100*

[4] *Journal of Stat. Soc.*, June 1886. 'Occupations of the People'—Chas. Booth.

times of 1841–51, the evil days of 'Sybil,' of 'Mary Barton,' of 'Sartor Resartus,' recently quoted by Mr. Giffen,[1] when the increase of the population was the slowest, that the proportion of the population supported by agriculture reached its highest point. And if we compare the vital statistics, as a whole, of our present town-dwelling population with the more rural one of 1838–54, as presented to us by Mr. Noel Humphreys in a recent paper read before the Statistical Society, we do not find that the conditions of town-life have told adversely on the population of the country as a whole. Mr. Humphreys answers the question, 'Do we have a greater enjoyment of life as the result of a decline in the death-rate, or are we only a little slower in dying? ' by demonstrating that 'although a large proportion of people cease to be dependent before twenty, and a large proportion of people do not become dependent at sixty, we shall not be far wrong in classing the forty years from twenty to sixty as the most useful period of man's life. Of the 2,009 years added to the lives of 1,000 males by the reduction of the death-rate in 1876–80 (as compared with 1838–54), no less than 1,407, or 70 per cent., are lived at the useful ages of between twenty and sixty.'[2]

Nor did the Anthropometric Committee, appointed on the recommendation of this Section in 1875, and which carried on its work until 1883, verify by its observations the generally prevailing notion that the population of the kingdom is degenerating. The observations of the Committee were on a comparatively small scale, but as far as the opportunities and resources of the Committee enabled them to be carried out, they showed that although in average height and weight the peasant in this country is superior to the artisan, as might be expected from the conditions of an outdoor as against a mainly indoor life, the stature and weight of factory children has decidedly increased. 'The increase in weight amounts to a whole year's gain, and a child of nine years of age in 1873 weighed as much as one of ten years in 1833, one of ten as much as one of eleven, and one of eleven as much as one of twelve years in the two periods respectively.'[3]

I have dwelt briefly on the subject of vital statistics, as being perhaps the most important subject of inquiry that can come under the consideration of the statistician or the economist. 'That which does no harm to the State does no harm to the individual'; we may state conversely this maxim of Marcus Antoninus, and claim that that which is beneficial to the individual is beneficial to the State; and if the prolongation of life be, and be rightly, an object of universal aim, it is especially desirable that we should inform ourselves accurately as to whether we are living under conditions favourable to its prolongation. And if we can prove to demonstration that this is the case, and that the average duration of life at the period when life is most useful and most enjoyable has increased, we shall have made one step necessarily preliminary to the inquiry, how far this has been due to the common-sense of the community rightly left alone, and how far to regulation by the State of man's apparent inclination to choose the evil rather than the good.

I do not propose to discuss here the precise extent to which the Factory Acts, Sanitary Acts, the greater recognition of the necessity for providing open spaces in large towns, or playgrounds and recreation for their children and inhabitants, have contributed to the results which have been obtained. I would rather limit myself to pointing out how, in such an all-important subject of inquiry, the utmost diligence is necessary if we would escape dangerous error. The population of a great city is not a mere inert mass of units, to be counted and compared with other similar aggregations, as we count and compare tons of iron or bales of cotton in stock. Before we can arrive at any pronouncement as to its welfare or otherwise, we must take into consideration many factors besides its actual population at successive periods, or its birth-rate as compared with its death-rate. I may cite, for one or two instances of these disturbing causes, the admirable essay by Mons. E. Cheysson, to which reference has already been made. He shows clearly how in the case of

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[1] 'Progress of Working Classes,' *Journal of Stat. Soc.*, March 1886; see also *Tooke's History of Prices*, 1848, vol. iv. pp. 56–57, as to the effect of the stoppage of flow of population from country to town in 1842–1844.

[2] *Journal Stat. Soc.*, June 1883, p. 204.

[3] *Report of British Association*, 1883, p. 298.

Paris the birth-rate is raised by the many cases in which provincial shame and crime seek concealment in the metropolis, and how the infant mortality of the city, frightful though it be,[1] is diminished by the custom of sending the children to be nursed in the country, with the apparently paradoxical result that of 1,000 births there are remaining but 421 of between one to two years of age, while there are 465 of two years and over. Again, the various motives which have their expression in attracting a vast immigrant population to Paris, place the city in some respects in the position of a new colony; the immigrants are of the age of the greatest vigour and energy, and consequently the population of Paris between the age of fifteen and twenty-five years is greatly in excess of that at even the earliest years of life. The disturbing influence which this state of things must exercise on the birth- and death-tables is obvious, and should serve to warn us how careful we must be in arriving at what on a previous page has been referred to as a 'primary statistical quantity' in matters of vital statistics, before applying to it the 'scientific procedure involving the employment of statistics,' of Professor Ingram.

It is therefore satisfactory to know that at the first meeting of the International Statistical Institute it will be proposed that the first work of the Institute shall be to consider what are the points in regard to vital statistics that it is most essential to be informed upon, and how far it may be possible to assimilate the returns in such matters of the civilised countries of the world. No better or more useful contribution to economic knowledge could be made by the distinguished statisticians whom the formation of the Institute has brought into relation with each other.

I cannot conclude the remarks which I am on this occasion permitted to make without reference to another subject which must be one of engrossing interest in a commercial centre such as Birmingham. The subject of currency and prices seems to me to be one as to which the economist, whether orthodox or latitudinarian, is distinctly waiting on the statistician. Has the currency of the world fallen, through interference here, and non-interference there, into a condition that has told adversely on the commerce of the world? In what year, or during what period of years, were prices at the normal level which may serve as a starting-point? Have prices since then fallen all round, and if so, by how much? or if they have not generally fallen, to what extent have they fallen in the cases in which the fall is admitted? These are clearly questions that should be definitely answered before we can discuss, except as a matter of speculative opinion, whether that fall has been to the advantage of the community as a whole or otherwise. But statisticians are not only divided in opinion as to the answer to the preliminary questions, it may be almost said that the opinion of no two are in accord. It is true that the investigation of the variation of prices by means of an 'index number,' seems to offer a means of forming some definite conclusion; but it must be admitted that the attempts to arrive at anything like a satisfactory index-number have as yet been very far from satisfactory in their result. It cannot be maintained that any comparison of the fluctuations in price of a selected number of principal articles of export or trade, or even of the ratio to the whole volume of foreign trade of all articles dealt with in the 'Statistical Abstract' can ever furnish a measure of the many sources of expenditure that make up the total cost of living. The inquiry is one that seems at the first blush attractive almost to fascination; and it is one that has for many years past exercised the ingenuity of careful thinkers. Mr. Joseph Lowe[2] more than sixty years ago devised a plan to which Mr. Poulett Scrope, writing ten years afterwards, appears to refer in the following passage:—'It has been proposed to correct the legal standard of value (or, at least, to afford to individuals the means of ascertaining its errors), by the periodical publication of an authentic price current, containing a list of a large number of articles in general

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[1] La mortalité des petits Parisiens est affligeante; ils vont, suivant un mot populaire, 'paver' les cimetières des campagnes, où on les envoie en nourrice. Il n'en subsiste plus que la moitié environ vers la deuxième année, lorsque tout ce qui n'est pas mort est rentré à Paris.—*Question de la Population en France*, &c. p. 22.

[2] *The Present State of England.* London: 1823, pp. 333–346, and Appendix, pp. 95–100.

use, arranged in quantities corresponding to their relative consumption, so as to give the rise or fall from time to time of the mean of prices; which will indicate, with all the exactness desirable for commercial purposes, the variations in the value of money, and enable individuals, if they shall think fit, to regulate their pecuniary engagements by reference to this *Tabular Standard.*'[1]

Mr. Poulett Scrope, holding alarmist views as to the appreciation of gold, as shown by the tables of average prices drawn up by the Board of Trade for 1819–1830, cordially approved such a plan; it was also shadowed forth by G. R. Porter and Thomas Tooke, the first part of whose 'History of Prices' appeared almost simultaneously with Poulett Scrope's book. The name of Thomas Tooke and his work will always be associated with that of the late Mr. Newmarch, by whom the idea of an index-number was further developed. The late Professor Jevons applied to the same subject his usual painstaking skill,[2] and it has only the other day been brought under the notice of so practical a body as the London Institute of Bankers by Professor Marshall,[3] in the discussion of a recent paper by Mr. Giffen. An ideal index-number is not inconceivable; if attained it would give us not only the ratio between commodities so called as among themselves, but also the ratio between commodities generally and the precious metals which serve as the medium of barter between them. But the attempt to arrive at it is attended with infinite difficulty; the almost innumerable total of commodities is not, even when ascertained, a number of articles to be measured in height by an arithmetical scale, but rather a series of circles, sometimes concentric, at others mutually intersecting to a greater or less degree until the space left to each is a matter of the most elaborate and intricate calculation. To take an apparently very simple instance, if we would attempt to investigate the fall in the price of pig-iron, we may find ourselves involved in the consideration of an antecedent fall in the freight-charges on Spanish hæmatite ore, no less than in that of a simultaneous fall in wages, consequent on a reduction in cost of food-products consumed by the wage-earners at the iron-works; or we may have to take into account a decreased demand coincident with the development of a more economical and safer system of coal-mining. The complexity of the conditions has led French statisticians to regard with very great suspicion the system of index-numbers, if not to reject them as altogether misleading. I cannot myself share this scepticism. Without expressing an opinion on the economic effects that might arise from the establishment of a 'Tabular Standard of Value,' I cannot but think that from a patient investigation of this arduous subject good results may follow, and that to the elaboration of some such common measure as an effective index-number we must ultimately look for the determination of the degree of prosperity or otherwise of trade at any given period of time. The valuable paper contributed by Mr. Stephen Bourne to this Section at Aberdeen[4] has served to show what has been done in this direction; and still more recently Mr. Palgrave[5] has constructed index-numbers for England and France, extending from 1865 onwards, in which the relative importance of each commodity included is estimated and a value put on it; thus meeting the objection of the French economists, that in our index-numbers we do not sufficiently distinguish the importance of each article. I cannot imagine any greater service that this Section could render to economic science than an elaboration of this most valuable adjunct to statistical and economic inquiry.

I do not venture to avail myself further of the licence as regards time which is accorded to me by custom in addressing you. The address of a Sectional President, unknown, I believe, in the earlier years of the British Association, and of comparatively modern origin in this Section, has attained in the hands of my predecessors

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[1] *Principles of Political Economy.* London: 1833, p. 406.

[2] *Money and Mechanism of Exchange*, p. 333; *Journ. of Stat. Soc.*, June 1865; Letter to *Economist*, May 8, 1869.

[3] *Journ. of Instit. of Bankers*, June 1886.

[4] Printed *in extenso* in *Report of British Association*, Aberdeen, 1885.

[5] *Third Report of Royal Commission on Depression of Trade*, &c. (C. 4797), Appendix B., pp. 312–90: 'Memo. on Currency and Standard of Value in England, France, and India,' by Mr. R. H. Inglis Palgrave.

in this chair a high standard of excellence. Of the difficulty of maintaining this standard I am only too sensible. The conception and elaboration of the observations which I have laid before you have been attended with grave doubts on my own part whether I should not have done better in working up some point of economics or statistics that has either come directly under my own observation and attention or that would have been of immediate interest at this present time and in this particular place. Of such there would have been no lack, and for taking such a course there would have been ample precedent. But it appeared to me that the address of a President to the Section should, unless there be some special reason to the contrary, be something more than a Sectional paper, emancipated from the ordinary restrictions as to length, and by courtesy almost equally sheltered from the free criticism to which Sectional papers are subjected. I have preferred to attempt, inadequately though it may be, to show how narrow are the limits which divide economic from statistical inquiry, how inseparably associated they must ever be, how wide is the sphere of their joint action, and how cognate in their method they are to other branches of research which are inclined to arrogate to themselves exclusively the prerogatives of science. In selecting for special, though cursory, mention two points of particular interest to the economist and the statistician, namely, vital statistics and that fluctuating basis for the estimate of wealth which we call the standard of value; in pointing out how specially these are subject to those disturbing influences which Professor Cairnes has carefully taught[1] us always to reserve in matters of economic speculation; and in admitting how tentative have been, and still are, our efforts to grasp the complexity of their conditions, I trust that I have not in any way derogated from the dignity of the cause which we are here assembled to advocate and to advance. The formulæ of economics and the lessons of statistics may not in all cases have been universally received or practically laid to heart; the ever-varying conditions of society may enforce a constant change in the appearance of social phenomena, and may lend an appearance of uncertainty to our conclusions, but it is not in this place, nor is it at the present time, that we need fear to meet the question, What has the science which you are investigating done for the good of mankind?

The following Papers were read:—

1. *On Manual Training.*[2] *By* Sir PHILIP MAGNUS.

Sir Philip said that this subject had been carefully considered by a Committee appointed to continue inquiries relating to the teaching of science in elementary schools. They had reported to the Council of the Association that it was desirable to make representations to the Education Department, and suggested that the encouragement for the teaching of handicraft work might take the form recommended by the Commission on Technical Instruction, so that the use of tools in boys' schools might be placed in the same position as practical cookery in girls' schools. It could not be too often repeated that the object of workshop practice, as a part of general education, was not to teach a boy a trade, but to develop his faculties, and give him manual skill, and to familiarise the pupil with the properties of such common substances as wood and iron, to teach the hand and eye to work in unison, to accustom the pupil to exact measurement, and to enable him by the use of tools to produce actual things from drawings that represent them. The author pointed out the collateral instruction that could be given in connection with the teaching of handicrafts, and showed that while the faculties of the children were being usefully exercised, and the area of their knowledge was being extended, they were at the same time acquiring manual skill which could not fail to be useful to them in every trade. It is often assumed that school time should be utilised for teaching a child those things he is not likely to learn in after-life, whereas the

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[1] *Logical Method of Pol. Econ.*, Lect. III. p. 85 (Edit. 1875), *et al.*

[2] The subject-matter of this paper has since been published in the *Contemporary Review*, November 1886.

real aim of school education should be to create a desire to continue in after-life the pursuit of the knowledge and skill acquired in school. He explained the method of teaching which should be adopted in order to make the instruction a real educational discipline. He believed that the stimulating effect of the instruction on the intelligence of the children would be such that their progress in literary studies would be in no way retarded by the time given to practical work. Experiments of introducing workshops in elementary schools had been tried in this country, with results sufficiently encouraging to justify the extension of the system; and on the Continent and in the United States much was done in technical teaching. An enthusiasm was spreading among Americans in favour of workshop instruction, which was likely to have an important influence on the industrial progress of that eminently practical and inventive people. As a general rule, he suggested that children should be required to have passed the fifth standard before being admitted into the workshop. As regards the expense, he stated that three items had to be considered: 1. Cost of erection and equipment of workshops; 2. Cost of material; 3. Cost of actual teaching. Considering these items separately, he showed that the introduction of workshop teaching would not materially increase the School Board rate. It might involve some slight addition to the Government grant. He estimated that not more than 30,000 boys would be ready to receive workshop instruction in this country, and the additional grants required would be about 5,000*l.* For this comparatively small expenditure about 30,000 boys might be annually sent out into the world from elementary schools with practical skill at their finger-ends, imbued with an aptitude and taste for the real work of their life, and so educated as to be able to apply to their work the results of scientific teaching and scientific methods. The importance of practical teaching, of studying things before words, had been many times urged, but as yet, such had been the inertia of school authorities and teachers, and such the force of tradition, that we were only now beginning to employ the methods of instruction that had been preached for years by the most eminent educational reformers. It was hoped that the committee of the Association would persevere in the representations it had already made on this important subject, and that the labours of the Royal Commission might result in making our elementary school teaching more practical, less verbal, and less mechanical. In any new Code it should be provided—(1.) That the subject be duly recognised, so that no part of the attendance grant be lost in consequence of the time devoted to it; (2.) That School Boards be empowered to erect and equip workshops in or near elementary schools for the instruction of children who had passed the fifth or qualifying standard; (3.) That grants be paid on the number of children receiving instruction and making the required number of attendances.

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2. *Technical Instruction in Elementary Schools. By* WILLIAM RIPPER.

Attention has been frequently called of late to the importance of technical education, but hitherto with comparatively little practical result. With a view to progress in this direction it is important to inquire whether suitable foundations are being laid in the public elementary schools. We are entitled to expect from the schools substantial help towards the future industrial, as well as social, progress of the country, and we should know whether anything more can be done than is being done to accomplish this object. Manufacturing processes are becoming more and more scientific, and the commercial value of the manufactured article more and more dependent upon artistic and tasteful design. We believe that the early training of the children will have much to do with our future national progress; and, while admitting the many points of excellence, we have to regret the total absence in elementary schools of instruction specifically bearing upon industry, an omission which a manufacturing community would do well to remedy. The energies of teachers and children throughout the country to-day—when not engaged on the three R's—are being expended on much that is unintelligible and useless to the children, such as nice verbal distinctions, elaborate parsing of parts of speech, and the intricate analysis of complex and compound sentences; or on cramming long lists of capes, lakes, rivers, and mountains. Such information may be good in itself, but is it of more importance to the artisan's child than the power to draw, which is the very foundation of all manual skill? And yet no child may be taught drawing unless he first learns parsing and grammatical analysis. We are often told that the school curriculum is an overcrowded one, but when the overgrown subjects of the Code have undergone a useful pruning process, it will be possible to make room for drawing as a compulsory class subject for experimental instruction in science, and for manual instruction in school workshops. Drawing is admitted on all hands to be of supreme importance as a subject of school instruction, and yet the regulations with regard to it as they at present exist are extremely unsatisfactory, their tendency being to seriously diminish, rather than increase, the number of children under instruction. If the class subject now called 'English' were made of practical use by being limited to the correction of provincialisms and common errors of speech, and drawing made a compulsory subject, some valuable work would be done.

Experimental science is almost unknown in our schools, and, as a consequence, the children go out into the workshops and factories crammed with information about moods and tenses, but absolutely ignorant of the elementary principles which would enable them to reason intelligently upon the physical facts and phenomena by which they will be continually surrounded. Systematic science instruction is being given in the Board schools of Birmingham and Liverpool, and with excellent results; the children are interested in their school work, they acquire information which no amount of mere book-reading would give them, and the advantage of such instruction will be reaped not by the children alone, but by the whole community.

Manual instruction in school workshops for boys should occupy a similar place in the Code to needlework for girls, though it would not be convenient to take it, except with the highest classes, in ordinary schools. A good school workshop system should include arrangements for working in wood and in metals, fitted with benches and supplied with the more ordinary tools. The course of instruction should be purely educational, and the exercises therefore properly graded as in any other subject. There should be no idea of teaching any trade, nor of making articles for sale or profit. The higher the grade of the school the more complete should be its fittings. The idea in the minds of many people has been that education was going to save their children from hard work, and the present system of instruction is still in danger of encouraging this notion and of creating habits and tastes which may unfit the mind for the work before it, instead of fitting and aiding it. There is a disposition among the sharp, clever lads of the schools to leave the ranks of labour in which their fathers have served before them to seek situations in any capacity where a black coat can be worn rather than a canvas jacket. They are conscious of skill with the pen, but they feel no aptitude nor desire for working with their hands, and they will escape manual work if they can. There can be no greater fallacy than to imagine that any boy is too good for the workshop. The workshops need, and urgently need, these very boys, and if the public elementary school is not helping to enlist its best talent on the side of skilled labour we are not on the right course. Manual training will provide the connecting link between the theory of the school and the practice of the workshop, between books and tools, and between abstract rules and phrases and the reality of things. It will teach the dignity of labour by example rather than by precept. It will help to form industrious, useful habits early in life, and give a taste for doing useful work with the hands which thousands never acquire. It will be a valuable relief from the sedentary, inactive life of the school, and so counteract the present tendency to develop a race of dyspeptic, pale-faced, small-limbed individuals whose goal is passing examinations, and whose ambition is to be somebody's book-keeper. It will cultivate a respect for the worker and an appreciation of the worth of his work, and it will provide a positive power to work in wood and metals with more or less precision, which will be a valuable aid to many a lad who is destined afterwards to be thrown on his own resources in our large towns and cities, or in some of our far-off colonies.

Manual training is being carried on with much success in France and America. A more practical system of instruction is destined to grow and to occupy an important place in our educational methods of the future, the aim of which will be, while sacrificing none of the present advantages, to enable the schools to render more efficient help than in the past to the nation's industrial progress.

3. *Technical Education. By the* Rev. H. Solly.

The author stated that preparation for technical training in handicrafts must begin in the Kindergarten and be continued by instruction in drawing, decimal arithmetic, and the elements of geometry in the Board schools and be completed in the workshop and class-room.

The apprenticeship system having for the most part broken down, the practical training of the workshop must be supplemented by the combined practical and scientific teaching which can be given only in the class-room. Systematic and scientific instruction in the principles which underlie all manual industries, and the application of those principles to the material of each handicraft (wood, iron, sheet-metal, chemical combinations, textile fabrics, &c.) is essential for thorough technical training, and can be given only by *class teaching*, not in the workshop. Illustrations of this statement were given from various facts and instances. At present it is apparently no one's interest, nor legally anyone's duty, and certainly no one is in general qualified to give this instruction to apprentices or youths; while it too often appears to be the employer's interest to keep the lads in particular grooves of work from which they learn nothing but very limited routine dexterity. Other nations have long since acted on a wiser system, and we are feeling the consequences.

The remedy is to secure systematic and thorough technical training for the rising generation of artificers, by returning to a regular system of 'indentured apprenticeships,' whereby the employers, if they take lads at all into their workshops, shall be bound to see that they attend technical training classes for a certain number of hours in the week during the first three years of their apprenticeship. The increased value of the services of the apprentice during the remainder of his term, and in some cases money premiums, should recoup the employer. The apprentice to be required to pass certain examinations, at the last of which, if passed satisfactorily, the indentures to be given up to the apprentice, constituting thenceforward his certificate of competency. Employer and apprentice to have legal remedy for neglect of obligations on either side.

Technical classes to be taught by men who, to practical knowledge of their trade, add scientific or artistic acquaintance with its principles. Teachers to show students how such principles are to be applied to manipulation of material. Advanced technical training to be carried forward by professors and college teaching. Representative working men agreed as to necessity of compulsory teaching for apprentices on plan now described and in force on the Continent. Legislation in this matter quite as important as in the case of 'half-timers.' First three years of apprenticeship to be regarded as a time not for earning money, but for learning a trade efficiently. Hours for attending classes, when possible, to be arranged for two afternoons in the week instead of evening classes. The interests alike of employers and the lads themselves, as well as the whole manufacturing and commercial prosperity of the nation, largely depend on these arrangements.

4. *Economic Value of Art in Manufactures.*[1] *By* Edward R. Taylor.

The lack of beauty in many English manufactures arises, not so much from bad taste on the part of the purchaser as from the producer's want of artistic culture. In this case supply must precede demand. Instances are given of this. Manufacturers too often ignorantly regard art as an adjunct, instead of an essential,

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[1] The paper will be published, with others by the author, in book form.

to their wares. Art, on the contrary, should be studied with as much daily care as the other branches of the manufactory. Facts are adduced to show that it is only when such care has been devoted that the work will live and be most pecuniarily profitable; and the attention which in former times was given in this direction is contrasted with the comparatively small amount of thought now, in several instances, devoted thereto. The designer employed, being insufficiently appreciated by his master, often either takes to some other branch of art or leaves England to seek more remunerative employment. This statement is confirmed by personal experience, and it is also borne out by the recent Report of the Technical Commissioners. Three ways in which artistic manufactures may be advanced: (1) By the encouragement of all hand manufactures and decoration; (2) by counteracting the apparently natural tendency of machinery and other inventions to vulgarise art by the inordinate use of ornament of a poor character; and (3) by making the training of the eye and of the hand by the use of tools an essential part of education from the beginning of school-life. Each of these suggestions is given in detail. The paper concludes by an allusion to the satisfactory influence which architects and architecture may have on art manufactures.

5. *Imperial Federation, or Greater Britain United.*
By ROBERT GRANT WEBSTER, *LL.B., M.P.*

In this paper the author set forth with a declaration that it was not his intention to place before his hearers anything in the nature of a scheme of his own for the accomplishment of Federal Government. He pointed out difficulties in the way of developing a solution of the question capable of practical adaptability, and said his desire was rather to put before them one or two prominent aspects of the great question with a view of inducing discussion that might bring it a little nearer probably towards consummation, and to suggest what he considered might be a necessarily first step towards the desired end. Starting with the declaration that the absolute advantage of the closer and more real union of the different parts of our vast empire was generally conceded, he claimed that not one of the various suggestions that had hitherto been made bore the faintest chance of being practically worked out. In his opinion the federation of the empire, if it was ever to be accomplished, could only be brought about on lines completely new to those hitherto advanced. Discussing the chief points on which it was desirable that the empire should be brought into closer union, he placed first that of defence against internal and external attack, which was only to be attained, he believed, by a quota of both arms of the service being recruited and quartered in, and paid for by the important dependencies. Secondly, he believed a thorough intercommunication of the various parts of the empire would do much to solve the question 'how to utilise the surplus population in any one portion of the empire by developing the resources of the other parts;' for to him the keeping in the empire of the tens of thousands of emigrants who now quitted our shores to swell the prosperity of other countries was a matter for deep consideration. The question of paramount importance, however, seemed to him to be the further consolidation of the commercial relations of the British Empire. He believed it to be practicable to unite the whole British Empire for commercial purposes. With regard to the means to this end, he deprecated radical changes in the Constitution—the starting of bran new constitutions. Rather let them work on old lines and proceed by gradual and tentative measures, substituting improvements for old systems. The 'High State Council' system of federal government advocated by Mr. Staveley Hill was unpracticable, and he believed the Imperial Parliament and the legislative bodies of the Colonies would never consent to place the great Imperial questions of the day in the hands of the body suggested, which would be less in touch with the actual existing feeling of the countries concerned than they themselves now were. In his view the only true course open to this country was to make an endeavour to place the matter within the range of practical politics by the appointment of a Royal Commission, composed of representatives from all parts of the British Empire, elected directly from the respective legislative bodies, which should sit continuously in London and report. On the other hand, if it was considered that the question was not yet ripe for so decisive a step, he suggested whether an impetus might not be given to the development of the germ of federation by summoning to England from the great representative colonies influential men who should be consulted by the Colonial Office in matters requiring colonial opinion. As a first step, this would foster and strengthen the undoubted link which bound together in love and unity the English-speaking race, and might, at no distant date, result in the consummation of a mutual determination to embrace federal government upon that wider and more comprehensive and practical basis upon which they all so much desired to see it established.

FRIDAY, SEPTEMBER 3.

The following Papers were read:—

1. *Boarding-out as a method of Pauper Education and a Check on Hereditary Pauperism.*[1] *By* Miss WILHELMINA L. HALL, *F.R.Met.Soc.*

The object of this paper is to put forward the claims of boarding-out as the most natural and economical system of pauper education, and the only one by which they are *entirely* severed from pauperising influence.

Pauper children are of two classes—permanents and casuals.

The various methods of educating them are—(1) Workhouse Schools; (2) District Schools; (3) Cottage Homes; (4) By Emigration; (5) By Boarding-out.

I. *Workhouse Schools.*—Children reared in a workhouse are acknowledged to be below the average of the working-classes both in physical and mental attainments. Educated away from the surroundings of family life, forced to associate with children of tramps and bad women, they are sent out into the world wholly untrained to resource, thrift, or self-dependence. They are frequently sickly, stunted in growth, and constant victims to ophthalmia and skin disease. Their education even is at a disadvantage owing to their indescribable apathy and dulness, and to the few points of illustration from the outside world available to the teachers. There are 52,000 children (1885) in receipt of indoor relief, 33,000 of whom are orphans or relieved without their parents. Some 8,000 of these are educated in district schools, 26,000 in workhouse or union schools, and 3,000 are boarded out; in 300 unions children attend Board Schools. Some 30,000, *at the least*, are still subjected to the pernicious influence of workhouse life, and 'have a distinct tendency to swell the crowd of pauperism.' Is it not a State duty to set them on new ways, and to take them from an institution rightly described as 'half penal, half charitable, and in its results wholly demoralising'?

II. *District Schools.*—This system, in operation since 1847, though a distinct improvement on workhouse training, has been well described as 'a gigantic mistake.' Apart from the evils of large institutions, its cost is enormous, varying from 25*l.* to 40*l.* per head per annum.

III. *Cottage Homes.*—A method used to a limited extent only by Poor Law authorities. The attempt to imitate family life is admirable, though not always successful. The cost, however, is excessive, the Banstead Cottage Homes of the Kensington Union costing 36*l.* 14*s.* 9*d.* per head per annum.

IV. *By Emigration.*—Most excellent in its results when care is taken to emigrate *suitable* children under due supervision.

V. *By Boarding-out.*—Boarding-out in England is carried on under two 'orders' of the Local Government Board: that of 1870, known as 'Boarding-out *without* the Union,' and that of 1877—'Boarding-out *within* the Union.' Compared with

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[1] Published by R. Clark, Dorking.

the order of 1870 that of 1877 has considerable drawbacks, most notably the want of help from certified voluntary committees, and consequently continued subjection of the children to pauperising connections. There are (1886) 102 certified committees, under the order of 1870, having charge of 1,022 children; under the order of 1877, 1,962 are boarded-out in 148 unions.

The advantages claimed for boarding-out as against other systems are:—

I. *Economy of Cost.*—The maximum cost of boarding-out is 13*l.*, and the average 11*l.* per head per annum. Speaking generally the cost of a child educated in district schools varies from 9*s.* to 16*s.* 10*d.* weekly; in the workhouse from 4*s.* 3*d.* to 9*s.* 5*d.* (all charges included); and boarded-out 4*s.* 3*d.* per week.

II. *No Preliminary Outlay required.*—No enormous buildings, necessitating raising of large loans, are required; merely the utilisation of an already existing simple village home.

III. *Entire Severance from Pauper Associations and the consequent Check given to Hereditary Pauperism.*—Placed in an ordinary village home the child forgets it is a pauper, and eventually becomes absorbed into the general population. Sir J. McNeil and the Scotch Inspectors unanimously testify that it is of the rarest occurrence for a boarded-out child to return on the rates.

IV. *Restoration to Family Life.*—Amidst the duties and responsibilities of family life children acquire that spirit of self-dependence and energy which enables them early to become self-supporting. They are moreover insured a home in after-life, when otherwise their only available refuge would be the able-bodied ward of the workhouse.

V. *Improvement in Health.*—'Boarded-out children,' to quote Mr. Henley, 'acquire a more robust constitution and greater mental activity than children reared in a workhouse, and these two points strike at the very root of pauperism.'

VI. *Greater Success at School.*—Set free from the *sole* companionship of the pauper class, and subject to the healthy variety of influence in village life, pauper children quickly lose their dulness and often attain even higher percentage of passes than the ordinary scholar, owing to enforced regularity of attendance.

VII. *Deterrent to Desertion.*—Deserting parents strongly object to the removal of their children beyond their ken, and often return and claim them when likely to be boarded-out.

There are two absolutely indispensable conditions to the success of the system:—(1) Efficient and systematic inspection and supervision; (2) Well-chosen foster homes.

Boarding-out in Scotland has been for forty years the adopted method of pauper education. During twenty years 14,000 children have been boarded-out; and out of 9,500 reported on, 2¾ per cent. only turned out doubtful or bad. The Secretary of the Poor Law Board says, 'Its success has been growing and uninterrupted.'

In Ireland since 1862 boarding-out has been practised; 2,549 out of 8,462 (of all classes) chargeable are now boarded-out at a cost of from 8*l.* to 10*l.* per annum.

In South Australia boarding-out was adopted in 1872, and has superseded industrial schools; 1,219 children are so placed (1885), at an average of 5*s.* per week. The system has saved the colony 36,000*l.* since its introduction.

In Victoria boarding-out was commenced in 1873, and has entirely superseded industrial schools. In 1885 2,105 children were boarded-out, and 639 'licensed to service' = 2,744. They are protected by Government till the age of 18.

In New South Wales the 'States Children Relief Department' commenced boarding-out in 1881, and by 1885 1,175 children had been withdrawn from institutions and placed out at an average cost of 5*s.* per head. The average cost in industrial schools was 24*l.* per annum, *not including rent*; that of boarding-out is 15*l.* 8*s.* 4*d.* (in 1885). The Chairman of the Board considers that the system has secured a saving of 25 per cent. to the country.

In all three colonies the authorities consider that the assistance of ladies' committees and systematic supervision are indispensable to success; with these they are unanimous in their conviction of the immense superiority of boarding-out over institutional training.

2. *Small Holdings and Allotments.*[1] *By* F. Impey.

The author entered into the history and condition of the English rural labourer, and pointed out that from the time of Elizabeth till our own times practically nothing had been done to help the labourer, and the system by which ten million acres of common lands had been enclosed and taken from the poor was the key to most of what was deplored in the condition of the labourer. He claimed that the facts met with established an unanswerable reason for interference with the land system on behalf of the class who had suffered most from its effects. Instances without number existed of exorbitant rents being demanded for allotments, and only public opinion and the growing force of the movement in favour of allotments at a fair rent could at present be brought to bear in bringing about a reduction. 'Three Acres and a Cow,' which he wrote, describing the arrangements on Lord Tollemache's estate, by which labourers to the number of 300 were allowed to have three acres of grass and keep a cow, besides encountering much misrepresentation, had called forth statements of similar advantages enjoyed by labourers elsewhere. The Allotments and Small Holdings Association had been accused of desiring to cut England into three-acre plots, and expecting everyone to get a living from them. Nothing was farther from the truth, but experience showed a man could do his duty to an employer, and benefit himself and family by hiring three acres of grass land and keeping a cow. Numerous particulars had been supplied him of properties on which allotments were greatly appreciated. In addition to the efforts of individuals in establishing allotments, Parliament had in a half-hearted way been induced to work in the same direction. It was important to bear in mind that not only—now perhaps chiefly—was the agricultural labourer interested in the allotments and small holdings question, but such a state of things brought about thriving villages, each with numerous persons following handicrafts and other trades, in addition to cultivating their land. The last return respecting allotments was made in 1886, and shows that there are 500,000 cottages with no ground attached to them. Much more land was required for allotments; and local representative bodies should have the power to own or hire land for the purpose of letting out to small tenants on the model of the Swiss communal system. Public opinion required a reversal of what had been the national policy for centuries with regard to the land. The first step in the direction of placing land within reach of small as well as large cultivators was the establishment of a national system of allotments and small holdings; and they need not go abroad, as had often been the case, to find out the good results of the system. The mistaken policy of the State had inflicted enormous and bitter wrong on a once helpless class, but what Parliament had done it might be called upon to help in amending. Irish local authorities were begged to apply for loans at 3½ per cent. interest, to provide houses and land for labourers, and no proposals for dealing with English rural self-government would be acceptable which did not contain similar provisions. The breath of popular life and power was being felt among the dry bones of the decaying system of their present rural institutions. The future had in store beneficent and far-reaching change, which it was the highest privilege of all who loved their country to help in bringing about.

3. *Peasant Properties and Protection.* *By* Lady Verney.

Peasant properties have grown up in curiously different ways in different countries. In France they were found to a great extent before the Revolution. Arthur Young says[2] throughout 'a third of the kingdom in 1789' the custom, though not the law of equal inheritance existed. In Russia, created by the stroke of the pen of a benevolent despot, twenty-five years have sufficed to ruin the landed proprietors, while their successors, the peasants, are wretched.

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[1] Republished under title of *Housed Beggars; or, the Right of the Labourer to Allotments and Small Holdings.* White and Pike, Birmingham. Price 3*d.*

[2] De Foville says proportion not so great, but equally good authorities assert the correctness of the estimate.

Effect of Code Napoléon in breaking up large estates only gradually felt in Germany and Italy.

Norway long considered a model country, her land tenure held up as superior to any other country—comfort of the bonders. Present time official reports of the Prefects sadly different, ruinous sub-division of land, increase of rural taxation, distress great, poor relief increased enormously, land left uncultivated, and a cry for protection. This is the demand in all the reports, France, Germany, Italy, Russia, and Switzerland.

'How else can the small proprietors live?' is constantly inquired. As they buy next to nothing, they care nothing for cheap imports, but require their manufacturing neighbours to pay dearer for their corn and meat as the price of their existence. No division of labour in production. Discomfort, misery, and ignorance described by French writers as grievous among the peasantry.

The population in 34 departments is diminishing. Average of three children necessary to keep up the number is not attained. Lafargue speaks of the 'alarming state of France, which is passing through a terrible agricultural crisis, great subdivision not allowing the use of machines,' &c.

'Average yield of wheat in France and Germany rather less than half in England,' says Sir James Caird. In Italy even less, Russia lowest of all. Mortgages oppressive everywhere. 'Getting rid of landlords and their rents the peasants subject themselves to an invisible order, the mortgagers and their heavier and more rigid rents,' says Lecouteux, 'who sell them up if they do not pay the interest.'

Three million proprietors out of eight are on the pauper lists of France. In Prussia 82 per cent. exempt from direct taxation by reason of poverty; 7,000,000 heads of families earn less than 9*s.* 7*d.* per week.

'All peasants certainly are not in debt, but in many parts of Germany their mortgages are from 54 to 94 per cent. on real property,' says the German report.

Strange remedies proposed, as to take away the power of mortgaging either wholly or in part (the heaviest charges incurred being to buy off the equal portions of the younger children), to make a majorat, *i.e.*, to restore primogeniture.

In Russia no labour is to be had, each man occupied on his own property, agriculture wretched, scarcely any manure used, the produce from 2½ to 4½ of quantity sown. (In England about 15 for winter and 20 for spring corn.) The land is worked out. Peasants in the hands of the Jews, who foreclose mortgages and take possession of the land. Whole country said to be on the verge of bankruptcy.

Report of Italian commission declares condition of rural population miserable, produce of corn only 11 hectolitres, in France 15, and Germany the same. England 32. Twenty-five per cent. of the 5,000,000 owners peasants. 'Our piecemeal agriculture without machines must fail, these impossible on such small properties.' Work entailed on the women so excessive that it is said 'women are bargained for like cattle, and toil like Indian squaws.'

The enormous interest paid to usurers complained of. In Apulia short loans charged even 120 per cent.

The account from Switzerland of agricultural population dismal, the produce very low, the land cut up into slices, overburdened with agricultural buildings, and heavily mortgaged. The farms so small that no machinery can be used; there is a cry to re-create large farms, and for help from State, notwithstanding cheap transfer of land, of property after a death, equal divisions, free education, &c.

British Consul at Nantes says that vines have failed, and farmers cannot compete with foreign corn, there is outcry for increased protection; number of peasants' votes so large in subdivision of property, that Government cannot resist pressure for increasing the prices of bread and meat to the rest of the community. At last election 6 Conservatives returned instead of 6 Liberals in the department of Nantes.

'The English labourer,' says Professor Voelcker, 'is unquestionably at least 50 per cent. better off than the small peasant proprietor.' 'He works twice as hard and lives half as well as the English labourer,' says Mr. Jenkins. 'A tenant,' says Sir James Caird, 'has the use of his landlord's capital at a very low rate, and can spend his own in a more remunerative way.'

Allotments, the number of which is little known; 242,342 in the Midland counties alone. 'Little takes' (and nearly three-quarters of the farms in England are of fifty acres and under) seem preferable to sinking money in ownership of land. Pasture, not arable. Labourer has fared better than owner and farmer in the present agricultural crisis, which we share with the rest of Europe. Wages, standard of living, education and openings to rise increased greatly during the last 20 years, while the peasant proprietors abroad have been steadily going down and clamouring for protection to enable them to live.

Is it worth while to create such a class in Ireland or England at the present moment?

4. *Co-operative Farming.* *By* BOLTON KING, *M.A.*

Two forces are bringing the English land question into unusual prominence—the economic force of foreign competition, and the movement towards a wider diffusion of landed property. The two are to a certain extent antagonistic, and no social solution will avail, unless it surmounts the difficulty of farming land at a profit. All evidence goes to show that large farms under skilled management, or with plenty of capital, are the only ones which are likely to pay. Hence we must reconcile the wider diffusion of property in land with the existence of large farms. Peasant proprietorship, therefore, will not solve the problem; co-operative farming, on the other hand, possesses the conditions of economic success. It can have all the economic advantages of large capitalist farms, and alone can realise the social ideal given above. But is it feasible? First, Can a body of agricultural labourers possess sufficient cohesion? Such evidence as there is on this head is distinctly favourable. Nor is there likely to be much difficulty in finding the capital. The difficulty lies in the supply of skilled managers. For the present the scarcity of such men will delay the extension of association farms, but as soon as we give due attention to agricultural education a sufficient number will be forthcoming.

Some suggestions as to the formation of an association farm may be in place. Nothing should be done till an efficient manager has been found. The land must be in fair order, and there must be a proper agreement as to compensation. The men should be carefully selected on the advice of those best acquainted with the locality. The constitution of the society must combine popular election with a strong concentrated management; the manager must be uncontrolled in the direction of the farming operations, but the body of the associates should decide on all other questions. The association's legal status should be that of a limited liability company; the capital should be obtained on loan, so that creditors have no control over the internal affairs of the society. In apportioning the profits a large amount—at least 40 per cent.—should go to a reserve fund; 5 per cent. should be appropriated to educational purposes; and of the residue half should be paid down in cash to the association, and half go towards redeeming the loan capital. Should several association farms be started in the same neighbourhood they should federate for common purposes, such as selling their produce direct to the consumer.

The evidence of the association farms in Warwickshire tends to show that with average agricultural labourers the scheme is perfectly feasible. The abnormal condition of the last two years has made it impossible for them to make a profit, and the system has thus had no fair test on this score. The chief factor in their economic success or failure is the economic value of high farming. As far as its social aspects go, the results have been thoroughly satisfactory.

5. *The Results of an Experiment in Fruit-farming.*
By the Ven. Archdeacon LEA.

The paper was divided into five heads, as follows:—

(1) The desirableness of increasing the class of small holders of land.

(2) Is it possible to make such holdings pay in the present day? Probably not by usual modes of cultivation, but only by the growth of fruits and vegetables.

(3) The account of an experiment on three acres of land for a period of fourteen years—with the receipts and payments during that period—from fruit, pigs, and poultry, with balance-sheets of the best and worst years.

BALANCE-SHEETS OF EXPERIMENTAL FRUIT FARM, ST. PETER'S, DROITWICH.

Worst Year, 1877	Receipts	Payments	Best Year, 1884	Receipts	Payments
	£ s. d.	£ s. d.		£ s. d.	£ s. d.
Pigs	39 0 0	—	Pigs (one being killed in 1885)	12 0 0	—
Pig-feed	—	24 15 0	Pig-feed and purchase of pigs	—	17 12 0
Chickens and eggs	14 5 6	—	Chickens and eggs	18 12 0	—
Chicken-feed	—	10 7 6	Chicken-feed	—	9 3 6
Gooseberries	16 0 0	—	Gooseberries	31 19 8	—
Black currants	7 7 10	—	Black currants	2 12 0	—
Plums	—	—	Plums	110 16 6	—
[1]Other fruits	22 0 9	—	Manure	—	5 14 0
Manure	—	4 7 6	Labour and fruit picking	—	72 10 9
Labour and fruit picking	—	59 13 0	Rent and payments	—	17 0 0
Sundries	—	1 4 10	Fruit and vegetables for house of seven, and given away	25 0 0	—
Rent and payments	—	17 0 0			
Fruit and vegetables for house of seven, and given away	25 0 0	—			
	123 14 1 117 7 10	117 7 10		201 0 2 121 10 3	121 10 3
Profits	£6 6 3		Profits	£79 9 11	

[1] I see that this year 7*l.* was for trees and bushes taken to plant another farm. The rest for pears, &c., sold, as there were no plums.

(4) The conditions necessary for success, and which will require to be attended to, if legislation on the subject of small holdings is to be adopted by the present Parliament.

(5) The grounds on which legislation in this direction is desirable.

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6. *Colonial Agriculture, and its Influence on British Farming.*[1]

By Professor W. FREAM, *B.Sc., F.L.S., F.G.S., F.S.S.*

An attempt was made in this paper to briefly indicate the present position and the recent tendencies of the agricultural industry in each of our larger colonies. Then followed an inquiry into the sources and the amount of the various kinds of colonial agricultural produce which find their way into the home markets, and there compete with produce of a like character raised in the United Kingdom. Finally, a plea was made in favour of the inauguration of some uniform and efficient system for the collection of agricultural statistics throughout the Empire, and particularly for the better equipment of the Department of Agriculture in the mother country.

The agricultural progress of each of the Australian colonies (New South Wales, Victoria, South Australia, Queensland, Western Australia, Tasmania, New Zealand) during the twelve years 1873 to 1884 was discussed, and illustrated by statistical tables. Comparing 1884 with 1873, whilst the population of Australasia increased one-half, the total area under cultivation increased two and a-half times, and whereas the cultivated area of 1873 represented only 1·57 acres per head of the population, it amounted in 1884 to 2·48 acres per head. The relative increase in acreage of each of the crops—wheat, barley, oats, hay, green forage—in each of the provinces, was stated.

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[1] Published *in extenso* in the *Mark Lane Express, North British Agriculturist*, &c. Also, as a pamphlet, by the author.

In 1884 the acreage of wheat in Australasia was one-third greater than that in the United Kingdom. But the acreage of barley was only one-seventeenth, and that of oats one-seventh, of the corresponding acreages of the United Kingdom.

A comparison of the number of live stock in the whole of the Australasian colonies in 1884 and in 1873 shows that horses had increased 50 per cent., cattle 42 per cent., sheep 28 per cent., and pigs 28 per cent.

In 1884 the horses of Australasia numbered two-thirds of those of the United Kingdom, cattle were four-fifths as many, and pigs were only one-fourth as numerous. Sheep, on the other hand, were two and a-half times as many.

Concerning Cape Colony there are not available any agricultural statistics of more recent date than 1875, and those are somewhat meagre.

The present position of agriculture in Canada can only be vaguely estimated. There is a Dominion Department of Agriculture, and most of the provinces possess a Board or Department of Agriculture, but with one or two notable exceptions no attempt is made to collect statistical information in a systematic manner. Among the older provinces Ontario is the only one whose system of collecting and collating agricultural statistics is in any way abreast of the times, and the work of this character now in progress under the Ontario Bureau of Industries deserves mention. But of all the provinces of the Dominion, the young province of Manitoba is distinctly in the van as regards the administration and efficiency of its Department of Agriculture, the periodical bulletins of which are as admirable as they are useful. The export trade in living animals and dairy produce constitutes probably the most powerful incentive to the further development of Canadian agriculture. Taking the twelve years 1874 to 1885 and comparing the last of these years with the first, it is shown that the export of horses from Canada has more than doubled, that of cattle has more than trebled, and that of sheep has increased one-third. The extraordinary precautions taken to keep their live stock free from disease are highly creditable to the Canadian authorities; without such precautions, however, this very large trade in live stock would be quite impracticable. The Canadian export of cheese in 1885 was three and a-half times as great as that in 1874; this trade, which has now attained such enormous dimensions, is the growth of only a quarter of a century, for in 1859 the Dominion imported 857,951 lbs. of cheese, whereas in 1885 it exported eighty-six and a-half million lbs. In the export of cheese, Quebec and Ontario are the only provinces which figure largely, but the former alone supplies quite three-fourths of the total export; Ontario, however, is rapidly diminishing the inequality between herself and Quebec in this respect. The total butter export of last year was only two-thirds of that of 1874, but Canadian dairy-farmers have in their own hands the remedy for this diminution.

Of the markets in which the home producer has to meet his colonial competitor, those of wheat, live stock, fresh meat, dairy produce, and wool are the most important.

During the three years 1881 to 1883, the import of wheat from Australasia into the United Kingdom was between two and three million cwt. annually. In 1884 it reached nearly five million, and in 1885 over five and a quarter million cwt. From Canada the import in 1881 and 1882 was over two and three-quarter million cwt. per annum, whereas during the last three years it has been about one and three-quarter million cwt. annually. Meanwhile, the import of wheat from the United States, though still our chief one, is declining, even if the import of wheat meal and flour from the same source be also taken into account. Viewing the subject from an imperial standpoint, British India has during the last five years sent us annually much more wheat than Australasia and Canada together. The ratio of the import of wheat from all parts of the Empire (Australasia, Canada, India) to the total import into the United Kingdom has, during the last five years, 1881 to 1885, shown the following increase: 0·23, 0·21, 0·25, 0·31, 0·31. Simultaneously, the ratio of the import of wheat from the United States to the total import into the United Kingdom has declined thus: 0·63, 0·55, 0·40, 0·48, 0·40.

As in the case of wheat, our largest supply of horned cattle comes from the United States, which sends us nearly two-fifths of the total number imported.

Denmark ranks next, and Canada third. It is significant, however, that whereas, in 1885, our import of cattle from all other sources fell off, the import from Canada increased fully one-eighth on that of the previous year.

The fresh meat trade is of recent but rapid growth. Excluding Australasia, Holland is the only country which has hitherto sent fresh mutton in any quantity into the United Kingdom, but the import from Holland last year was less than one-fourth of that from Australasia. Taking the last four years, 1882 to 1885, the ratio of the import of fresh mutton from Australasia to the total import from all sources exhibits the following rapid increase: 0·19, 0·40, 0·60, 0·59. Australasia, therefore, now sends us more than half the total import, and the actual quantity derived from this source last year was 336,495 cwt., the total import being 571,646 cwt. Most of the Australasian export is from New Zealand.

Of dairy produce, nearly the whole of the cheese, and more than three-fourths of the butter, exported from Canada, enter the markets of the United Kingdom. Cheese also comes in large quantity from the United States and Holland, and butter from Holland, France, Denmark, the United States, and Belgium, in the order named. Canada, however, has taken a firm hold on our cheese markets, and owing to the superior and uniform quality of her produce is likely to maintain and even to increase it. Were the Canadian butter as well manufactured and as reliable a product as the Canadian cheese, our imports of butter from Canada would probably be far larger than they are. Canadian dairy-farmers are looking into this matter, but they must not delay, for a new competitor in this industry is arising in the Southern Seas. The enterprising colony of Victoria, encouraged by the satisfactory results flowing from the British trade in fresh meat, is bent on tempting the English markets with fresh Australian butter. It is argued that the system of refrigeration, by means of which meat is kept fresh during the long voyage to England, will serve equally well in the case of butter, and it is pointed out that butter produced during the early part of the Antipodean summer would reach the English markets in time to command a ready sale during mid-winter. When it is borne in mind that the little kingdom of Denmark sent us, from 1872 to 1882, between one and two million pounds worth of butter every year, and during 1883 and 1884 over two million pounds worth per annum, the ambition of Victoria does not seem altogether hopeless.

Coming lastly to wool, many English farmers who are now struggling with adversity can remember the time when the wool of their sheep would pay the rent. Those palmy days have gone, never to return, for the United Kingdom now imports over 500 million lbs. of wool per annum, most of which comes from Australasia and Cape Colony. Arranging these colonies in the order of their wool-exporting capacity, they stand thus: 1. New South Wales; 2, New Zealand; 3, Victoria; 4, Queensland; 5, South Australia; 6, Cape Colony; 7, Tasmania; 8, Western Australia. But New South Wales produces more than New Zealand, Victoria, and Queensland together, whilst Tasmania and Western Australia collectively produce less than one-third as much as Cape Colony. How very important to the colonial farmer in the Southern Hemisphere is the price of wool on the English market may be judged from the fact that a difference of only one farthing per lb. in the selling value of the wool exported in a single year, 1883, would make a difference amounting to nearly half-a-million sterling in the aggregate value. The total value of the wool imported into the United Kingdom from our colonies of Australasia and the Cape since 1831, estimated at the average selling price in London of the last twenty-five years, is 421,121,192*l*., of which 77,416,721*l*. represents the South African exports. This splendid creation of wealth can be better appreciated when it is stated that the total value of all the gold found in Australasia has not yet reached 300 millions sterling.

In each of the three great departments of his industry, whether it be the growing of corn, the raising of meat, or the production of cheese and butter, the British farmer is called upon to face severe colonial (and foreign) competition. In the case of cattle and cheese from Canada, and in that of wheat and fresh meat from Australasia, this competition is rapidly assuming greater proportions. This, however, is no matter for regret, for since the mother-country is quite incapable of satisfying her own requirements in agricultural produce, it is rather a subject for congratulation that she is every year becoming a better customer of her colonies. It has, moreover, been demonstrated in the case of Australasia, and it is probably true also of Canada, that the capacity for agricultural production is increasing at a greater rate than the population. How the home farmer is to continue his struggle against such heavy odds is a problem that yet awaits its final solution, and one which it would be outside the scope of this paper to discuss.

Finally, it is asked, what means exist whereby the agricultural production of the Empire may with fair accuracy be currently estimated, and, what is equally important, in what direction the agricultural practices of each province of the Empire are tending? The answer is that there are no such means. We can only judge of these things by their effects: we have little means of anticipating them. At any time there may be a ruinous glut of one kind of produce and a simultaneous disastrous deficiency of another. The great centres of production in the South, in the West, and in the East, all look to the heart of the Empire as the centre of insatiable consumption, and year after year their surplus production is landed at the ports of the mother-country. Then, and not till then, does the stern arbitrament of the markets differentiate between over-production in the case of one commodity, and, possibly, of under-production in that of another. But the lesson is learnt too late, for by this time preparations have already been made for another year's production.

Bound together by a common language, and employing the same systems of weights and measures, it would surely be not only possible but practicable for every province of the Empire to officially collect and annually publish comprehensive agricultural statistics, which, to facilitate comparison, should all be arranged on one uniform plan. It may fairly be urged that the mother-country should lead the way, but, unfortunately, our own Department of Agriculture has not yet begun to discharge many of the functions which pre-eminently appertain to it. To cite only one example, no official return is made of the produce of crops in the United Kingdom, and until 1884 no such return was made for England and Wales. Our methods of collecting agricultural statistics, particularly such as relate to the yield of crops and to the relation between crop, soil, and climate, require revision, and demand improvement. We can point at home to no organisation qualified to rank alongside the Department of Agriculture, Statistics, and Health of Manitoba, or capable of doing such valuable work as is performed in the Office of the Government Statist of Victoria. Agriculture, the primal art, the pioneer of our colonial affluence, and still associated with enormous interests and great responsibilities at home, has always been neglected by the State. But an Imperial nation has its duties as well as its rights, and when we have a Department of Agriculture, one branch of which shall be devoted to the collection, assimilation, and prompt publication throughout the Empire of reliable agricultural statistics, not of the United Kingdom alone, but of the whole realm, there will remain to this nation one duty the less unfulfilled.

In an appendix are collected the following tables:—Agricultural statistics of the Australasian colonies; comparative agricultural statistics of the United Kingdom and the colonies; average yield per acre of wheat, barley, oats, and hay in the United Kingdom, the colonies, and the world; agricultural progress in the Province of Manitoba; exports from Canada of horses, cattle, sheep, butter, and cheese for twelve years; imports of wheat into the United Kingdom from the colonies and India, and from all sources; total imports into the United Kingdom of cattle, sheep, pigs, wool, butter, and cheese; imports of fresh mutton into the United Kingdom from Australasia, and from all sources; produce of wool in the Australasian colonies and Cape Colony.

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7. *The Public Land Policy of the United States.*
By Worthington C. Ford.

The author sets forth in some detail the manner in which the public domain of the United States has been disposed of since the treaty of 1783. He shows how one barrier after another to the acquisition of the land by individual settlers has been broken down, until there is no civilised country in which a more liberal land policy exists. In fact, if the rapid disappearance of the public domain may be taken as a proof of the success of such a policy, it would be difficult to instance another case where the fiat of the legislator has worked such wondrous results.

The author describes the most important features of the existing public land system of the United States—the pre-emption and the homestead laws. He expresses the opinion that those laws sadly interfere with each other, and that with the passage of the latter, the former should have been repealed. He proceeds to show that as soon as the available supply of food began to fail the expediency of continuing existing methods became a serious question. If the land reached the actual settler, complaint would be less loud; but, as it is, there is every reason to believe that the bulk of the lands disposed of reaches the hands of speculators and land-grabbers.

The cheapness and abundance of land have been said to result in the premature diffusion of population and loose and insufficient methods of cultivation; but in the author's opinion these evils are self-correcting.

In spite of the outcry against the waste of the public lands, the underlying principle of the land laws—that the land should belong to the actual settler—has never been questioned. The theories of Henry George, however popular they have become among a certain class, have not created any feeling against the cession by the Government of a full and free title to public lands, where, if anywhere, a favourable field is offered for a trial of his scheme.

The paper concludes by stating that three policies have been suggested and require to be considered—(1) That the land laws be changed and honestly administered, so as to favour the settler. (2) That a restriction be placed upon immigration so as to decrease the demand for land. (3) That a career of conquest or acquisition be entered upon, by which new and unoccupied territory can be secured.

The old land policy is still working out its ends; as to the future policy, tendencies only can be noted and conclusions drawn. Just now it is sufficient to say whether the existing system is to be commended or criticised.

8. *The Effect of Aspect on Wheat-yields.* *By* Dr. A. Haviland.

SATURDAY, SEPTEMBER 4.

The following Papers were read:—

1. *Working Men's Co-operative Organisations in Great Britain.*
By A. H. Dyke Acland, *M.P.*

This paper deals not with so-called civil service co-operative societies, nor directly with the question of industrial partnerships.

The question here considered is as follows:—

How far does the development of the working men's co-operative organisations, especially during the last twenty years, throw light on—

I. The possibility of the accumulation of large sums of capital by working men.

II. The possibility of the successful utilisation of such capital by working men in industrial enterprise.

III. The improvement of the position of the worker, or the lessening of the antagonism of employer and employed in consequence of such successful utilisation of capital.

I. The main source of savings is to be found in the co-operative stores or distributive societies, which do a business of considerably over 20,000,000*l.* a year.

Method adopted by these stores:—

Anyone may join on depositing one shilling. The ordinary prices of the district are charged. Ready-money payment only is allowed. The profits of the business are allotted to members in proportion to their purchases, quarterly or half-yearly. The sums so allotted must remain in the society till a share of 1*l.* has been made up. The result is a gradual saving of capital, till there is often much more than can be employed in the business. The difficulty with many societies is too much capital, not too little.

Increase of business of these societies between 1865 and 1885 from about three millions per annum to over twenty millions per annum. Large sums now lying idle at the banks.

II. At the present time from three to four millions a year of productive or manufacturing business, on a large or small scale, is carried on, the capital of which comes mainly from the distributive or retail societies.

There are several forms of this:—

(1) Manufacturing by the wholesale societies of England and Scotland annually about 200,000*l.*

(2) Tailoring, dressmaking, corn-milling, baking, &c. by distributive stores, 2,000,000*l.*

(3) Manufacturing by independent societies unconnected with the wholesale societies or distributive stores, 1,500,000*l.*

(1) The two wholesale societies are the property of the retail stores, which have created them for their own convenience for the supply of articles direct to their shops from England and abroad.

The English wholesale society (like the retail societies) has had to refuse capital which its members (that is, the retail stores) would willingly have deposited with it.

It has adhered mainly to the work of merchant, and has done comparatively little in the way of manufacturing.

It has two manufactories of boots and shoes, which do a business of 150,000*l.* a year. It also manufactures soap, biscuits, and confectionery.

Reasons for not extending manufacturing more rapidly:—

Difficulty of locking up money in plant and buildings.

(2) Some of the large stores have erected large corn-mills and large butteries, and many societies employ tailors, dressmakers, and the like, and some are now beginning to rent farms.

In the large stores there is a great demand for milk, butter, and agricultural produce.

Many of these societies, like the wholesale society, might, if they would, retain much larger sums of savings deposited with them by members at five per cent. than they now have.

(3) The productive societies' business, position, profits, and various methods of working.

The Manchester Printing Society does 35,000*l.* a year. The Hebden Bridge Fustian Company, 25,000*l.* a year. Both these give the workers a share of the profits.

The great difficulty in getting capital for societies of this class, especially at starting.

The failures of societies of this kind—their causes.

The Oldham joint stock companies—how far they have utilised the capital of co-operators.

III. Co-operation is sometimes defined as being only truly so called when the worker has a share in the profits.

This limitation is not adopted here.

The Scottish wholesale gives a share to workers; the English wholesale does not.

Some of the distributive societies give a share to workers; the great majority do not.

The independent productive societies do so in most cases.

CONCLUSION:—

The great value of the work as it is to one-sixth of the working classes of Great Britain. Remove its influence during the last forty years and England would be very different from what it is.

Take a country village store in Warwickshire as an instance of its benefits. A society, managed by labourers, with 700 members, with a business of 18,000*l.* a year, of which nearly 2,000*l.* a year is saved, and owning freehold land and buildings (including twenty cottages), worth nearly 4,000*l.*

Take a large town. Consider the educational work done, the hopefulness on the part of the worker who is encouraged, and the value of the savings during a time of depression.

Industrially it has more influence than is perceived. It is a great educator to the working classes in the methods of handling capital. It trains many able men, and labour becomes less and less looked upon as a 'commodity' only.

Much of the best side of human nature is called out in this associated work. It is the development of this throughout business life, without impairing efficiency and promptitude in management, which is needed.

The capacity which has been developed by the movement was dormant and unsuspected forty years ago.

Other unthought of developments possible in the future.

2. *On the Economic Exceptions to* Laisser faire.[1]

By Professor SIDGWICK, *Litt.D.*

Political economy, as commonly understood, includes a general argument showing how wealth tends to be produced most amply and economically in a society in which Government confines itself to the protection of person and property and the enforcement of contracts not brought about by force or fraud, leaving individuals free to produce and transfer to others whatever utilities they choose, on any terms that may be freely arranged. The argument is, briefly, that in a society so constituted the regard for self-interest on the part of consumers will lead to the effectual demand of the things that are most useful; and regard for self-interest on the part of producers will lead to their production at the least cost.

It is, however, now generally held that the broad rule of 'leave alone' to which this argument points must in practice be limited by various exceptions.

The aim of the present paper is to distinguish clearly between two different classes of these exceptions to *laisser faire*, viz., (*a*) those exceptions which are due to the limitations under which abstract economic theory has to be practically applied in the art of government, owing to the complexity of the ends at which government has to aim, and to the fact that actual human beings only partly conform to the type usually assumed in abstract economic reasoning; and (*b*) those which it is the more direct business of economic theory to analyse and systematize, since the reasons for them apply to the state of things assumed for purposes of abstract reasoning, no less than to the actual facts of existing societies.

In class (*a*) may be distinguished—

(1). Governmental interference to regulate the education or employment of children.

(2). Interference for the promotion of health, or morality, or culture.

(3). Interference, not with a view to the more economical production of wealth, but with a view to its more equitable distribution.

(This is often spoken of as 'socialistic,' or 'semi-socialistic.')

(4). Interference on the ground that certain industrial classes are found by experience not to take sufficient care of their private economic interests.

(This is sometimes spoken of as 'paternal' legislation; *e.g.*, restrictions on freedom of contract between landlord and tenant. The same phrase is also applied to (2).)

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[1] See also *Contemporary Review*, Nov. 1886.

As leading cases of class (*b*) may be noted—

(1). Where, for the production of a certain utility, or avoidance of detriment, a combination is required of which the value largely depends on its universality. *E.g.*, protection of lands against flood; protection of useful animals against certain diseases.

(2). Especially where the combination of a large majority increases the interest that the minority have in standing aloof. *E.g.*, abstinence from certain times, places, or instruments in fishing or hunting, for the sake of future supply.

(3). Where a branch of industry, for technical or other reasons, has a tendency to fall under the conditions of monopoly (total or partial). *E.g.* provision of gas in towns.

(4). Where, from the nature of the required utility, its producers could not be remunerated adequately in the ordinary way by free exchange of their commodity. *E.g.*, utility of forests in relation to climate; scientific discoveries.

(5). Where the process of exchange which would be required to remunerate a certain social service would seriously detract from its utility, from waste of time or otherwise. *E.g.*, provision of roads and bridges.

(6). Where Government is peculiarly adapted to produce the kind of utility required. *E.g.*, if what is required is security, as in the case of savings banks; uniformity, stability of value, as in the case of currency.

It is not argued that Government necessarily ought to interfere in all cases that come under these heads; only that the general economic argument for *laisser faire* falls away in such cases, wholly or to a great extent, or is balanced by strictly economic considerations on the other side; and that it is important to bear this in mind in discussing any particular practical case.

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3. *On Allotments.* *By* Lord Onslow.

The author pointed out that it was unfortunate this subject should have formed matter for political controversy. It was astonishing how little appeared to be known on the subject by those who were not directly connected with the land. It was unnecessary to dwell at any length on the advantages accruing to labourers from the occupation of a small plot of ground, as all interested in the question admitted this. The supply of land for the purpose appeared to be greatly regulated by the demand. In the North, where wages were high, the allotment system might be said almost not to exist, while in the purely agricultural counties the practice prevailed extensively. The Voluntary Allotments Association, of which he was hon. secretary, had publicly announced its desire to be informed of any unsatisfied demand which might exist; but these applications might be counted on one's fingers. Even where land was let on lease, and possession could only be obtained with difficulty, the local committees of the association expected at Michaelmas next to be able in most cases to satisfy the demand. The points chiefly in dispute were: (1) Whether there was a sufficient supply of land for labourers who desired allotments; (2) what was the size of allotment which a labourer could cultivate without interfering with his regular wage-earning hours; and (3) what should be the rent and conditions of tenancy. On the first point, the recently-issued Government return showed that allotments had increased from 242,000 in 1873 to 356,458 in 1886, while the number of labourers had only increased from 746,918 to 766,712. If to these they added the potato-ground, cow-runs, and cottage-gardens, of over one-eighth of an acre, they found there were no less than 708,712 plots of land cultivated by labourers, which, if held each by separate men, would leave only 58,000 labourers unprovided. In Wiltshire allotments exceeded the number of labourers by 460. Arranging the counties in the order of the labouring population, of the number of allotments, and of the number of cottage-gardens, they found that the provision was nearly, though not quite, adequate. For instance, Suffolk is fifth, both in labourers and allotments, and fourth in cottage-gardens. Lincoln was first in population, and though only tenth in allotments, was second only to Norfolk in cottage-gardens. Wiltshire, which came only tenth in labourers, was first in allotments; but Kent showed a bad record, coming second in population, but was twenty-sixth in allotments, and only eighteenth in cottage-gardens. As to the size of the allotments, all parties agreed with Mr. Arch that it should be in accordance with the ability to stock and cultivate it. The real point to bear in mind was to endeavour to give the labourer an opportunity to rise from his position to something a little above that, as was done by Lord Norton, Lord Henniker, and Mr. Goring, who endeavoured to give the industrious labourer a means of adding some other employment to that of a day labourer; and, finally, to become a small farmer. As to rent, the proper charge appeared to be that which the land would fetch, if let for other purposes; and it must be borne in mind that to rent must be added all outgoings and also cost of collection, though as compared with land let in farms there were no buildings to be erected or kept in repair. Another important point was to afford security to the tenant that he would neither be capriciously evicted, nor evicted at all, without adequate and complete compensation, so that every inducement might be offered to the occupier to bestow his money and labour on the allotment. What was still sadly lacking in this country was an adequate supply of milk for young children. The efforts of philanthropists might with great advantage be devoted to promoting this consummation. Nothing tended to attach a man so deeply to his country as an interest in its soil, and it should be the object of statesmen and philanthropists alike to do all in their power to give the cultivator of the soil a personal and pecuniary interest in it.

MONDAY, SEPTEMBER 6.

The following Papers were read:—

1. *One-pound Notes. By* Professor J. S. Nicholson.

The object of this paper is to discuss the effects of introducing with as little disturbance as possible into the present system of currency in England one-pound-notes. The subject being thus limited, it is necessary to assume that the principles of the Bank Act of 1844 remain undisturbed. Banknotes, according to that Act, are regarded merely as a convenient form of currency, and not as a form of bankers' credit. Why, then, should the English public not have the option, open to the people of Scotland and Ireland, of using one-pound notes in place of sovereigns? The preference for these notes in Scotland is so strong that it must rest on a solid foundation. The authorised issues of the Scotch banks are about two and three quarter millions, but the actual issues are about six millions, of which four millions are one-pound notes. There is no gain, but some loss, on all issues beyond the authorised maximum, so that there is no inducement for the banks to force their issues. Still it may be admitted that in matters of currency the maxim *quieta non movere* has much force, and merely for convenience the adoption of one-pound notes by England might not be advisable. But a stronger practical argument is found in the state of the gold currency, which is notoriously under its nominal value. Unless something is done, in a short time, we are threatened with a relapse into a rudimentary system of currency by weight. The expense of restoration might be met by issuing one-pound notes. There would be no danger of inconvertibility if all the gold withdrawn were used as a reserve after allowing for the expense of restoration and meeting the gold coins at their real value. The only change necessary in the Bank Act would be an extension of the limit of issues not against gold. If, as the experience of Scotland renders probable, the notes issued remained to a large extent in circulation, the wear and tear of coins would for the future be much less, and it would be more easy to keep them up to the standard.

Answers to Objections.—(1) There is the fear that the gold withdrawn would, after a time, not be kept in reserve, and that the money market would become more sensitive. But the practical question is, would the security be less than at present? For at present the gold in circulation is absolutely unavailable for banking purposes, and to meet a foreign drain. Besides this, the whole force of the objection lies in the assumption that the Act would not be enforced. If, however, the Act were only suspended, as before, in cases of real need the position of the Bank of England would be much strengthened.

(2) The fear of an internal drain and a run on the bank does not seem warranted by the experience of Scotland. In any case, so long as the Act as amended is enforced the issues are safe.

(3) The danger of forgery is not great, as shown by the fact that in Scotland spurious sovereigns are more common than forged one-pound notes. The art of engraving has made much progress since such notes were used in England.

Conclusion.—The reform suggested in this paper, though not extreme itself, is a step towards a better system; but the only practical question offered for discussion is whether it is worth while adopting one-pound notes on the same footing as other notes, simply on the grounds of convenience and the facilities offered for restoring and maintaining the coinage.

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2. *The Causes affecting the Reduction in the Cost of Producing Silver.*
By HYDE CLARKE.

Mr. Clarke stated his object was to continue the course of his former papers on the depression of prices, and to examine whether there was a reduction in the cost of producing silver. It was very difficult to collect the facts, as several inquirers had found, and thus the subject had remained obscure. He had considered that the fall in the price of quicksilver, consequent on the introduction of the New Almaden quicksilver, to a certain extent afforded a criterion of the influences in operation. Although in later years there had been an occasional spurt, quicksilver rising to 4*s.* 3*d.* in 1875 and to 5*s.* 10*d.* in 1874, yet during a long period quicksilver which forty years ago was from 10*s.* 6*d.* to 7*s.* 6*d.* had been as low as 1*s.* 10*d.* To these prices had to be added carriage and local charges, in Mexico for instance, greatly raising the cost in some mining localities. The value of quicksilver with some classes of ore might not be more than ½*d.* to 1*d.* per oz. of silver, but as compared with the former range of prices the difference on some ores was equivalent in some instances to 6*d.* per oz. of silver, and was to be estimated as an appreciable reduction of charge. Amalgamation with quicksilver only applied to some ores, but other ores, as silver lead ores, were reduced by the ancient processes and by Pattinsonising and other processes for the better extraction of silver. The zinc process, sodium amalgam and the Agostin process have also been brought to bear on various ores. One of the best proofs of the more economical reduction is the conversion of the *desmontes*, refuse or slag heaps of South America, and those of the Athenian silver smelters at Laurium. The production of more powerful stamping and milling machinery, and the conveyance of this and of steam engines by railway, instead of by mules, llamas or bullocks to the mining districts, had also materially assisted economical working.

With regard to the quotations for silver a distinction must be made of two markets, one a coin market and the other the jewellery market. So long as the coin market was not overstocked a price of five shillings per ounce could be maintained, and the fall in the cost of producing silver was masked or concealed; but now a variety of operations have contributed to bring about a heavy decline in the price of silver and a falling market. With regard to silver mining the cheaper production has allowed a lower class of ores to be raised and worked and thereby augmented the supply. The Indian Government has continued to coin silver, to disturb the market and to disturb prices. The United States Government has coined large amounts of dollars, which remain in stock. While gold was coming into favour in India and the prices of commodities and wages were rising, the Government did not adopt a gold mohur or sovereign, as was strongly recommended, but continued to coin silver rupees. With regard to the tendency of the market there was no evidence that the lowest rate for the rupee or silver ounce had been reached, for the downward influences are still in operation. The chief causes which have operated on the silver market have been, 1st, reduction of cost of metal; 2nd, over-production of silver; 3rd, over-coinage of silver; 4th, over-stock of coin and other silver.

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3. *On some Defects in English Railway Administration.*[1] *By* J. S. JEANS.

One of the most remarkable and serious features of English railway economics was the enormous increase of expenditure that had been incurred within recent years on already existing lines. The average capital outlay per mile of line open in the United Kingdom rose from 35,900*l.* in 1872, to 42,500*l.* in 1885. During that interval the mileage of line open had been increased by 3,553 miles, and the capital expenditure by about 247,000,000*l.*, so that we had expended about 73,000*l.* per mile of new line open. Between 1862 and 1872 the increase of railway mileage was 6,263 miles, and the increase of capital outlay 184,000,000*l.*, representing rather over 43,000*l.* per mile of new line. In both cases the additional expenditure was, however, by no means entirely expended on new mileage, although it was impossible to say how much had been spent upon that item, and how much had been expended on already existing lines. Since 1872 the average capital expenditure on English lines alone had increased by 7,500*l.* per mile; and as the mileage at the end of 1885 was 13,612 miles, it would appear as if during this interval 102,000,000*l.* had been expended on already existing lines, since the cost of constructing new mileage in later years could hardly be greater than in the earlier years of the railway system, when prices of materials took a much higher range.

The author next proceeded to refer to the possible sources of this expenditure, and referred incidentally to the fact that the L. & N. W. Railway Company alone had expended in the ten years ending 1885 something like 4,000,000*l.* in additions and improvements to their terminal stations at London, Liverpool, Birmingham, and Manchester. It was probable that the chief source of the increased outlay on existing lines was the furnishing of additional terminal and other facilities for traffic; and the public, perhaps, required to be reminded that they could scarcely expect to possess at the same time magnificent stations and the same low range of rates and fares as obtained in countries where such facilities were not so abundant. It was time for the British public to determine that their railways should not be encouraged in this prodigal expenditure on lines the capital account of which ought to have been closed many years ago. Such a system of mortgaging the future was not creditable to our appreciation, either of what was best for our present needs or most likely to advance the interests of posterity.

Remarking on the enormous differences that are found in the construction cost of different English railways, it was remarked that this item varied from a maximum of over 500,000*l.* to a minimum of less than 2,000*l.* per mile. Four railways—the Metropolitan, District, North London, and L. C. & D. had each cost over 140,000*l.* per mile. Seven others—the M. S. & L., L. & Y., S. E., W. Lancashire, L. B. & S. C., L. & N. W., and Midland—had cost between 55,000*l.* and 82,000*l.* per mile, and all the others were under 50,000*l.* per mile. The cost was increased the nearer the railways approached the metropolis, a fact that might be attributed to the more expensive works involved, and the higher price of the land required.

English railways have at command the largest volume of traffic relatively to their extent, and even to their capital expenditure, of any system in the world, so that, notwithstanding their enormous cost, they might and should be worked so as to produce a higher average range of dividends with the same range of rates and fares than the railways of any other country; but this had not hitherto been the case, in consequence of grave defects in their administration, and especially the cardinal

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[1] The complete paper has been published as a chapter in a work entitled *Railway Problems*, published by Longmans.

defect of running only partly filled trains where full train-loads might and should be adopted. There were, no doubt, certain descriptions of traffic more or less perishable in their character that could not afford to wait to be made up into full train-loads; but this did not apply to the great bulk of the goods traffic on English railways, and especially not to mineral traffic, which forms nearly 70 per cent. of the whole. It was not only that the train-loads, as such, were light, but it seldom happened—at any rate in the case of ordinary merchandise—that the waggons were loaded to more than one-half of their capacity; and as the cost of working goods traffic decreases in an almost direct ratio with the weight of the 'live' or paying load, the effect of adopting fuller waggon-loads would obviously be the establishment of a much higher range of receipts in relation to the ordinary working expenses.

Specific reference was next made to the improvements that had been effected within recent years in the systems and costs of transport on American railways, whereby the working expenses had been enormously reduced relatively to the gross earnings. The author attributed this improvement to the increase of capacity in the goods waggons employed, to the running of larger train-loads, to the adoption of a better permanent way, and to the use of more powerful locomotives; and he showed that, relatively to the weight of the train, the principal railways were now carrying a much greater 'live' or paying load than they did some years ago, while the total weight of the train had in many cases been increased by nearly 100 per cent. On the principal American lines the average train-load was more than twice that of English railways, and in Continental countries there was also, generally speaking, a considerably larger train-load than in England, where the average train mile receipts were lower than in any European country, except Luxemburg, although the average range of rates and fares was considerably higher.

The special circumstances of the passenger traffic on English railways next claimed consideration; and the author dealt at some length with the relation of passenger vehicles to the number of passengers carried, and to their average gross earnings from year to year, showing that the tendency within recent years had been to provide a larger number of carriages than was necessary, and so to diminish the average annual gross income per carriage, which had fallen from 888*l.* in 1874 to 774*l.* in 1885. The average receipts per passenger carriage were still higher in England than in most Continental countries, but that was probably due, not so much to the greater amount of work got out of English carriages, as to the higher range of passenger fares.

The same want of economy was traced in the working and the earnings of the locomotives employed on English railways. Within the last twelve years there had been a decrease in the annual income per locomotive of 570*l.* This decrease was certainly not due to any corresponding reduction of rates and fares, but could easily enough be traced to the practice of running trains that were only partially full. On the Continent the average earnings of a locomotive generally, took a higher range than in England, the only exceptions to this rule being Germany and Belgium, where, however, the traffic rates were very much lower than on English lines.

The effect of the element of speed in railway working was next considered, and it was pointed out that, in England, both goods trains and passenger trains were worked at a much higher average speed than in Continental countries. The English railways were also distinguished for the larger number of express trains that were run between the principal centres of population. There were no official data to show how much it cost to carry on this express train traffic *per se*, but it was probable that when the wear and tear of the railway stock and permanent way were considered, together with the cost of shunting, and the delay occasioned to the slower traffic, the express train service was not adequately remunerative, if indeed it did not entail an absolute loss.

On a survey of the whole matter, there was too much reason to believe that the financial position and prospects of English railways were going from bad to worse. Our railway Boards had not as yet apparently realised this great fact, and had consequently done little or nothing to stem the tide of reduced dividends that threatens to overtake them. On English lines in 1885 about 36,500,000*l.* of ordinary railway stock received no dividends whatever, and 14,500,000*l.* received less than 2 per cent. These two items together make up 20 per cent. of the total ordinary capital of English lines. This was certainly not an adequate result for a system that had the largest volume of both gross and net receipts, the cheapest materials of construction, and nearly, if not quite, the highest range of rates and fares.

In conclusion the author referred to the following as among the sources whence economy of working and consequent increase of dividends, or reduction of rates, or both together, may be expected in the future:—

1. The adoption of a slower average rate of speed for goods trains.
2. The reduction of tare, so as to allow of a greater 'live' or net load being carried relative to the weight of the vehicle employed.
3. The adoption of heavier loads, or, in other words, the running of fewer empty waggons and carriages, and possibly fewer trains.
4. The avoidance of duplicate trains from practically the same termini, for practically the same destinations.
5. An endeavour to redress the differences in the balance of goods sent in opposite directions.
6. The transfer of a great part of the heavy traffic to the canals, or an increase in the number of special lines provided for such traffic, so as to get rid of the loss of time and capital involved in shunting to make way for passenger traffic; and
7. The publication of railway accounts on a principle that would allow of the ton-mile rates being ascertained as regards both cost and profit.

4. *Canals.* *By* MARSHALL STEVENS, *F.S.S.*

Importance to commerce of means of intercommunication. Increasing necessity for economies in transit. Altered conditions which manufacturers are compelled to recognise. To-day when production is not confined to England alone, and when supply overtakes demand, the cost of carrying raw material from the seaboard to the manufactory and of the manufactured article back to the seaboard has become so vital a factor as to change the possibility of profit into the impossibility of competition. Impracticability of suggested movement of manufacturers to the seaboard.

Such a movement of English industries would scarcely stop at the seaboard but extend to lands over the seas, tempted by cheaper labour, cheaper transit, and the protection of tariffs hostile to English manufactures.

Maintenance of commercial status of England depends largely on provision of facilities at least equal to those enjoyed by competitors.

The method of the development of the English railway system has led to the crippling and practical strangulation of the essentially cheaper canal system.

It is imperatively necessary that our canals should be made available for our present necessities.

Period of the inception of the English canals.

The impossibility of canal competition against railways under existing conditions.

Illustration of the measure of ignorance with regard to English canals.

Fully one-half of the mileage of English canals owned or controlled by railway companies.

Railway control of canals inimical to public interests. Railway acquisition of canals in spite of the express prohibition of Parliament.

Misleading figures published by railways as to the paying capacity of canals.

Reasons why railways do not adopt a policy with regard to their canals more consistent with the public interest.

Much greater cheapness of canal transit as compared with railway transit.

Examples of the few English canals which have been worked in the public interest.

Comparison of cost of maintenance on canals and railways.

Greater volume of Manchester goods taken to Liverpool by the canal than upon the lines of any one of the three competing railways.

Examples showing that although railway rates are considerably lower on the Continent than in this country, the water traffic increases in a greater ratio than the railway traffic.

Goods suffer less injury during conveyance by canal than upon railways.

The advantages derivable from canals are governed by the physical and commercial conditions of the districts to be served.

Division of canals into four classes.

Examples of the different types of canals.

Illustration of greater traffic on canals in proportion to mileage than on railways.

The Bridgwater Canal shown to pay a better dividend than the competing railways.

The River Weaver as an illustration of what can be accomplished by a waterway free from railway control, and worked entirely for the public advantage.

Type of canal which can be constructed with advantage to points as far inland as Birmingham.

No type of canal, however, can afford the advantages to be derived from a waterway which gives access for ocean steamers to the centres of industry.

Examples at Glasgow, at Newcastle-upon-Tyne, and at Middlesborough.

The difference between the Manchester Ship Canal and the other examples of inland access for ocean steamers.

Function of the Manchester Ship Canal.

Great saving to traders which the Manchester Ship Canal will accomplish.

Comparatively small volume of traffic (in relation to actual known volume of traffic) required to make the canal a success.

Summary.—The neglect of our waterways.

Suggestions for the emancipation of our canals.

Their capacity for improvement.

Urgent action necessary in view of the keenness of foreign competition.

Necessity for turning our opportunities to account. Comparatively cheap facilities in France and other countries.

The Manchester Ship Canal movement and the agitation in Birmingham for improved water communication are steps in the direction of general national effort to revitalise our canal system.

5. *Canal Communication.*[1] *By* SAMUEL LLOYD.

The author maintained that the continued unsatisfactory condition of many canals, especially of the 1,306 miles under the control of railway companies, led, in 1883, to the appointment of a Select Committee on Canals. It sat for four months, and much valuable evidence was brought forward, which was published in a Blue Book of 331 pages. It showed that while a *laisser faire* policy respecting canals had prevailed in England, the Governments of France, Germany, and Belgium, aware of the importance of water communication, had acquired, and were improving their principal water routes with very great advantage. There was a virtual monopoly on the part of the railway companies of the canals, and in October last, in answer to the question issued by the Royal Commission on Depression in Trade, 'Are there any special circumstances affecting your district to which the existing condition of trade and industry there can be attributed?' the Birmingham Chamber of Commerce replied: 'The exorbitant cost of carriage of goods from Birmingham to the seaboard, which has placed inland districts at a great disadvantage compared with maritime towns.' Birmingham and South Staffordshire objected to pay higher rates than any other district, and to enforce them might not prove to the permanent advantage of the railway companies, as it tended to cripple trade and seriously

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[1] Published *in extenso* by T. H. Lakins, Birmingham.

lessen the carriage of goods. The evidence brought before the Select Committee on Canals in 1883 proved conclusively that goods might be conveyed as cheaply in England by water as on the Continent; for instance, on the Weaver, in Cheshire, salt was conveyed a distance of thirty miles for 6*d.* a ton, equivalent to a rate of one-fifth of a penny per mile, which was even lower than that between Liege and Antwerp. This was not a solitary instance. It was also known that goods could be transported from Birmingham to London by an improved canal system at a wharf-to-wharf rate of 4*s.* 6*d.* a ton. The improved canal would deprive the railways of some heavy traffic, but their general traffic would increase with the prosperity of the district. When canal routes were handed over to railways, in 1846, much of the foreign trade of the country did not exist. In 1840 the export of British produce only amounted to 1*l.* 18*s.* 9*d.* per head, while in 1883, after making due allowance for population, it was 6*l.* 14*s.* 8*d.* per head, an increase of 370 per cent. If Mid-England was to enjoy the advantages of cheap water communication to the ports, and thus be enabled to send its manufactures abroad at a cost that would leave a margin of profit beyond the cost of production and delivery, it was essential that a trust under Parliamentary powers should be obtained for the purpose. A joint-stock company would not avail, as its aim would be to exact the highest tolls possible, and it would soon act in compact with existing railways. The estimated cost of improving the Severn route was 600,000*l.*, and merited attention, especially on account of the rising importance of Cardiff and Newport as great shipping centres. The improvement of the route to London should be first carried out: there were no engineering difficulties that could not easily be overcome. A trust should be formed by the towns of the district, and the State should be asked to advance the money at a moderate rate of interest to the local authorities; if at 3 per cent. this would leave the Government a margin of ½ per cent. beyond the interest paid to savings-bank depositors. The canal rates should be fixed so as to yield a clear ½ per cent. after payment of the interest on the Government loan and the expenses of working and maintenance; this ½ per cent., if invested by the trust at 3 per cent. per annum compound interest, would in a period of sixty-six years extinguish the loan, and the whole undertaking belong to the towns and district represented by the trust. Interest was felt at the present time in the creation of village industries. The improved canal, with dwarf walls on both sides, would form along its entire distance an almost continuous wharf, and thus provide numerous favourable sites. It was strange that England, so far surpassing every other nation on the seas, should have so totally disregarded the national importance of inland navigation. Surely it was time to give the subject the attention it deserved.

6. *The Birmingham Canal.* *By* E. B. MARTEN.

The district around Birmingham abounds in canals; and as some of the engineering works are important and interesting, mention of them may be useful to visitors.

The Act was obtained in 1766 and the canal was made by Brindley, the celebrated engineer, and completed from Birmingham to Autherley in 1772, and connected with canals to London in 1783. In 1824 the canals had become so out of order as to be little better than 'crooked ditches,' when Thomas Telford, also a well-known canal engineer, made a vast improvement by straightening and deepening, so as to reduce the length from twenty-two to fourteen miles, and, after expending much capital, produced what was considered a perfect specimen of a canal. The supply of water to the canal was also much improved by the large reservoir at Edgbaston, with a good system of feeders for economising water. In 1835 the Acts were consolidated, and subsequently arrangements completed with the London and North Western Railway. The group of large works at Smethwick still forms a striking feature, with canals on two levels, railways also one over the other, and railway and road bridges over both canals and railways. In 1850 the splendid Netherton Tunnel was made under the Rowley Hills by James Walker, another engineer well known as a canal-maker, to relieve the Dudley Tunnel under the Castle Hill, which is still maintained in use and is a most interesting work.

The numerous pumping engines are interesting as giving specimens of the progress of such machines, and the chief station at Ocker Hill contains a row of six large engines, all lately put in good order under one roof.

The working of the mines, especially the thick coal (30 feet), caused very great injury to the canal, but conjointly with the South Staffordshire Mines Drainage Commissioners both canals and basins have been so much repaired that the canal works were perhaps never in more efficient condition.

7. *The Stourbridge Canal.* *By* E. B. Marten.

This canal forms an important link between the Birmingham Canal Navigation and the Severn and Bristol Channel, and is the water-outlet for the Black Country in that direction. It was made in 1778, and as an engineering work it has points of interest in its twenty locks and two large reservoirs, with a good system of feeders to gather a supply of water, so important for working the locks. It also receives water from a level about four miles long, cut from Coalbournbrook to 'The Level' near Woodside Dudley, to drain a large tract of mines, which was itself a very clever piece of engineering for that time. Some wooden pumps of curious construction were lately found in the level. The canal gathers toll at the locks as road trustees did at turnpikes; and as the through traffic has been much diverted by railways, and the traffic on the level part pays no toll, there is not much more than will pay the cost of maintenance.

The difficulty is increased by a branch called the Stourbridge Extension Canal being now owned by a railway company, and used, like the older canal, to collect traffic for the railway without paying toll to the canal. The traders on the level parts also have the use of the canal without toll or contribution towards its maintenance.

TUESDAY, SEPTEMBER 7.

The following Reports and Papers were read:—

1. *Report of the Committee for continuing the Inquiries relating to the Teaching of Science in Elementary Schools.*—See Reports, p. 278.

2. *The Character and Organisation of the Institutions for Technical Education required in a large manufacturing town.* *By* Dr. Crosskey.

The phrase 'technical education' requires strict definition, being employed in various senses. Technical education must be distinguished from general scientific study in its abstract methods; and also from the definite teaching of a special handicraft or trade.

It may be defined as education in the scientific principles which underlie manufacturing processes, those manufacturing processes themselves being employed as illustrations of the scientific principles they involve. In a large manufacturing town the requirements of several classes of the population have to be considered.

Class A.—The children of the great mass of working men who are compelled to earn their living at the earliest possible age. No higher grade school will meet their wants, and yet they ought to be scientifically prepared to take advantage of technical evening classes on leaving school. The mass of our people need technical education, and not merely a few exceptional scholars. To secure this the rudiments of science must be taught in all public elementary schools under the following conditions: (1) it must be taught experimentally—this is essential; (2) experts must be employed with command of well-appointed laboratories; (3) scientific instruction must be made a part of the ordinary curriculum of the school.

The experiment carried on by the Birmingham School Board has proved that thoroughly sound instruction may be given by observing these conditions. The English 'code,' however, acts against the development of this system. Managers, as a rule, are protected in teaching the subjects which pay best and cost least. Two great difficulties exist. 1st. A scholar, after receiving 'object lessons' as a child, may reach the fourth standard in the upper school without any training whatever corresponding to that received in the infants' department. What is called 'elementary science' in the lower division of the school should be made as compulsory as 'object lessons,' of which it should be the natural continuation; taken out of the regulations limiting class subjects to three, and paid for by a grant. 2nd. In the upper division of a public school, as our system now is, the school may be classed as 'excellent' without one single scientific subject being studied. No school ought to be classed as 'excellent' unless some branch of science is experimentally studied. Special grants should be made for instruction in the use of tools in wood or iron. The building of laboratories and provision of apparatus should also be aided by the State.

Class B.—A second class of the population consists of those able to stop at school for two or three years after having passed the ordinary sixth standard. For these, special technical schools should be opened, at a low fee, in which there should be a well-arranged two or three years' course of scientific instruction.

The Birmingham Board has established a school of this character, which has met with striking success.

The present state of the law, however, throws unnecessary obstacles in the way of the development of these schools. They have to work under the code as well as under the regulations of the Science and Art Department, and many practical difficulties inevitably result. The only way to secure proper provision for the technical education of our artisans is to authorise school boards to establish schools giving a two or three years' technical course to those who have passed the seventh standard, and received a preliminary scientific training during their ordinary school career, and to connect these schools directly with the Science and Art Department.

The mass of the people being taught the rudiments of science in the elementary schools, and a technical training lasting over two or three years being provided in special schools, at a low fee, for those not forced to go to work at the earliest possible period, evening technical classes for working men could be far more systematically managed than they now are, and would be attended by students prepared to profit by them.

Class C.—The last class comprises those able to give whatever time may be needed for the perfecting of their technical education. To supply their wants every large manufacturing town requires a school or a college in which the technical training should be as complete as the classical training in the old grammar schools. Voluntary contributions afford far too uncertain a support for institutions of such supreme importance. Two sources of income present themselves: (1) the old endowments which have hitherto been devoted to classical schools ought to contribute their quota; (2) grants from the State should supplement any deficiencies. Regarding management, every district understands best its own wants. The great centres of manufacturing industry differ widely in their specific requirements. Technical schools and colleges ought therefore to be managed by local representative bodies.

3. *Report of the Committee on the Regulation of Wages by Means of Sliding Scales.*—See Reports, p. 282.

4. *Sliding Scales and Hours of Labour in the Northumberland Coal Industry.*

By Ralph Young.

The Northumberland Sliding Scale was established in 1879. During the preceding years an important rise occurred in the price of coal, and from 1871 to 1873 it advanced 200 per cent. Three general advances were conceded in wages, and these advances with special local advances amounted to 74 per cent. When the price of coal began to fall the mine-owners claimed a reduction in wages, and in April 1874 the men agreed to a reduction of 10 per cent. A second reduction of 20 per cent. occurred in October. A third reduction of 20 per cent. was demanded in 1875, but was strongly resisted by the miners, and a strike was only arrested by a reference to Sir Rupert Kettle, who awarded a reduction of half the amount claimed. Further arbitrations in January and October 1876 resulted in a reduction of 16 per cent., but in 1877 Lord Herschell decided in favour of the miners. Three months later the owners gave notice of a reduction, and an eight weeks' strike followed, but in the end the miners submitted to a reduction of 12½ per cent., and ten months later the owners again demanded and enforced a reduction of 10 per cent.

The irritation and disturbance in trade produced by these constant disputes about wages led to the appointment of a committee of miners and mine-owners to consider the possibility of framing a sliding scale; and eventually a scale was framed, of which the chief features were (1) that when the average price of all coal raised was the price realised in November 1878 [5/1·28] the wage of hewers was to be the average wage earned after the last 10 per cent. reduction, *i.e.*, 4/9½.

(2) An advance or reduction of 2½ per cent. was to take place for every rise or fall of 0/4 in the price of coal, with an extra 2½ per cent. when the price reached 6/4, and so on, every 1/4 carrying an extra 2½ per cent.

(3) The ascertainments of price to be made four times a year.

(4) The scale to remain in force for twelve months certain, and after that from year to year, unless terminated by one month's notice.

In 1882 the standard price was reduced from 5/1·28 to 4/8, and it was arranged that wages should rise or fall 1¼ per cent. for every rise or fall of 0/2, and that an extra 1¼ per cent. advance should be given when the price of coal was 6/0, 6/4, 7/2, 8/6, and 9/0.

The adoption of the scale led to a great improvement in the coal trade. From 1874 to 1879 the output in Northumberland gradually declined 14·35 per cent., though the output for the rest of the country had increased 7 per cent. The first year the scale was in operation the output in Northumberland increased 23 per cent. as compared with an increase of 9 per cent. in the rest of the country. From 1879 to 1884 the output increased 35·79 per cent. as against 19·55 per cent. for the rest of the country.

The sliding scale is a much more effective method of settling wages than arbitration. The defects of arbitration are:—

1. There can be no agreement as to how long prices are to rise or fall before arbitration is resorted to.

2. There can be no agreement as to what advance or reduction is to take place for a given rise or fall in the price of coal.

The sliding scale avoided both difficulties, and greater continuity of employment was worth at least 10 per cent. to both miners and mine-owners.

The hours of hewers are 6¾ at the coal-face, or 7½ from bank to bank; of other undergroundmen 8 from bank to bank; and of boys under 16 years, 10 from bank to bank.

The 7½ hours system was introduced between 1852 and 1856, when the process of getting coal by wedging gave way to blasting, the hours previous to that year being 9 to 12 hours per day. The produce per man per shift of 7½ hours under the new system was as great as the produce under the old system of an average 10½ hours' shift. The 7½ hours' shift continued until 1873, when the Mines Regulation Act came into force, and the restrictions placed by that Act on the employment of boys (10 hours being a maximum) led to the hours of hewers being reduced from 7½ to 6½ per shift; but in 1878 the depression in the coal trade led to an increase of half an hour in the length of the shift. This additional half-hour represented an increase in the hours of labour of 8·3 per cent., but the corresponding increase in production was only 5·1 per cent. It was therefore extremely doubtful whether an economic advantage would result from an extension of the hours of hewers.

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5. *Remarks on the Principles applicable to Colonial Loans and Finance.*

By HYDE CLARKE.

The author dealt with the development of our colonies and India by the application of credit in the shape of loans for the construction of railways, irrigation, and other public works. He stated that in order to equip itself a new country must begin in debt, and that this condition is not, as it has been made by some, necessarily a cause of reproach to the colonies. The borrowed moneys have in most cases been applied to the provision of railways and works producing an equivalent revenue. Thus in the end the debt, as in the case of New South Wales, becomes a property. He objected to indiscriminate application of debt totals, debt per head, taxation per head, &c., as fallacies and real abuses of statistical methods. He maintained that the comparisons must be equal, and that a debt incurred for public works cannot be set off as equal to a debt incurred for deficits and war, or with a case of the railways being formed by joint-stock capital. He pointed out the confusion between capital and current expenditure, which had embarrassed the financiers of India and injured the development of the empire. This, he said, was partly caused by the neglect of a national balance-sheet at home showing the capital stock of the nation. Approximations to such a cadastre were to be found in the Domesday Book of 1086, and the census of the United States, showing the resources of each State. The agricultural returns are an approximation to this. The first requisite of a colony, as of all countries, is means of transit and transport in the shape of railways such as can compete with other districts in the conveyance of goods to market. It is in this way alone the wilderness can be made a fertile and a productive land. Railway material, not being of local supply, can only be obtained from abroad and from borrowed means. With regard to such cases he took that of New South Wales according to the budget of July 1886. A debt of 30,000,000*l.* had been, or was being, contracted, and of this 25,000,000*l.* had been applied to railways, besides what has been applied to other work and what remains to be applied to railways. The net railway revenue for the year amounted to 1,000,000*l.*, equivalent to 4½ per cent. (4·48) on the loan moneys, and leaving a small surplus of profit, after payment of working expenses and interest as loans. The debt of New South Wales per head was only for public works, while the home debt of England is wholly unrepresented by assets. Mr. Clarke then considered the market price of colonial securities, which was high for the old 6 and 5 per cent. loans, and has enabled these to be replaced by 4 per cent. loans, the Government of New South Wales having lately placed five millions at 3½ per cent., a rate towards which colonial securities are approximating. In the case of New South Wales the saving in interest gives the colony a further power of borrowing and of creating assets without increasing the fund for interest. Mr. Clarke showed also that English figures were fallacious as a standard for the cost per mile and rate of earnings. English railways are trunk lines, and many are suburban lines with heavy payments for land, for tunnels, and underground lines, and with large stations, more engines, carriages, waggons, rolling stock and appliances than on the light colonial lines with land free. Where a line is constructed by the State, as it has supplemental resources from increase of taxation, it can even afford to make a loss in its railway charges for public purposes. He then referred to the low price of rails, steel, and iron caused by the inventions of Bessemer, Siemens, &c., and the advantages thereby conferred on the colonies, which can now obtain their extensions at reduced rates of cost. At the same time he pointed out that this low price of material had opened up all the land in the world capable of producing wheat, maize, sugar, and coffee, and given cheap steel ship ocean freights. The increased supply of perishable food articles had aggravated the differences of prices, and it would be dangerous for India and the colonies to depend on increased food exports, but they must extend other branches of trade. He pointed out that India and the colonies required an immense extension of railways and waterworks. As to India, he said there was one mile of railway to 20,000 people with a revenue of about 1*s.* 6*d.* per head per annum, and with the Government expending about as much on extensions. In connection with colonial development he advocated reproductive emigration, that every man who had a free passage should be taxed for its repayment, so that the fund should constantly be employed in sending out more emigrants.

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6. *The Mathematical Theory of Banking.*

By F. Y. Edgeworth, *M.A., F.S.S.*

The higher mathematics make two contributions to social economy—the calculus of probabilities and what we may, after Jevons, call the calculation of utility. Of these branches the former is more fruitful; and, as it has been cultivated by the most distinguished mathematicians, so it appears at first sight to belong to the same genus as physics. But, when we examine the root and ground from which it springs, the science whose object is the calculation of credibility is found to be nearly as speculative as the other branch of mathematics applied to human affairs. They both are developed from somewhat conjectural first principles, and they yield, for the most part, very hypothetical conclusions. We gather from them, rather appropriate general ideas, than results immediately applicable to practice.

I. Probability is the foundation of banking. The banker contracts liability to pay amounts which he never could pay if all his creditors should at the same time demand full payment. His solvency and profits depend upon the probability that he will not be called on to meet at once more than a certain amount of his liabilities. There is involved not only the calculation of averages—which is an affair of arithmetic—but also the doctrine of deviations from an average, of *errors,* which has exercised the ablest mathematicians. The general theory is that, when any quantity fluctuates under the influence of a number of independent causes, the values assumed from time to time by the variable quantity occur each with a frequency which fulfils a certain mathematical law—the so-called *law of error.*

The following experiment, which the writer has partially performed, illustrates the principle. Take at random a hundred digits from the pages of a mathematical table or statistical journal, and add them together. This aggregate may be regarded as formed by a hundred independent agencies. Accordingly, sums thus formed will fluctuate about their mean value (450) according to the normal law. The probability of any such sum deviating in excess or defect to the extent of 42 from the mean 450 is about $\frac{1}{6}$. The probability of a deviation twice as great is about $\frac{1}{200}$, and the odds are about fifty thousand to one that the limits 576 and 324 will not be passed. It is upon this principle that the anthropologist, armed with the formulæ of Quetelet, could, by inspecting some samples of a new race, determine the probability that there should be found among a thousand taken at random from them a single *six-footer* or a dozen whose average height is six feet. Now the variables with which the banker is concerned, such as the amount of notes remaining out in the hands of the public and the demands on the reserve, depend in ordinary times upon a multeity of causes, the fortunes and actions of the bank's numerous customers. Accordingly the theoretical banker, interpreting experience by mathematics, can calculate with nicety the chance that the demands on him in the immediate future will exceed a certain extent. Ideally in the planet Saturn, the banker may determine the probability of demands of different extent, and make such arrangements, that to demands of different probability may correspond different degrees of facility in meeting them. The use and beauty of this ideal arrangement are somewhat marred when we descend to the affairs of Earth. The fluctuations of banking business are not entirely subject to the rules of chance. They have been partly reduced to law. There is a tide in the affairs of business men. There are periodical variations, which have been calculated by Jevons. But when we have taken account of these regular disturbances, when we have 'eliminated' the 'tides,' there still remain undulations which are amenable to the principles of probability. It may be objected, however, that the irregular variations most important to the banker depend, not on a number of small agencies, but on a few great causes, such as weather destroying harvests, war, or adverse exchanges. It is submitted, however, that such great causes, being themselves the results of a multiplicity of varying conditions, may, to a considerable extent, and with due reservations, be reduced under the theory of errors. Proceeding upon this hypothesis the writer attempts to determine, by the formulæ of Laplace and Poisson, the amount of Bank of England notes which may be regarded as certain to remain out in the hands of the public. The reserve of private banks in ordinary times may be similarly treated. The reserve of the Bank of England presents peculiar difficulties. We may at least obtain from the rules of probability a presumption in favour of an increased reserve. This indication is agreeable to the opinions of many high authorities. But there is one argument frequently employed by practical sagacity for which mathematical theory does not vouch. It seems to be generally assumed that, if the volume of banking business increases, the reserve should increase proportionately, if safety is to be maintained. But the *à priori* presumption is the other way. A banker may be compared to the manager of a club who undertakes to have dinner ready for any number of members who may present themselves any evening. Suppose (as in a case with which the writer is conversant) the average attendance is 18; and suppose that deviations in excess from that mean to the extent of 8 and 16—that is, attendances of 26 and 34—correspond to different degrees of improbability ($\frac{1}{12}$ and $\frac{1}{400}$ respectively), and different arrangements, such as keeping provisions in the house or sending out to borrow them. Suppose, now, that two or three such clubs amalgamate. The deviations (of probability $\frac{1}{12}$ and $\frac{1}{400}$) for which provision as before must be made will not be two or three times the deviations found for the single club. The theoretical ratio will be not 2 or 3, but the *square root* of 2 or 3. Similarly if the liabilities of the Bank of Saturn should double, while the ratio between the liabilities to the reserve should diminish from 52 to 41 per cent. (as here in England between 1844 and 1873), this circumstance *per se* would not there cause any alarm. The same principle is applicable to the theory of banker's balances. If several Saturnian banks should be subordinated to one bank of banks, with whom they all keep their reserves, in estimating the safety of the system it would be improper to deduct *en bloc* the balances of the bankers, and to be alarmed if the remainder was inadequate to meet the liabilities of the prime bank, or even less than nothing. A smaller reserve is required for a consolidated system, not only in so far as the demands upon one bank correspond to payments into another—the principle of clearing which is admitted—but also, what is less evident, in so far as the demands upon one bank are independent of the demands upon another. How far this condition is fulfilled, or how far 'other things are equal,' in particular whether the presumption raised by increased volume is counteracted by the increased rapidity of drains upon the reserve, the writer does not pretend to decide. The mathematical method supplies to practical men rather general ideas than exact propositions.

II. The mathematical theory of exchange, constructed by Gossen, Jevons, and Walras, applies to the money market, at least as well as to the other bargains, which are the subject of economics. From the abstract point of view may be discerned an unobvious, perhaps unimportant, reason why the money market should be particularly sensitive, more so than the labour market. In an ideal market, consisting in its simplest type of two sets of dealers and two kinds of commodities exchanged, each individual belonging to one of the sets should be free to enter into contract at the same time with any number of dealers belonging to the other set. But the workman cannot, or does not often, at the same time contract with different employers—sell on the same day this week's work to one employer, and next week's work to another. Accordingly, if the balance of supply and demand should be turning in a sense unfavourable to the workman, a new equilibrium will be reached, not by the workman buying up the aid of several employers (at a rate slightly below that hitherto prevailing, so as to cut out his competitors), but solely by the employer refusing to buy at the existing rate as many workmen as he has hitherto done. The resilience of the money market is not impeded by any similar defect. Another subject which may be usefully contemplated by the aid of mathematical conceptions is the effect of a quasi-monopoly, such as the Bank of England used to enjoy. However interesting such inquiries, we must always remember that they are at an enormous height of abstraction above real life. It has been well said of the economical theorist that he has a key which has unluckily been left within the chamber which is to be opened. Yet though we cannot determine the exact shape and number of the wards, it is something to have a general knowledge of the difficulty to be resolved. We can at least confute the charlatan when he offers his patent picklocks. It is melancholy to contemplate the waste of emotion and errors of conduct following upon the bogus theory of value which a certain sect of Socialists has adopted. The Jevonian theory may not enable us to predict what will be the price of money or any other article to-morrow, but at least it helps to dissipate the sophisms incidental to a subject whose natural obscurity is darkened by interest and passion.

7. *The Definition of Wealth.* *By* H. D. McLeod.

8. *The Cost of Shipbuilding in H.M. Dockyards.*
By Frank P. Fellows, *Kt.S.J.J., F.S.S., F.S.A.*

This paper showed that about 1,000,000*l.* per year *less* was spent on the navy in each year (1869 to 1872) than before or since; that the plant, buildings, and machinery of the dockyards were better kept up then than before or since; that if since, up to 1884, as much had been expended on such plant, &c., 3,655,000*l.* more would have been expended; and that, nevertheless, the warships *built* in H.M. dockyards and *bought* were many thousands of tons yearly more in 1869 to 1872 than before or since, as the table below will show:—

Groups of Years	Ironclads, Tons per year	Wooden, Iron, and Composite, Tons per year	Total Tons per year
1865–1869	12,243	8,011	20,254
1869–1872	17,114	5,273	22,387
1872–1880	8,563	8,854	17,417
1880–1884	11,103	7,553	18,656

That, taking the cost per ton (displacement), *i.e.*, the *actual weight* of the *ironclads' hulls built in H.M. dockyards,* and adding incidental charges as added or shown in the Admiralty final expense accounts of the cost of ships built, they cost about 67*l.* per ton from 1869 to 1872, about 100*l.* per ton from 1880 to 1884, and about 110*l.* per ton in 1884.

The author of the paper believed that the excess cost, 1880 to 1884, arose largely because the recommendations of Mr. Seely's Committee on Admiralty Moneys of Accounts of 1868, carried out under the superintendence of the author in 1869 and afterwards, and which led to the great results stated, had not been kept up in their entirety and integrity.

The author referred to papers on this subject read by him before the Statistical Society of London, and at the meeting of the British Association at Swansea, which stated in detail what these reforms were, and how they had caused this great saving concurrently with increase of tonnage built, and gave it as his carefully considered opinion that there was no sufficient reason for the present great excess cost, and that much more tonnage of new ships ought to be produced for the money expended.

He pointed out that it had been decided, after great inquiry and deliberation, that at least 20,000 tons of new war shipping ought to be added yearly to our navy under normal circumstances to keep up its strength properly, that in 1869 to 1872, under the administration of Mr. Childers, carrying out the recommendations of Mr. Seely's Committee of 1868, 22,387 tons (of which 17,114 tons were iron-clad) had been yearly added at a much less cost than a smaller tonnage before or since; and that he (the author) never could discover sufficient reason why these data resulting in the decision as to 20,000 tons yearly, were departed from, and only about 17,000 to 18,000 tons yearly added.

The consequence was panics arose, and our navy had to be suddenly increased at an enormously excessive cost—indeed, at any cost almost that those who had war-ships chose to ask.

He concluded by stating if he had *carte blanche* he believed he could again bring about similar results to those of 1869 to 1872.

WEDNESDAY, SEPTEMBER 8.

The following Papers were read:—

1. *Proportional Mortality.* *By* BALDWIN LATHAM, *M.Inst.C.E., F.G.S.*

The author of this paper describes a method of very correctly arriving at the proportional death-rate of a district with great facility by the use of 'constant' or basic numbers. These 'constant' numbers were obtained at census periods by ascertaining the average death-rate at such periods, and then adding a quantity equal to ten times the proportion of births to one death found in the same period. As one example he gives the case of the combined district of Birmingham and Aston, where the average death-rate at the census periods of 1861, 1871, and 1881 was 22·31, and the average proportion of births to deaths in that period, when multiplied by 10, was 17·69, giving, when added together, a constant number of 40; so that if ten times the proportion of births to deaths was deducted from 40 it would show the proportional death-rate in any period as compared with the average at the last three census periods. There might be cases in which a modification in procedure would be necessary in arriving at the proportional death-rate, as in those places and years when the deaths exceed the births, in order to arrive at a result in such a period, which now fortunately seldom occurs in this country, but which was common years ago. When the births and deaths were equal it was equivalent to deducting 10 from the constant number. If therefore when the deaths exceeded the births 10 was deducted from the constant number, and the remainder multiplied by the ratio by which the deaths exceed the births, it would give the proportional mortality.

A second and more correct method was described in this paper, in which the constant number was exactly equal to twice the average death-rate at the census period, the proportional mortality being arrived at by deducting a quantity equal to the proportion of births to one death when multiplied by a number obtained by dividing the average death-rate by the average proportion of births to deaths. Under this system, in Birmingham and Aston districts, the constant number became 44·62, and the multiple $\frac{22{\cdot}31}{1{\cdot}769}=12{\cdot}6$; so that the proportion of births to one death multiplied by 12·6, and deducted from 44·62, would give the proportional mortality in this district at any time.

2. *The State of the Poor in* 1795 *and* 1833.
By GEO. HERBERT SARGANT.

The working classes only emerged from a state of semi-slavery towards the end of the eighteenth century. The dwellings of the poor in the eighteenth century especially defective in their fireplaces. Clothing, in the south mostly bought from a shop, in the north made at home; great thrift in the north in their clothes and in using clogs. The unhappy conditions under which miners and refiners, &c., worked; also those who worked in cotton mills, especially children. Fever and small-pox prevailed. Agricultural wages varied from 5*s.* or 6*s.* a week (Cumberland, Devon) to 15*s.* (Kent); the average put at 9*s.* Mechanics' wages varied from 10*s.* to 42*s.*; average put at 16*s.* or 18*s.* The labourer with the smaller income lived better than the mechanic; their children often uneducated. Diet in the north varied, including much barley, oatmeal, and vegetables; in the south almost exclusively wheaten bread. Prejudices in the south in favour of plain bread diet. Beer drunk constantly in the south, occasionally in the north. Labourers could save; mechanics subscribed to friendly societies. The general condition of labourers from 1760 to 1790 was better than it had ever been before; but the scarcity of 1795 produced famine, for which no remedies were provided in the poor-laws, which were administered by irresponsible overseers. Objections to raising wages. Expedients resorted to to cope with the distress. The *allowance* system by *scale*, resulting in early marriages, idleness, and loss of independence. Workhouses mostly hotbeds of vice, and extravagant in diet. Poor, when unemployed by parish, idle and vicious. Jobbery caused by payment of cottage rents out of rates. Paupers were purposely dirty and ragged to extort relief; children and sick relatives neglected. Pauperisation spreading towards the middle classes. Reformation effected by enforcing labour from the able-bodied, and rent and rates from the cottagers. The flourishing condition of the *unsettled* and the independent labourer, and general improvement in the condition of the working classes. Wages in 1833 similar to those in 1886.

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3. *The Insufficient Earnings of London Industry, and specially of Female Labour.* *By* WILLIAM WESTGARTH.

The author commented on the striking fact that over a large section of regular London industrial life the usual earnings were more or less insufficient to maintain the earner. Female labour was especially under this disadvantage, because a woman was more helpless as to the cheap shifts in straits than a man. He took as a typical case the needlewomen of East London, a vast class of London's regular industry, estimated to number over a quarter of a million, and to average, from a long day's work, an earning per head of only one shilling a day. Now, probably no man, certainly no woman in any way possible to her respectability, can live in London on a shilling a day, or 6*s.* a week. Then how does all this class live from day to day and year to year? Why, sad to say, they do not live; they die—die morally and physically. But quickly as the way is ever thus cleared, it is ever refilled by the fresh tide of victims. The ranks of these needlewomen are probably the main source of London's great social evil, and a social revolution would result from solving their problem.

Well, if we cannot help them to a greater money earning, we may help to make the little money they do earn go further. This is to be done by means of co-operation and the wholesale scale. The author went into this question, looking on the one hand at all the possibilities of the cheapest housing and dieting, and considering, on the other hand, the habits and wants, and even the prejudices, of those we aim to help, in case we attempted plans which, however economical, would not practically work. Experience tended to abolish bedrooms in which individuals or families were huddled together day and night, and to substitute sleeping berths, somewhat as in ships' cabins, with their common saloon as the day accommodation.

Taking this fundamental idea, to which he was also guided by the form which cheap lodging took in East London, the author could furnish a marvellously cheap estimate of living, to include, besides sufficient food, a home that was comfortable, cheerful, and respectable, and all well within the 6*s.* a week of wages. He would rear a building for the purpose, with its great common hall in the centre, and its successive floors of sleeping accommodations, accessible from the hall by stairs and balconies, the latter wide and roomy, so as to increase and vary the sitting area. He would institute a 'house diet,' the result of science and experience in cheap, wholesome, and palatable food, but the tenants must be free as to their custom, nor would they be bound in partnership arrangements. He would, however, make a redemption fund by a small addition to rent, so that in twenty or forty years the edifice would fall to the tenants. There was social difficulty and danger in bringing, for instance, many young women under one roof. A matron was insufficient. He would seek the intervention of a committee of benevolent ladies, each of whom might take charge, say, of twenty young women, and thus make an approach to a family influence. He estimated the 'house diet,' or minimum cost of food-finding, at 2*d.* per day, the sleeping berths at 9*d.* per week, the redemption at the same, and all costs of hall and management, together with 5 per cent. on capital, at 2*s.* 6*d.* He would have a minimum of tidy and suitable furnishing as fixtures, instead of tenants' furniture, and this would add 1*d.* to 2*d.* to weekly rent. He would have an entrance deposit of 5*s.* to 10*s.* to begin the redemption fund, which the tenant might afford by help of the furnishing convenience. There must be strict selection to ensure success to first experiments. He supposed a scale of 1,000 to 2,000 tenants, whose minimum of expenses, clothing excepted, would fall within 5*s.* 4*d.* per week. But by larger numbers, say of 5,000, and consequent economising in hall and management, the cost to each might be brought substantially under 5*s.* So great a number, with their great edifice and large and lively hall, might resemble a street, a well-ordered and pleasant street, we may hope, with the occupants sitting out in the genial air, to pursue their work under cheerful circumstances or to enjoy the sociabilities. The poor young needlewoman's dream, when she left her country home for golden London, might thus be even more than realised.

4. *London Reconstruction and Re-Housing.* *By* WILLIAM WESTGARTH.

The author introduced his subject by alluding to the heritage of debt usually left to the ratepayers, as the result hitherto of urban sanitation and reconstruction undertaken by the municipality. He proposed to reconstruct ill-conditioned areas of central London as a self-remunerative business; and he explained how the recoupment of cost was to be effected by what he called the 'natural increment' of site value (using that term in place of the invidiously so-called 'unearned increment' of the economists), besides the increase of value due to the improvement itself. He meant to do this by means of a joint stock company or trust, and there were certain facilities and privileges which the trust would reasonably ask of the Government, in return for the sanitation and reconstruction the trust contemplated, all of it cost free to the ratepayers.

He then explained natural increment as simply the result of the increase of population, commerce, and wealth upon and around sites or areas which were themselves inextensible. It was the feature in common of all progressive countries, and especially of their larger towns, and had been markedly the feature of London, and of central London particularly, whose natural increment during the last thirty years might have availed for an entire systematic reconstruction. Such a considerable term of years must be dealt with, because natural increment, like other things commercial, is subject to sub-waves of excitement and depression, as illustrated by the excitement and site-value increase between 1870 and 1878, as compared with the eight subsequent years of depression, or comparative depression. He went on to allude to the great Paris reconstruction, where, by the immediate re-sale in fee simple of the expropriations, after clearing, realignment, &c., all the natural increment had been abandoned to the private investors and speculators, leaving thereby an enormous debt upon the city. But so enormous also had been the subsequent value-increase that he was warranted in saying that Paris could have been successfully reconstructed as a private enterprise by holding for an adequate term to the sites, much in the way he now proposed for London.

Having stated principles, the author then passed to details. In the first place he must be helped by a special Act of Parliament, to enable the Government to deal with and authorise a trust when of adequate resource and responsibility. Without this special facility no body of responsible and busy men would attempt such a work, and this Act, while they were about it, he would make general and not merely for London, so that public-spirited persons elsewhere might institute similar trusts. The proposed trust to be upon a scale of adequate resource, should have ten millions of capital to start with; but this could take the convenient form of a small paid-up, and a large liability, capital. The advantage of this form, as much successful experience had shown, was that, while a dividend might be large and satisfactory as compared with the paid capital, it yet weighted the concern with only a small charge as upon the whole capital. This plan answered well where there was confidence in the undertaking. And responsible shareholding would still be secured by making the shares of exceptionally large amount.

But this form of the capital would involve large borrowing from the public, and in order to do this cheaply (for it was everything to tide over, at lowest cost, the considerable interval till natural increment became effective), the trust would claim a contingent rating liability as additional security for its loan issues. The ratepayers, protected by the trust's capital and judicious business procedure, would have only a nominal liability. Under this concession the trust's dividends must be by agreement with the Government.

Then followed conditions or limits to the full powers of action given to the trust. No step could be taken without approval, or in face of the veto of Government or municipality. Hostility on their part was not to be even dreamed of in this beneficial work. The Board of Management would include a representative of the Government, of the Corporation, and of the Board of Works. A further condition would be that, in its possibly large expropriations, the trust should, as far as practicable, offer siteholders, on fair agency terms, the option of co-operation instead of expropriation. This seems only fair, where the object is not such disturbing expropriation, but improvement.

Finally, Mr. Westgarth, in commending his project to favourable attention, said that he was ambitious to invite the help of the very highest London names in forming his Board, and thus alike to inspire public confidence in an enterprise somewhat novel in character, and to do full justice to a project which contained all the possibilities of the grandest and most beneficent of business enterprises.

5. *On the Application of Physical Science to Economics.*
By Patrick Geddes.

The present isolation of economic from physical and biological studies, in spite of the clear dependence of the social sciences on the preliminary ones, is to be accounted for, not on rational, but simply on temporary grounds, that of the press of detailed labour upon every specialist. Yet these sciences are needed on every hand. The population question is a strictly biological one; so too that of competition, and even of individualism *versus* socialism, which largely comes down to a dispute between the advocates of natural and artificial selection respectively. Progress especially needs interpretation in terms of evolution—*i.e.*, the popular idea of progress as lying essentially in quantity of wealth and in number of population needs thorough replacement by the scientific one, that of the improved average individual quality of the organisms composing the society, and of the material surroundings upon which their evolution depends.

Foreign though such views may nowadays seem to economists, it was in this way that the science actually arose: the original French 'Physiocratic' school was one of naturalists and physicians, and the subsequent character of political economy is to be rather accounted for by the passage of the science out of the hands of scientific men into those of scholars and business men alone.

The view of industry as a physical process[1] in which the energies of nature are applied was next discussed, and the bearing of the physical doctrine of energy upon the subject outlined. Interest, for instance, is thus viewed, not simply as 'reward for abstinence' or the like, but as resting fundamentally as the surplus of income over expenditure in the year's struggle to seize the energies of nature; like the energy of coal, in short, it comes primarily from the sun. Money, of course, being a mere mode of notation of material realities, we must distinguish between apparent saving and real storing.

The highest aspect of production is thus seen to be not in simply individual effort for personal gain, but in the resulting sum of such efforts—in the accumulation and handing on of the total results of industry—in other words, in the collective energy, or *synergy*, of the community.

Finally, the supposed opposition of economics to morals is thus seen to lie essentially in a too narrow definition of the aim of production, and disappears in proportion as the individual increase of often imaginary wealth—mere claims upon the labour of the future—becomes subordinated to the accumulation of the only real and intrinsic wealth—the permanent apparatus of general well-being. Such a city as Birmingham exhibits a typical example of such a change, showing clearly the new city, rich in permanent dwellings and in treasure for the commonweal, in the heart of the older city of merely individualistic production around it. It is in this way that the reconciliation of political economy with morals is to be effected, and the good of the socialistic movement retained while avoiding its dangers.

6. *The Resources and Progress of Spain during the last Fifty Years of Representative Government, in connection with the British Empire. By* Don ARTURO DE MARCOARTU.

The author said that the population and the wealth of Spain has increased lately, in spite of wars and political disturbances, more than her national foreign debt; that the value of the railways alone, which will revert to the State, is equal to her foreign debt at par; and that Spain has sufficient assets and means to develop her public works by making a loan of forty millions without increasing her present budget of expenses, and without selling her forests; that Spanish agricultural products will supply a great deal of the wants of Great Britain; and, in the mining wealth of Spain, the United Kingdom can find the basis of her metallic production; that between 1853 and 1883 the degree of activity of construction of Spanish and British railways was quite equal; that the total trade in the last twenty-five years (1860–1884) between England and Spain was 288,252,347*l.*, or nearly 296,000,000*l.*, although there was no treaty to favour commerce, and although Spain was disturbed by revolutions.

British capitalists and British industry made enormous profits from the Spanish mines by selling to Spain steamers and railway plant, although British capital was not employed in the Spanish railways.

The new Anglo-Spanish treaty is most favourable for England, but unfortunately has not settled some important claims on the part of Spain, inasmuch as the sherry and Tarragon wines will pay 100 per cent. and 175 per cent. of their value in duty, the Spanish dried fruits still pay 35 per cent., and the smuggling at Gibraltar has not been extinguished.

Per head of population, the Spanish Peninsula is the most highly taxed exporter to this country, while the Spanish treasury is most seriously defrauded by Gibraltar; British produce commands a greater consumption per head in Spain than in France, Germany, Italy, Russia, and Austria; the total commerce of Spain

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[1] See the writer's analysis of the Principles of Economics, *Proc. Roy. Soc. Edin.* 1885; and Williams & Norgate, 1885.

with the United Kingdom is double the total commerce of Italy with the United Kingdom.

Diversity of production and the short distances between Great Britain and Ireland and the Spanish Peninsula in Europe, between Canada, and Cuba, and Porto Rico in America, and between the Philippine Islands and the British possessions in the East, must help the natural stream of trade between the British and Spanish Empires all over the world; but in order to attain this end it would be necessary to append to the new commercial convention a clause of international arbitration, such as was agreed upon by England and Italy in the last treaty of commerce between those countries, and such as has been introduced into over twenty other international treaties, namely, a clause for the settlement by arbitration of all controversies which may arise on the interpretation or the execution of the largest commercial treaty which has ever been made; and lastly, that in order to diffuse in both countries the knowledge of each other's resources it would be wise to create Spanish Chambers of Commerce in the British Empire, and British Chambers of Commerce in Spain and her colonies, and to promote an Anglo-Peninsular delegation of these corporations.

SECTION G.—MECHANICAL SCIENCE.

PRESIDENT OF THE SECTION—Sir JAMES N. DOUGLASS, M.INST.C.E.

THURSDAY, SEPTEMBER 2.

The PRESIDENT delivered the following Address:—

THE present occasion is one of special interest to the members of this great Association, this being the first instance of their holding a fourth meeting in any town. An opportunity is thus afforded me of referring briefly to the principal subjects dealt with at the previous meetings of Section G in this important centre of mechanical industry, and the good work done in their advancement.

At the Birmingham meetings in 1839, 1845, and 1865 the following papers, special to this Section, were read and discussed, viz., 1839, Testing Iron by long-continued strains; Proportion of Power to Tonnage in Steam Vessels; and Wood Paving with Vertical Blocks. In 1845, Machine Ventilation for Coal Mines; Centrifugal Pump (improved principle); Balancing Locomotive Wheels; Oil Testing by Mechanical Means; Chemical Copying Telegraphs; and Macadamised Roads (superiority). In 1865, Bessemer Steel Manufacture as substituted for that of Wrought Iron; Siemens' Regenerative Furnace and Gas Producer; Hot Blast for Furnaces at very High Temperatures; Compressed Air Machinery for Transmitting Power; Weldless Tyres; Giffard's Injector; Covering of Deep-Sea Telegraph Cables. I need not remind the members of Section G of how great value in the progress of mechanical science these subjects generally have proved, and how their beneficial influence is now being felt throughout the whole world. With these preliminary remarks on the past good work of Section G at Birmingham, and which I have no doubt will be fully maintained at this meeting, I propose to address you on a subject with which I have been practically connected for nearly half a century, that is, the development of lighthouses, light-vessels, buoys and beacons, together with their mechanical and optical apparatus.

Such a subject being of the first importance to this great maritime country, her colonies, and generally to the whole world, appears to be particularly fitting on this occasion, when we are favoured with the visit of so many eminent Colonial and Indian brethren from various portions of this great Empire.

It is also to be remembered that in the immediate neighbourhood of Birmingham are situated probably the largest works in the world for the manufacture of lighthouse apparatus; indeed, the only establishment in which the glass portions are cast, ground, polished, and finished on the same premises, and where many of the most perfect optical apparatus for lighthouse illumination have been produced.

Samuel Smiles, in his 'Lives of the Engineers,' writes: 'Our lighthouses are among the youngest triumphs of modern engineering.' Ancient lighthouses were erected on prominent parts of coasts beyond actual attack by the sea, and in many instances they were at considerable distances from navigable water, and thus, with their feeble and uncertain wood or coal fires, they were far from efficient as aids to mariners. So slow was the development in lighthouse illumination for many centuries that, so recently as 1822, the last beacon coal fire in this country was replaced by catoptric oil light apparatus at Saint Bees Lighthouse on the coast of Cumberland. With Winstanley's structure on the Eddystone in 1696 may be said to have commenced the modern engineering efforts 'in directing the great sources of power in nature for the use and convenience of man;'[1] efforts which, followed up by Rudyerd, Smeaton, the Stevensons, and others, have since been so successful in converting hidden dangers into sources of safety, and ensuring the beneficent guidance of the mariner in his trackless path. These works of modern mechanical science are now to be found around all the nautical centres of civilisation and commerce, and are so numerous that time will not permit of my referring, except incidentally, to any of them at home or abroad. I will therefore proceed to the particular branch of mechanical science to which I desire to invite your attention, viz. lighthouses, light-vessels, buoys, and beacons.

During the last century a very considerable increase has occurred in the number of lighthouses and light-vessels on the various coasts of the world, which have been required to meet the rapid growth of commerce. Only during the last twenty-five years can accurate statistical information be obtained, and it is found that in the year 1860 the total number of coast lights throughout the world did not exceed 1,800, whereas the present number is more than 4,000.

The relative progress of each of the chief maritime countries, in the extension of their system of lighthouses and light-vessels between 1860 and 1885, is shown approximately in the statement on the next page, from which it will be observed that Japan, which had not a single coast light in 1860, has now fifty-seven, eight of these being lights of the first class; while China, which had only four secondary coast lights in 1860, has now fifty-five lights, fourteen of these being of the first class. The greatest increase, however, is found in British America, where in 1860 there were only ninety-one coast-lights, whereas in 1885 there were 636.

Concurrently with the enormous increase in the number of coast lights during the last fifty years, very great improvements have been effected from time to time in their efficiency. In 1759 Smeaton's lighthouse on the Eddystone was illuminated by 24 tallow candles, weighing $\frac{2}{5}$ lb. each. The intensity of the light of each candle, I find, from experiments made with similar candles prepared for the purpose, to have been about 2·8 candle units each; thus the aggregate intensity of radiant light from the 24 candles was only about 67 candle units. No optical apparatus, moreover, was used for condensing the radiant light of the candles, and directing it to the surface of the sea. The consumption of tallow was about 3·4 lbs. per hour; therefore, the cost of the light per hour, at the current price of tallow candles, would be about 1*s.* 6$\frac{3}{4}$*d.*, sufficient to provide a mineral oil light, at the focus of a modern optical apparatus, to produce for the service of the mariner a beam of about 2,400 times the above-mentioned intensity.

The introduction of catoptric apparatus for lighthouse illumination appears to have been first made at Liverpool, about 1763, and was the suggestion of William Hutchinson, a master mariner of that port. The invention by Argand, in 1782, of the cylindrical wick lamp, provided a more efficient focal luminary than the flat wick lamp previously employed, and was soon generally adopted, for both fixed and revolving lights. In 1825 the French lighthouse authorities effected another very important improvement in lighthouse illumination by the introduction of the dioptric system of Fresnel in conjunction with the improvements of Arago and Fresnel on the Argand lamp, by the addition of a second, third, and fourth concentric wick.

Coal and wood fires, followed by tallow candles and oil, have been referred to as the early lighthouse illuminants. In 1827 coal gas was introduced at the Troon Lighthouse, Ayrshire, and in 1847 at the Hartlepool Lighthouse, Durham, the latter for the first time in combination with a first-order Fresnel apparatus. The slow progress made with coal gas in lighthouses, except for small harbour lights, where the gas could be obtained in their vicinity, was chiefly due to the great cost incurred in the manufacture of so small a quantity as that required and at an isolated station. In 1839 experiments were made at the Orford Low Lighthouse,

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[1] Charter of the Institution of Civil Engineers.

COMPARATIVE STATEMENT SHOWING THE APPROXIMATE NUMBER AND DESCRIPTION OF THE COAST LIGHTS IN THE CHIEF COUNTRIES OF THE WORLD (EXCLUSIVE OF THEIR OUTLYING POSSESSIONS) IN THE YEARS 1860 AND 1885 RESPECTIVELY.

COUNTRY	LIGHTHOUSES									LIGHT-VESSELS		
	1860			1885			INCREASE			1860	1885	
	NUMBER			NUMBER			NUMBER					
	1st Class	Secondary	Total	1st Class	Secondary	Total	1st Class	Secondary	Total	NUMBER	NUMBER	INCREASE
England and Wales	24	178	202	43	296	339	19	118	137	42	57	15
Scotland	17	112	129	23	166	189	6	54	60	1	4	3
Ireland	11	74	85	19	108	127	8	34	42	5	11	6
United Kingdom	52	364	416	85	570	655	33	206	239	48	72	24
United States	26	314	340	51	1,917	1,968	25	1,603	1,628	39	23	16[1] (Decrease)
France	32	193	225	39	374	413	7	181	188	3	9	6
British America	4	87	91	5	631	636	1	544	545	1	15	14
Sweden and Norway	3	115	118	8	321	329	5	206	211	2	8	6
Italy	3	88	91	16	234	250	13	146	159	—	13	13
Russia	2	63	65	14	164	178	12	101	113	12	16	4
Australia	6	33	39	24	231	255	18	198	216	5	14	9
Austria	—	10	10	2	61	63	2	51	53	—	—	—
Denmark	2	68	70	7	45	52	5	23 (Decrease)	18 (Decrease)	7	11	4
Spain	9	41	50	11	167	178	2	126	128	—	—	—
Netherlands	3	55	58	8	94	102	5	39	44	—	3	3
India	—	42	42	13	74	87	13	32	45	7	9	2
Germany	1	31	32	10	193	203	9	152	161	8	22	14
New Zealand	—	3	3	6	66	72	6	63	69	—	2	2
China	—	4	4	14	41	55	14	37	51	1	13	12
Turkey	1	13	14	—	—	129	—	—	115	1	5	4
Japan	—	—	—	8	49	57	8	49	57	—	2	2
Brazil	—	16	16	9	47	56	9	31	40	—	1	1
Portugal	1	14	15	1	29	30	—	15	15	—	—	—
Belgium	1	5	6	1	21	22	—	16	16	2	3	1
Greece	—	—	—	3	54	57	3	54	57	—	1	1
Totals	146	1,559	1,705	335	5,383	5,847	190	3,827	4,132	136	242	122

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[1] This is in consequence of a large number of permanent lighthouses having been substituted for light-vessels.

Suffolk, with the Bude light of the late Mr. Goldsworthy Gurney. This light was produced by throwing oxygen gas into the middle of a flame derived from the combustion of fatty oils. The flame was of the dimensions of that of the Fresnel four-wick concentric burner. An increased intensity over that of the flame of the large oil-burner was obtained, but it was not found to be sufficient to justify the increased cost incurred. In 1857 a trial was made by the Trinity House, at Blackwall, under the advice of Faraday, with one of Holmes' direct current magneto-electric machines for producing the electric arc light for a lighthouse luminary, and the experiment was found to be so full of promise for the future that a practical trial was made during the following year.

At the South Foreland High Lighthouse, on December 8, 1858, the first important application of the electric arc light, as a rival to oil and gas for coast lighting, was made with a pair of Holmes' machines, and thus were steel magnets made to serve not only, as in the mariner's compass, to guide him on his path, but also to warn him of danger. In 1859 the experimental trials at the South Foreland were discontinued, but they were sufficiently encouraging to lead to the permanent installation of the electric light at Dungeness Lighthouse in 1862. In 1863 the electric arc light was adopted by the French lighthouse authorities at Cape La Hêve.

In 1871, after practical trials with a new alternating current machine of Holmes, two of such machines were supplied to a new lighthouse on Souter Point, coast of Durham, and in the following year the electric arc light, with these machines, was established in both the High and Low Lighthouses at the South Foreland, where it still shines successfully. The early experience with the electric light at Dungeness was far from encouraging. Frequent extinctions of the light occurred from various causes connected with the machinery and apparatus, and the oil light had, at such times, to be substituted. As no advantage can counterbalance the want of certainty in signals for the guidance of the mariner, no further step in the development of the electric light was taken by the Trinity House until the latter part of 1866, when favourable reports were received from the French lighthouse authorities of the working of the Alliance Company's system at the two lighthouses of Cape La Hêve. Complaints were also received from mariners, in the locality of Dungeness, of the dazzling effect on the eyes when navigating, as they are there frequently required to do, close inshore, thus being prevented from rightly judging their distance from this low and dangerous point. Therefore, in 1874, the electric light was removed from Dungeness, and a powerful oil light substituted. In 1877 the electric arc light was installed at the Lizard Lighthouses on the south coast of Cornwall, and arrangements are now being made for establishing it at St. Catherine's Lighthouse, Isle of Wight, and at the High Tower, on the Isle of May, Frith of Forth. I have mentioned that the first machines of Holmes at the South Foreland were direct current, the machines provided by him for Dungeness being also of the same type. The French lighthouse authorities, however, adopted for their lighthouses at Cape La Hêve the 'Alliance' Alternating Current Magneto-Electric Machines, and, in consequence of the less wear and tear of these machines with greater reliability through their having no commutator, Holmes was required to supply alternating current machines for Souter Point and the South Foreland. Those machines have been running at these stations fourteen years and fifteen years respectively. They have during this period required only a very trifling amount of repair, and are still in excellent order, but the time must soon arrive for replacing them by more powerful machines.

In 1876 a series of trials was made by the Trinity House at the South Foreland, with various dynamo-electric machines, for the purpose of ascertaining the then most suitable machine for adoption at the Lizard. The results were decidedly in favour of the Siemens direct current machine, and machines of this type were accordingly installed at the Lizard Station in 1878. In consequence of irregularities in their working, and because, at the time, Baron de Meritens, of Paris, had perfected a very powerful alternating current machine, it was resolved to send one of the latter machines to the Lizard for trial, where it has worked most satisfactorily for several years. The experience gained at the Lizard suggested that, for the

St. Catherine's Station, where it had been resolved to adopt the electric arc light, the De Meritens machines should be employed, and they were accordingly ordered; but, as arrangements were then being made for experiments at the South Foreland for testing the relative merits of electricity, gas, and oil as lighthouse illuminants, it was determined that these machines should first be sent there for the experiments. In 1862 a practical trial was made by the Trinity House at the South Foreland of the Drummond or lime light, but the results were not so satisfactory, after experience with the electric arc light, as to encourage its adoption. In the meantime the successful development of the electric arc light for lighthouse illumination very soon acted as a keen stimulus to inventors of burners for producing gas and oil luminaries for the purpose; in 1865 the attention of lighthouse authorities was directed to the gas system of Mr. John R. Wigham, of Dublin, which system was tried in that year by the Commissioners of Irish Lights at the Howth Bailey Lighthouse, near Dublin, and in 1878 he introduced at the Galley Head Lighthouse, county Cork, his system of superposed gas burners. At this lighthouse four of his large gas burners and four tiers of first-order annular lenses, eight in each tier, were adopted. By successive lowering and raising of the gas flame at the focus of each tier of lenses, he had previously produced the first group flashing distinction. This light shows, at periods of one minute, from ordinary annular lenses, instead of the usual long flash, a group of short flashes, varying in number between six and seven. The uncertainty, however, in the number of flashes contained in each group is found to be an objection to the optical arrangement here adopted. In the meantime the attention of the Trinity House, the Commissioners of Northern Lights, and the French lighthouse authorities was being directed to the question of substituting mineral oil for colza as a lighthouse illuminant. In 1861 experiments were made by the Trinity House for the purpose of determining the efficiency and economy of mineral oils in relation to colza for lighthouse illumination; but, owing to the imperfectly refined oil then obtainable and its high price, the results were not found to be so satisfactory as to justify a change from colza oil, at that time generally used. In 1869 the price of mineral oil, of good illuminating quality and safe flashing point, having been reduced to about one-half the price of colza, the Trinity House determined to make a further series of experiments, when it was ascertained that, with a few simple modifications, the existing burners were rendered very efficient for the purpose, and a change from colza to mineral oil was commenced. It was found, during these experiments, that the improved combustion effected in the colza burners, in their adaptation for consuming mineral oils, had the effect of increasing their mean efficiency, when burning colza, 45¾ per cent. A further advance was made during these experiments by increasing the number of wicks of the first-order burner from four to six, more than doubling the intensity of the light, while effecting an improved compactness of the luminary per unit of focal area of 70 per cent.

With coal fires no distinctive characters were possible beyond the costly ones of double or triple lighthouses. There are at present not less than 86 distinctive characters in use throughout the lighthouses and light-vessels of the world; and, as their numbers increase, so does the necessity for giving a more clearly distinctive character to each light over certain definite ranges of coast. This important question of affording to each light complete distinctive individuality is receiving the attention of lighthouse authorities at home and abroad, and it is hoped that greater uniformity and consequent benefit to the mariner will be the result.

During the old days of sailing vessels, when the duration of voyages was so uncertain, sound signals, as aids to the mariner, were but little demanded. The seaman on approaching the coast in fog trusted entirely to his lead, and, when he found circumstances favourable for doing so, he anchored his vessel until the atmosphere cleared. But, since the application of steam to navigation, with keener competition in trade, these conditions have been entirely changed. The modern steam vessel is expected to keep time with nearly the same degree of precision as a railway train, and it is evident that, even with the utmost care and attention on the part of her commander, this requirement cannot possibly be fulfilled, and collisions and strandings must occur, unless efficient sound signals for fog be carried by each vessel, and powerful signals of this class be provided at lighthouse and light-vessel stations.

These circumstances have led to a rapid development of fog signals, both ashore and afloat, there being now about 700 of these signals, of various descriptions, on the coasts of the world. We therefore find, as might naturally have been expected, that coast fog signals have been made, by lighthouse authorities, the subject of careful experiment and scientific research; but, unfortunately, the practical results thus far have not been so satisfactory as could be desired, owing, 1st, to the very short range of the most powerful of these signals under occasional unfavourable conditions of the atmosphere during fog, and, 2nd, to the present want of a reliable test for enabling the mariner to determine at any time how far the atmospheric conditions are against him in listening for the anxiously expected signal. In 1854 some experiments on different means of producing sounds for coast fog signals were made by the engineers of the French lighthouse department, and in 1861-62 MM. Le Gros and Saint Ange Allard, of the Corps des Ponts et Chaussées, conducted a series of experiments upon the sound of bells and the various methods of striking them.

In 1863–64 a Committee of the Elder Brethren of the Trinity House made some experiments at Dungeness upon various fog signals. In June 1863 a Committee of the British Association memorialised the then President of the Board of Trade, with the view of inducing him to institute a series of experiments upon fog signals. The memorial, after briefly setting forth a statement of the nature and importance of the subject, described what was then known respecting it, and several suggestions were made as to the nature of the experiments recommended. The proposal does not appear to have been favourably entertained by the authorities to whom it was referred, and the experiments were not carried out.

In 1864 a series of experiments was undertaken by a Commission appointed by the Lighthouse Board of the United States, to determine the relative powers of various fog signals which were brought to the notice of the Board.

In 1872 a Committee of the Trinity House visited the United States and Canada, with the object of ascertaining the actual efficiency of various fog signals then in operation on the North American continent, about which very favourable reports had reached this country. Among other instruments, they witnessed the performance of a siren apparatus, patented by Messrs. A. & F. Brown, of New York. One of these instruments was, in 1873, very kindly sent to the Trinity House by the United States authorities, and tested with other instruments in the experimental trials at the South Foreland in 1873–74. This investigation was carried out at the South Foreland by the Trinity House, with the object of obtaining some definite knowledge as to the relative merits of different sound-producing instruments, and also of ascertaining how the propagation of sound was affected by meteorological phenomena. These experiments were extended over a lengthened period, in all conditions of weather, and the well-known scientific and practical results obtained, together with the ascertained relative merits of sound-producing instruments for the service of the mariner, are of the highest scientific interest and practical importance.

The investigation at the South Foreland was followed up by the Trinity House by further experiments, in which they were assisted by the authorities at Woolwich, with guns of various forms, weight of charges, and descriptions of gunpowder. The powders tested were (1) fine grain, (2) larger grain, (3) rifle large grain, and (4) pebble. The result placed the powders exactly in the order above stated; the fine grain, or most rapidly burning powder, gave indisputably the loudest sound, while the report of the slowly-burning pebble powder was the weakest of all. Experiments were also made with the object of ascertaining the relative value of the sound produced by the explosion of varying quantities of gun-cotton. Here again the greater value of increased rapidity of combustion in producing sound was clearly demonstrated. It was found that charges of gun cotton yielded reports louder at all ranges than equal charges of gunpowder, and further experiments proved that the explosion of half-a-pound of gun-cotton gave a result at least equal to that produced by 3 lbs. of the best gunpowder.

These results led the Trinity House to adopt this explosive as a fog signal for isolated stations on rocks or shoals where previously, from want of space, nothing better than a bell could be applied. It is also applied with success to light-vessels. But, wherever the siren can be installed, it is found to be the most efficient fog signal yet known, chiefly in consequence of the prolongation that can be given to its blasts, and the ease with which it can be applied, with any amount of motive power available, to the production of any desired combination of high and low notes for distinctions corresponding with those of white and red, or short and long, flashes of light, and thus affording the required individuality of each station. The experience, however, with the most powerful fog signal is not at present to be considered altogether satisfactory. With siren blasts absorbing about 150 H.P. or nearly 5 millions of foot-pounds per minute during the time they are sounding, the signal is occasionally not heard, under some conditions of fog and wind, beyond one mile, while at other times it is distinctly heard above ten miles.

For marking shoals, channel fairways, and landfalls, in positions where it is found to be impossible to erect a permanent structure, important service is rendered to the mariner by light-vessels. The first of these aids to navigation was moored at the Nore in 1732. Her illuminating apparatus consisted of a small lantern provided with flat wick oil lamps, the latter unaided by optical apparatus of any kind. In 1807 the late Mr. Robert Stevenson, the eminent engineer of the Bell Rock Lighthouse, designed a larger lantern to surround the mast of the vessel, capable of being lowered down to the deck for trimming the light, and raised when required to be exhibited. With the introduction of the catoptric system of illumination on shore, these lights were improved by the introduction of Argand burners, aided by paraboloidal silvered reflectors, each reflector and lamp being properly gimballed to insure the horizontal direction of the beam during the pitching and rolling of the vessel.

In 1872 the Trinity House increased the dimensions of their lanterns and reflectors for floating lights, the lanterns from 6 feet to 8 feet in diameter, with cylindrical instead of polygonal glazing, and the reflectors from 12 inches to 21 inches aperture, which improvements effected a tenfold increase in the intensity of these lights. The present 8-foot cylindrical lanterns are just large enough to admit of the lamplighter entering them to manipulate the lamps. Further improvements have lately been made in the lamps, and some of these lights have an intensity in the beam of about 20,000 candles. In 1875 the first group flashing floating light, showing three successive flashes at periods of one minute, was exhibited from a new vessel moored at the Royal Sovereign Shoal, off Hastings. Since the above date this class of floating lights, showing two or more flashes in a group, has been considerably extended with advantage. In connection with this class of distinctive lights, I would here remark that, in the following year, a 1st Order Dioptric Double Flashing Light Apparatus, designed by Dr. John Hopkinson, F.R.S., for the Trinity House, and intended for the Little Basses Lighthouse, Ceylon, was exhibited at the Special Loan Exhibition of Scientific Apparatus at South Kensington. In a few cases the dioptric system has been adopted for light-vessels; but, so far, the catoptric system has been found to be most efficient for the special circumstances of a floating light. Up to the present, neither electricity nor gas has been tried as an illuminant for light-vessels, but an interesting experiment is now being made by the Mersey Docks and Harbour Board, with the electric arc light on board one of the light-vessels at the entrance to the Mersey.

The difficulties attending the maintenance of an efficient floating light in some of the most exposed positions are great, and at times the service is a very arduous one to the men on board, yet any failure whatever is of very rare occurrence, and there is no instance on record of a British light-vessel having ever been deserted by her crew during a storm. Collisions, which unfortunately are of frequent occurrence, are probably the greatest source of danger to these vessels and their crews.

As it is a necessity that light-vessels remain at their stations with safety and efficiency as long as possible, usually seven years, they are generally built of wood, or are of composite construction, fastened and sheathed with Muntz metal. A few vessels have been built of iron, but these are found at the end of one or two years to require removal from the station, docking, and the external submerged portions of the hull cleaned and painted.

Chinese gongs about two feet in diameter, sounded at short intervals, have been for many years the recognised standard fog signal of light-vessels, owing probably to their peculiar characteristic sound. This signal is undoubtedly distinctive and serviceable at very short distances, but, like the sound of a bell, is soon dissipated after leaving the immediate vicinity of the instrument.

Many of the light-vessels of this country and other maritime nations are now provided with powerful sirens or whistles, sounded by compressed air or steam. Their positions (generally at considerable distances from the shore, and in some instances in fairway channels, where the sound is radiated on all bearings) are, from the uncertainty of the range of fog signals, found to be more efficient aids to navigation than those installed at shore stations.

The question of utilising lighthouses and light-vessels as signal stations in telegraphic communication with each other, and connected with a central station for reporting arrivals, departures, casualties, and meteorological observations, has, for some time, received the consideration of lighthouse authorities generally, and among the foremost in this direction as regards lighthouses may be mentioned Canada, which has a large proportion of them so arranged. In Ireland the experiment is being made at Fastnet, a well-known exposed rock station off Cape Clear, where considerable difficulties have been experienced in defending the cable from the enormous wear and tear to which it is subjected at the submerged side of the rock.

During the past year experiments have been in progress by the Trinity House, and I believe also by Germany, in the more difficult task of establishing telegraphic communication between a light-vessel and the shore. Off the coast of Essex the Sunk light-vessel has been so connected with the Post Office at Walton-on-the-Naze, through nine miles of cable; and, although many difficulties are being experienced, and the system must prove costly, ultimate success is expected.

Very important accessories to lighthouses and light-vessels are buoys and beacons. Besides indicating the navigable channels on the coast, in estuaries, and in rivers, in positions where the erection of permanent beacons is frequently impracticable, they mark the position of rocks and shoals. History appears to be silent as to the origin of the first buoy. Probably the piece of wood or cork for buoying and marking the position of the fisherman's net led to the primitive rude buoy for marking a dangerous shoal. Buoys built with staves of wood, and banded with wrought iron hoops, have been adopted for probably over a century, and are still used by all maritime nations; but they are being rapidly superseded by buoys constructed of iron or steel. In 1845 the first iron buoy was submitted to the Trinity House by the late Mr. George W. Lenox, and since that date very great improvements have been effected in the forms and construction of buoys generally, owing to the ease with which any desired forms and dimensions can be produced in iron and steel, as in shipbuilding. A very important improvement was introduced in iron buoys in 1853 by the late Mr. George Herbert, of the Trinity House, who suggested the raising up and hollowing out the bottom of buoys to about the level of the plane of flotation, and the attachment of the mooring chain at a point very near, but just below, the centre of gravity; he thus secured a more uniformly erect position of the buoy in a seaway and strong tidal current. The Herbert form of bottom is now generally adopted. Water-tight bulkheads were early employed with iron buoys for ensuring their safety. A modern iron or steel buoy may be, and often is, cut into by the stem of a steam-vessel, or by her screw-propeller, but is seldom caused to sink, its flotation being maintained by an uninjured water-tight compartment. The immunity from sinking, under such circumstances, of these iron or steel floating bodies, with their heavy iron mooring chain attached, is suggestive of an important requirement of the present day, viz., an unsinkable passenger steam-vessel. In the interests of humanity, no more important question than this could engage the attention of engineers, and certainly none more deserving of the best efforts of modern mechanical science. With the rapid increase in the number of buoys throughout the world, it has been found desirable, if such a result could possibly be accomplished, that something approaching to a universal system of distinctive individuality in these sea-marks should prevail; and, in 1883, a Conference was held at the Trinity House, under the presidency of H.R.H. the Duke of Edinburgh, K.G., Master of the Corporation, at which were represented the Board of Trade, the Commissioners of Scotch Lights, the Commissioners of Irish Lights, the Admiralty, and the local authorities of the Tyne, Tay, Clyde, Mersey, Thames, and Humber. The Conference met on several occasions for deliberation, and for obtaining evidence from witnesses serving in various capacities in the royal navy, mercantile marine, and lighthouse and pilotage service. Valuable information was also obtained from all the principal maritime States. Inasmuch as the need for uniformity of system was found not to be particularly pressing until the number of buoys had become considerable, its adoption became, by the same fact, more difficult, owing to the number of changes it would involve. The first conception of the object to be attained by a buoy was one rather of warning than of guidance, to indicate the hidden danger rather than to point out the path of safety. Both these services to navigation are at present very efficiently rendered.

Originally, one buoy to a shoal was thought sufficient; by degrees a second and third was demanded and laid, until each danger became hedged round with buoys whose names denoted their positions with reference to it. The Committee arrived at the conclusion that, if practicable, a uniform plan was to be desired, and they considered its application first in regard to harbours, rivers, and estuaries, and, secondly, to general coast navigation. As a preliminary, it was found to be necessary to determine the nomenclature of the various shapes and features common in all our buoyage services, so that the same thing should not be called by different names in different parts of the kingdom, as had previously been the case. The process of deliberation and inquiry led to the issue, that, with a uniform system, its fundamental principle must be that one certain shape shall be used for starboard and another for port invariably. The two forms most convenient for adoption as contrasting shapes were found to be the 'conical' and the 'can'; and, further, that middle grounds occurring in a channel, or which may divide two channels, should have at each end a spherical buoy; also that outlying dangers or positions requiring an extraordinary mark should be indicated by pillar or spar buoys. Considering, first, the application of a system to harbours: if all were approached by a single deep-water channel, the adoption, say, of 'can' for starboard and 'conical' for port, would appear as simple and practicable, but when large estuaries having four or five channels of approach have to be dealt with, some distinction other than mere shape is necessary. Important evidence was received by the Committee on the wider question of coast buoyage in outlying roadsteads, highways of navigation rather than approaches to any port, where warning is the first necessity, then guidance, and where the limitations of shape acceptable in the case of harbours might prove an injurious restriction unless a conspicuous mark in the open sea were required.

The primary distinction of form having been determined, the Committee proceeded to the deliberation of the subordinate or particular distinctions of colour, surmounting beacons, names, numbers, letters, &c.

With the uniform system, which is now being rapidly adopted throughout England, Ireland, and Scotland, an important step has been taken towards identity of practice throughout the whole maritime world.

In 1878 the successful illumination of buoys was accomplished by Messrs. Pintsch, with compressed oil gas, and since then the system has been very considerably developed in this country and abroad, and thus these important aids to navigation are being rendered efficient by night as well as by day, thereby becoming more perfect accessories to lighthouses and light-vessels. The Pintsch gas buoys now in use are found to burn continuously for three to six months, according to size, without any attention. Neither oil nor electricity has yet been successfully applied to the lighting of buoys, but there now appears to be no reason why electricity from storage batteries should not be found efficient for the purpose, at a reasonable cost.

Automatic bell buoys, of various designs, and the Courtenay automatic whistling buoy are found to render important aid to navigation in fogs, but, unfortunately, none of these apparatus have at present that reliability which should be characteristic of a coast signal, and all such buoys should be used with caution, owing to their action being dependent on the motion of the sea surface. The remedy for this defect is a problem which has yet to be satisfactorily worked out.

Until very recently a beacon was known to the mariner as a day signal only. Numerous structures, varying in form and dimensions, have for many years occupied prominent positions on shore and on rocks and shoals at sea, in all the maritime countries of the world, and some of these have been the work of considerable labour and cost. The iron beacon on the Wolf Rock, off the west coast of Cornwall, completed by the Trinity House in 1840, and which in 1870 was replaced by the present lighthouse, required, before the days of steam tenders, five years to erect, and cost nearly 11,300*l.* The recent successful lighting of beacons with automatic apparatus, in occasionally inaccessible positions, by electricity, compressed mineral oil gas, and petroleum spirit, forms an important epoch in the history of lighthouse illumination. In 1884 an iron beacon, lighted by an incandescent lamp and the current from a secondary battery, was erected on a tidal rock near Cadiz. Contact is made and broken by a small clock, which runs for 28 days and causes the light to show a flash of 5 seconds, followed by a total eclipse of 25 seconds. The clock is also arranged for eclipsing the light between sunrise and sunset. The apparatus is the invention of Don Isas Lavaden.

In 1881 a beacon, lighted automatically by compressed oil gas, on the Pintsch system, was erected in the river Clyde, and many other such structures have been erected in this country and the United States. In 1881–82 several beacons, lighted automatically by petroleum spirit on the system of Herr Lindberg and Herr Lyth, of Stockholm, were established by the Swedish lighthouse authorities, and are reported to be working efficiently. Last year a beacon lighted on this system, and another lighted by Pintsch's compressed gas, were erected by the Trinity House on the banks of the Thames, near Erith, and are found to be very efficient aids for the navigation of the river by night as well as by day. The petroleum spirit lamp burns day and night at its maximum intensity, and shows a white light with a short occultation at periods of five seconds. The occultations are produced by a screen, rotated around the light by the ascending current of heated air from the lamp acting on a horizontal fan. As there is no governor, the periods of occultation are subject to slight errors, but the gas beacon, which shows a white flashing light at periods of two seconds, is provided with a clock (specially designed for this beacon), which not only regulates with precision the flashes and eclipses, but also extinguishes the light a few minutes before sunrise and re-lights it just before sunset, a very feeble pilot light being left burning during daylight. Arrangement is made in the clockwork for a bi-monthly adjustment to meet the lengthening or shortening of daylight. These two lighted beacons are in the charge of a boatman, who visits them at least once a week, when he cleans and adjusts the apparatus, and cleans the lantern glazing. These systems of lighted beacons are not yet sufficiently matured for forming a decided opinion as to their relative efficiency and economy, but it may be considered certain that they will both be extensively adopted, because, in numerous cases, for the secondary illumination of ports, estuaries, and rivers, automatic lighted beacons can be installed to meet fairly the local requirements of navigation, at a fraction of the first cost and annual maintenance of a lighthouse with its keepers and accessories.

In 1881 it was considered by the lighthouse authorities of this country that the time had arrived when it was absolutely necessary that an exhaustive series of experimental trials should be made, on a practical scale, for the exact determination of the relative merits (both as regards efficiency and economy) of the three lighthouse illuminants, electricity, gas, and mineral oil, which, by the process of natural selection, may be regarded as the fittest of all those at present known to science. After many unforeseen difficulties had been overcome, this question of universal importance was, in July 1883, referred by the Board of Trade to the

Trinity House, who accepted the responsibility of carrying out the investigation.

A Committee was formed of members of the Corporation, who secured the friendly co-operation of the Scotch and Irish Lighthouse Boards, and many distinguished scientific men at home and abroad. I had the honour of acting, in my official capacity as Engineer-in-Chief to the Trinity House, in making the arrangements for exhibiting the experimental lights, and in reporting to the Board from time to time, as in all other matters referred to me professionally.

These investigations were carried out in full view of all who were in any way interested in the subject. The whole arrangements were open to public inspection, and, in their desire to arrive at a wise and just decision on so important a question, the Trinity House Committee courted the fullest inquiry. Many members of scientific societies, especially those connected with engineering, were invited, and visited the station. The French lighthouse authorities, who rendered much kind assistance in obtaining observations, sent their representatives to view the arrangements, and officers from the lighthouse services of Germany, Denmark, Norway and Sweden, Russia, Italy, Spain, Brazil, the United States, and Canada visited the station and witnessed the experiments.

In order to obtain, with uniformity and method, a consensus of comparative eye-measurements—in addition to the measurements of the Committee and their officers at their different stations ashore and afloat, to those of the coastguard men at nine stations between Dungeness and the North Foreland, and to the more precise scientific measurements of the experts—special observation books were prepared and widely distributed to shipping associations and port authorities, with a view to their securing the co-operation of masters of vessels, pilots, and others navigating in the vicinity of the South Foreland.

The South Foreland Station is especially adapted for lighthouse experiments generally, because of the existing facilities for observations on land and sea. The land in the neighbourhood has no hedges and few trees, and affords facilities for observations at distances of between two and three miles. The station is provided with surplus steam power for driving experimental machines for electric lights, and it is easily accessible from London.

Three rough timber towers of sufficient strength to withstand, without tremor, the effects of heavy gales were erected at the rear of the High Lighthouse, 150 feet apart. These towers were marked in large letters A, B, and C. A tower was devoted to electricity, B to the gas system of Mr. Wigham, and C to such gas or oil lamps as might be proposed to, and approved by, the Committee for trial during the experiments. A lantern of the usual first-order dimensions, but with an additional height in the glazing for the passage of beams from superposed optical apparatus of the first order, was provided for each tower. The optical apparatus in each lantern was, in the outset, special in relation to the illuminant to be used for producing fixed and flashing lights. For the electric arc lights, optical apparatus of the second order of Fresnel was adopted, the apparatus having a focal distance of 700 $^{m}/_{m}$. The dimensions of this apparatus are greater than optically required for the largest electric arc light yet tried for lighthouse illumination, but the internal capacity is found to be only just sufficient for the perfect manipulation of the light by a lightkeeper of possibly robust build. For the large gas and oil flames in the A and C lanterns the apparatus adopted was of the usual first-order size, having a focal distance of 920 $^{m}/_{m}$.

The lanterns were partially glazed on opposite sides, north and south, the southern arc being chiefly for observation from the sea. To the northward the land is better adapted for observations on shore, and here three observing huts were erected at the respective distances of 2,144, 6,200, and 12,973 feet; each hut was provided with accommodation for two watchers, and a chamber fitted with a large plate glass window in the direction of the experimental lights, and special apparatus for their photometric measurement. The third hut proved to be practically of but little value for photometry, the distance being too great; it, however, afforded an accurately known distance for eye-measurements, and a barrack and starting-point for watchers endeavouring to determine the vanishing distance of each light during hazy weather. In this they were further assisted by white painted posts, placed throughout the whole track to the experimental lighthouses, at distances of 100 feet apart, the distance of each post from the lights being plainly marked on it in black figures. For the more exact examination and measurements of the intensity of each luminary and that of the beam from each optical apparatus, a photometric gallery was erected in a convenient position, 380 feet long by 8 feet wide, and provided with all the necessary appliances.

During a period of over twelve months the experimental lights were exhibited, and watched by numerous observers, trained and untrained, scientific and practical. During that period a vast amount of valuable evidence was collected; by the aid of which the Committee were subsequently enabled to state their conclusions with definiteness. During these investigations intensities were shown in a single oil and gas luminary about three times greater than the electric arc luminary first adopted at Dungeness in 1861, while, with a single electric arc luminary, there was shown a practically available focal intensity about fifteen times greater than that of the Dungeness luminary, and the highest yet shown to be practically available for the service of the mariner.

With gas and oil the highest intensity of a single luminary and optical apparatus was tripled by the use of three superposed luminaries and optical apparatus, and although optical arrangements were made for triple electric luminaries, and experiments were carried out with these at comparatively low intensities, it was soon found that all the electro-motive force available at the station could be conveniently applied with efficiency and permanency in one compact focal luminary, and its optical apparatus. This fact demonstrated that the electric arc has the most important requisites of a lighthouse luminary; viz., maximum intensity and minimum focal dimensions, and in all states of the atmosphere, from clear weather to thick fog, an incontestable superiority over the utmost accumulative efforts of its rivals—gas and oil. It was therefore considered to be unnecessary to incur additional cost for exhibiting the electric arc light, under the same conditions of accumulative powers as its rivals, for showing a maximum intensity. With the best gas and oil luminaries it was found that, where gas of the ordinary commercial quality is employed, there is no appreciable difference, either in the intensity or focal compactness of the luminary, but when the richest gas, from cannel coal, and mineral oil are used, there is found to be a superiority in the maximum intensity of this luminary over oil of about 45 per cent., and in focal compactness of about 10 per cent.; but in haze and fog, when the maximum intensity only is required, this difference was found to effect no appreciable gain in penetrative power, therefore the question of merit between these illuminants was found to resolve itself into one of economy only, and in this respect mineral oil at the present market prices was found to have a considerable advantage.

The relative penetrability per unit of light of the best gas and oil flames in haze and fog is so nearly identical that the question is of no practical importance in lighthouse illumination. But, with regard to the relative atmospheric absorption of these lights and the electric arc light in certain impaired conditions of the atmosphere, the electric arc light is found to compare somewhat unfavourably. The general result of the photometric measurements of the three illuminants showed (1) that the oil and gas lights, when shown through similar lenses, were equally affected by atmospheric variation; (2) that the electric light is absorbed more largely by haze and fog than either the oil or the gas light; and (3) that all three are nearly equally affected by rain. Experiments, made in the photometric gallery at the South Foreland with the electric arc light, have shown that the loss by atmospheric absorption is by no means so great as was previously supposed. It would have been most interesting and instructive to have obtained data for exactly determining the relative coefficients of atmospheric absorption of the electric arc, gas, and oil luminaries, but the necessary observations and measurements for effecting this would have prolonged the time too much, and added too much to the cost of the investigation, especially when it is remembered that with the electric arc light there is for coast illumination such an enormous preponderance of initial intensity at disposal that a small percentage of penetrating efficiency is of no practical importance.

In 1836 Faraday showed by actual experiment that the penetrating power of a light in atmosphere impaired by such obstruction as fog, mist, &c., is but very slightly augmented by a very considerable increase in the intensity, and M. Allard, late Engineer-in-Chief to the French Lighthouse Board, has more recently shown, after long experimental and practical research, that, in an atmosphere of average transparency, a beam of light equal to 6,250 becs (Carcel) would penetrate 53 kilometres, yet when augmented to twenty times that intensity, or 125,000 becs (Carcel), it would only penetrate 7,540 kilometres; showing that, in the average condition of atmospheric transparency, 2,000 per cent. of increased intensity only gives 42 per cent. longer range.

The South Foreland experiments have demonstrated that, while with both gas and oil an ordinary intensity of light can be adopted for clear weather sufficient to reach the sea horizon with efficiency for the mariner, a maximum light can be shown with impaired atmosphere fifteen to twenty times this intensity, and that in these respects both illuminants are practically on an equality. This maximum light of gas and oil is considered by the Committee to be sufficient for all the ordinary purposes of navigation, and, for this, mineral oil is the most economical illuminant; but for some special cases, where the utmost intensity and penetration are demanded, these results can only be attained by electricity, and by this agent an intensity more than ten times that of the maximum of either oil or gas is found to be practically available.

With regard to the gas and oil lights, the report of the Committee states that: 'It appears from the direct eye observations, made at distances varying from 3 to 27 miles in clear weather, that through annular lenses, light for light, there is practically no difference. Both reach the horizon with equal effect. In weather not clear the records indicate practically the same relation. In actual fog, again, the records indicate a general equality of the lights. Both are lost at the same time, both are picked up together; and although here and there a very slight superiority is attributed to the gas, this superiority is of no value whatever for the purposes of the mariner.' A point referred to in favour of gas is the well-known one of greater handiness and ease of manipulation than oil, which is of importance for small beacon lights, where a constant attendant is not provided; but this does not apply to a coast light, where a light-keeper is always required to be on the watch in the lantern from sunset to sunrise. With oil the great advantage, in addition to economy, lies in the simplicity of its application to a coast lighthouse in any part of the world, however limited the space the lighthouse is necessarily required to occupy. The final conclusion of the Committee on the relative merits of electricity, gas, and oil as lighthouse illuminants is given in the following words:—'That, for ordinary necessities of lighthouse illumination, mineral oil is the most suitable and economical illuminant, and that for salient headlands, important landfalls, and places where a very powerful light is required, electricity offers the greatest advantages.'

In conclusion it may safely be asserted, now that the relative merits of electricity, gas, and oil have been accurately determined, that these investigations of the Trinity House Committee will, for many years to come, furnish to the lighthouse authorities of all maritime nations of the world, and their engineers, very valuable data which cannot fail to assist very largely in the development of lighthouse illumination, and thus tend very materially to the present aids to navigation, and to a consequent reduction in the loss of life and property at sea.

The following Papers were read:—

1. *On some points for the Consideration of English Engineers with reference to the Design of Girder Bridges. By* W. Shelford, *M.Inst.C.E.*, and A. H. Shield, *Assoc.M.Inst.C.E.*—See Reports, p. 472.

2. *Louisville and New Albany Bridge.*
By T. C. Clarke *and* C. Macdonald.

The paper confined itself mainly to a consideration of novel features in the superstructure of this cantilever bridge recently built by the Union Bridge Co. of New York over the Ohio River.

The structure consists of two main cantilever spans, 480 ft. and 483 ft. long respectively, from centres of piers, joined by a continuous span of 360 ft., two anchor spans of 260 ft. each, a swinging span 370 ft., and a fixed span at the New Albany end 240 ft. long, making a total length of 2,453 ft. between centres of abutment cylinders.

After describing a number of accompanying photographs, mention was made of the fact that, in consequence of the current in what is known as the 'Canal Channel' which passes under the 483 ft. span being at an angle of 60° to the axis of the bridge, it was thought necessary to construct skew piers for this span, with their faces parallel to the direction of current, the details being thereby much complicated.

Normally all river traffic passes under this span, but at high water the 480 foot span is used.

The several dimensions of the bridge, total width of which is 49 feet, were then given. Open hearth steel was employed in its construction, and, for compression members, sample bars $\frac{3}{4}$ in. in diameter were required to show an elastic limit of not less than 50,000 lbs. per sq. in., an ultimate strength of 80,000 lbs., elongation of 15 per cent. in 8 inches, and reduction of area at point of fracture of 35 per cent. The carbon ranged from 0·34 to 0·42 per cent., and phosphorus was under 0·100. Full-sized bars were allowed an elastic limit of 35,000 lbs., and ultimate strength of 65,000 lbs. The wrought iron plates had an elastic limit for standard sample bar of 24,000 lbs., ultimate strength of 47,000 lbs., elongation of 10 per cent., and reduction of area of 15 per cent.

The structure is designed to carry 1,200 lbs. per foot on the roadway and sidewalks as well as the following load on the railway—a train weighing 2,240 lbs. per foot drawn by two locomotives and tenders, weighing 356,000 lbs. together. Wind strains resist a force at right angles to the axis of 450 lbs. per foot of span on lower lateral system, and 150 lbs. on the upper.

In connection with the work of erection it was pointed out that the Ohio River is subject to extraordinary floods, when quantities of ice and drift are carried down by a current of more than six miles per hour. On one occasion during erection the river rose 57 feet in six days, and frequently to a height of 25 or 35 feet.

The work was commenced in the spring of 1885, and after a satisfactory series of tests had been made in June last the bridge was thrown open to the public.

The total weight of metal in the bridge is 6,000,000 lbs., or at the rate of 1·09 tons, or 2,446 lbs., per lineal foot.

3. *Freezing as an Aid to the Sinking of Foundations.* *By* O. Reichenbach.

After referring to the extended use that has been advantageously made of caissons as a means of founding the supports of bridges at great depths, especially in India over the Sutlej and Ganges, the author referred to the difficulties experienced when, adopting this method, obstructions or boulders are met with far below the surface, or where the piers are finally founded on rock of an uneven surface. Whereas piers have been founded at depths of 140 feet below water-level by this method, the pneumatic method, to which preference was given in the case of the St. Louis Bridge over the Mississippi, is limited in its application to depths of about 120 feet. An instance of well-sinking in 1862 by freezing the ground was mentioned. A method of sinking foundations was patented by Mr. F. Poetsch in 1883. It consists in freezing the water contained in the surrounding ground, and thus providing a watertight lining, which enables the necessary excavations to be carried out without difficulty. The author proceeded to give an account of the manner in which the process is carried out, by passing a freezing liquid down numerous bore-holes surrounding the ground to be excavated. After the freezing has been effected, the excavations are commenced and secured in the ordinary manner.

Several shafts through water-bearing strata, extending to a depth as great as 76 metres (250 feet), are enumerated as having been sunk in this manner; the cold is usually obtained by means of a Kroppf's (Carré) ammonia machine. The system is readily applicable in bridge-construction, and will at times obviate the necessity of using very large spans.

After discussing many practical points in regard to the application of the system, the author considered the question of cost, and gave a mathematical investigation of the cooling effect and time required for the operation, &c. Calculation shows that, to take an imaginary case, the freezing of the ground to sink a pier 60 metres below water-level, and 40 metres below the river-bed, and having a base 18 by 8 metres, would occupy 2,250 hours and require a cooling effect equivalent to 2,230 cubic metres (or tons approximately) of ice. About 2,900 cubic metres of ground would be frozen in the operation, the wall attaining a mean thickness of 2 metres.

4. *On the Laffitle Process of Welding Metals.*
By WILLIAM ANDERSON, *M.Inst.C.E.*

The author pointed out that in order to make a sound weld it is necessary that the surface of iron be free from oxide, and that the usual mode of approximating to this condition is to heat to the 'welding' heat—about 2,800° F. Such a high temperature, however, impairs the quality of iron and, to a far greater extent, of steel. Many qualities of steel cannot be welded.

In order to overcome these difficulties, powders, with borax as a basis, are generally employed.

With a view to overcome the difficulties experienced in spreading these powders evenly over surfaces, often irregular and of considerable extent, M. Laffitte has invented plates, usually consisting of very pliable wire gauze, on both sides of which the flux, being vitrified, is evenly spread. Paper may also be used as a support, and in the case of small surfaces it is often sufficient to form a sheet of the flux and metal filings agglomerated together.

After describing the method of preparing these plates and various modes of applying them, the author mentioned that they have a very extensive use in France for all branches of metal work, including fancy iron-work, and in the arsenals, gun factories, and on the railways, &c.

Tables were given showing the satisfactory results of severe tests made both in this country and on the Continent.

FRIDAY, SEPTEMBER 3.

The following Papers were read:—

1. *Furnaces for the Manufacture of Glass and Steel on the Open-hearth.*[1]
By JOHN HEAD, *F.G.S.*

The author first referred to the simple furnaces formerly used in the manufacture of glass and iron, to the special facilities of Birmingham in the possession of clay beds, iron and coal mines, as a manufacturing centre, and to the surrounding dis-

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[1] Published *in extenso* in *Industries*, September 1886.

trict being known as the Black Country, on account of the wasteful manner in which fuel was burnt. Of the many forms of furnace employed attention is mainly drawn to those of the reverberatory class, and figures illustrating the old forms used for melting, puddling, and re-heating iron and steel, and for the production of glass, were given.

The Rev. R. Stirling was mentioned as having originated, in 1817, the idea of a regenerative furnace when describing his regenerative caloric engine. He was followed by Mr. J. Slater in 1837, and by Mr. R. Laming in 1847, the former two employing solid coal and the latter gas made from coke. Mr. F. Siemens's invention, in 1856, differed from the suggestions previously made in the novel principle of heating both gas and air previous to combustion in the furnace, an arrangement that had never before been adopted or even proposed. Another feature introduced by the late Sir William and Mr. F. Siemens was the employment of a separate gas producer.

A reference was next made to the calorific power of carbon and carbonic oxide respectively, showing a loss of 30 per cent. by the employment of the latter, and to the composition of gases made in a gas producer, from which the author deduced the necessity for the use of gas regenerators in gas furnaces when economy and maximum temperature are desired.

The various types of the Siemens gas producers were next described and illustrated. In the earlier forms the gas evolved by distillation of coal passes at once through cooling tubes to the furnace; in the later forms the gas passes through heated channels, and is thereby rendered more permanent than before. One of these arrangements, moreover, may be modified, if desired, for the extraction of tar and ammonia from the hydrocarbons, which are for that purpose treated separately from the other gases leaving the gas producer.

The old form of regenerative gas furnace was illustrated and described; it was so arranged that the flame came into intimate contact with the materials on the bed of the heating chamber.

Before proceeding to a description of Mr. F. Siemens's radiation furnace, the method of making steel on the open hearth and glass-melting are described. The furnace being at steel-melting temperature, pig iron and scrap steel are charged, and, when melted, iron ore is added in small quantities until the metal boils, or, in other words, the ore reacts chemically upon the pig metal, some gases being thereby liberated. Afterwards it is tested for carbon, and when in a fit condition it is tapped, spiegel-eisen or heated ferro-manganese being added in small pieces while it is being run into the ladle.

Sand, lime, and alkalies, well mixed and pulverised, are employed in various proportions in the manufacture of glass. The 'batch,' as it is called, is melted in pots or tanks, fresh batch being added as required; a large proportion of gaseous matter is contained in the batch, which is liberated from the metal when 'fining' takes place, or when the metal is fused without contact of flame.

The continuous method of making glass invented by Mr. F. Siemens was described and illustrated. It allows of batch being charged and glass gathered simultaneously, the gathering being effected by means of floating vessels, containing two compartments, in the first of which the glass raised from the lower part of the mass becomes heated, and, increasing in density, sinks to the bottom and enters the second, from which it is gathered.

The author, having observed that more or less 'seedy boil' (or gaseous blowholes) were found in glass gathered at different gathering holes in a semicircular furnace, showed the plan of the furnace to Mr. F. Siemens, who at once inferred that the 'seedy boil' was due to the flame striking the 'metal.' He made experiments with a view to removing the defect, and eventually brought out his radiation furnace, described by him at the Chester meeting of the Iron and Steel Institute in 1884.

In this furnace the gas and air ports open at some distance above the materials to be treated, so that the flame does not come into contact with them or with the walls or roof of the furnace. In this way there is free development of the flame, resulting in great economy of fuel, an increased life of the furnace, improvement of the product, and a diminished loss of material. The author also referred to the importance of this mode of applying heat as preventing blow-holes in steel and 'seedy boil' in glass manufacture; a subject which he treated in detail in his paper before the Iron and Steel Institute in May last.

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2. *On American and English Railways in reference to Couplings, Buffers, and Gauge, with a suggested Improvement in Couplings.* *By* WILLIAM P. MARSHALL, *M.Inst.C.E.*

The railways of North America are of particular interest on account of their very great extent, amounting to nearly one half of the total railway mileage of the world. Their standard gauge is the same as in England, but there were formerly five other gauges in extensive use in North America, three of them larger than the standard, 5 ft., 5 ft. 6 in., and 6 ft., and two smaller, 3 ft. 6 in. and 3 ft.

In England two other gauges besides the standard 4 ft. 8½ in. were formerly in use, namely, 5 ft. and 7 ft., but the necessities of traffic, requiring through transit for passengers and goods without change of vehicle, have gradually led to the standard gauge being adopted all over the country (excepting a short length of 7 ft. gauge still remaining unaltered); and as much as 2,300 miles of railway have accordingly been altered in gauge in this country for this purpose. The same experience has been gone through in America, but on a very greatly increased scale, about 20,000 miles of railway having been altered at different times to the standard gauge; which is an amount as great as the total railway mileage of this country. A very remarkable case was that of the Southern States railways, which were originally all made 5 ft. gauge for the purpose of causing a break of gauge at the frontier of the Slave States; and the whole of these, amounting to 13,000 miles length, were altered simultaneously to the standard gauge on June 1st of the present year, the work of change having been in preparation for some years previously.

The standard gauge has now become so far universal as to include about 80 per cent. of all the railways of the world, the exceptions being about—

6	per cent. of	5 ft. 6 in.	gauge in	Spain, India, and part of South America.
5	,,	5 ft.	,,	Russia, in Europe and Asia.
3	,,	3 ft.	,,	North American narrow gauge.
2½	,,	5 ft. 3 in.	,,	Brazil, part of Australia, and Ireland.
2½	,,	3 ft. 6 in.	,,	Norway, Australia, Cape Colony, &c.
1½	,,	3 ft. 3⅜ in.	,,	Metre gauge in India, &c.

with some smaller amounts of other exceptional gauges.

The present general adoption of the standard gauge has been brought about simply from commercial reasons, and from the traffic objections experienced with break of gauge; but it has also to be noticed that this gauge, 4 ft. 8½ in., has the advantage of being applicable both to the cases of main lines with first-class traffic, and of light lines with inferior traffic or mountain character of line. Where, as in the case of India, a wider gauge has been adopted for the main lines, it has been found ultimately requisite to supplement this with a narrow gauge for the lines with inferior traffic, thus involving the serious evil of break of gauge; and the alternative view is strongly forced into consideration, that, if the standard gauge had been originally adhered to, it would have answered for both sets of lines, as the 'happy medium' for universal application.

In Australia, a country as large as the United States, there is a still worse case of break of gauge; one colony having the standard gauge, another 5 ft. 3 in. gauge, and the others 3 ft. 6 in. gauge; and the American experience forcibly suggests that the ultimate bringing of the whole to uniform gauge may be only a question of time. At all events, the striking fact stands that in America there has been already altered in gauge, for the purpose of obtaining uniformity, nearly as much as the whole present railway mileage of Australia and India added together.

In reference to buffers, on the American railways the striking difference is seen of single centre-buffers universally used, instead of the double side-buffers of this country and the Continent; and this is a point that calls for special consideration, because although centre-buffers are so unfamiliar in this country, they are really in the majority, as regards the length of railways upon which they are used, which include North America, great part of South America, Australia, and part of India.

The double side-buffers of this country are intended to transmit the shocks of buffing to the side sole-bars of the underframes; but in practice, on account of the frequent curves on the railways, the shocks of buffing are received mainly upon one corner only of the frame, with a tendency to strain the frame; with centre-buffers, however, the shock is always received at the same point of the frame, whether on a straight line or a curve. Any steadying action to the carriage in running derived from the contact of buffers at both sides, is also materially interfered with by the difference in pressure of the two buffers when upon curves; but with centre-buffers the hold of the buffer-faces for steadying action is continuous and independent of curves. A very important advantage in working is gained with centre-buffers, in the open and safe access to the couplings that is afforded, thus getting completely free from the obstruction of side-buffers which is so serious a source of accident to the men in the present English system; and this point is now made of still greater importance by the extensive use of continuous brakes, which require the coupling of brake air-pipes in the centre, in addition to the draw-bar couplings.

In the English carriage couplings there is not any provision against the telescoping of the carriages in a collision, which is the great source of injury in train collisions, the coupling being flexible vertically as well as horizontally; but the American carriage coupling most extensively used is rigid vertically, preventing displacement beyond a limited range, and it forms a provision for preventing one frame mounting upon the next one in a collision, and the consequent telescoping of the carriage bodies; this coupling has a strong metal bar projecting from the end of each carriage frame under the next carriage, which must be broken away before either carriage can mount. This coupling is automatic, and is worked by bumping the carriages together; the coupling jaws are wedged apart horizontally by the striking together of the projecting tapered ends, and then engage together by springing back to the central position. There is, however, no means of tightening up this coupling beyond the original compression of the buffers in bumping up; and although the carriages are usually held very steady in running, it happens not unfrequently, with the extra stretch of the draw-springs in a heavy train, that the buffer-faces get slack or even separated, allowing a side oscillation of the carriages, which cannot be checked, and which is a serious defect in this coupling. The very severe bumping blow that is required with this coupling is also particularly objectionable to the passengers.

The American wagon couplings are made by a link with a drop-pin, the link passing through an opening in the centre of each buffer-head, and the link is long enough to allow the required amount of slack between the buffers; the buffers are made with a combined buffing- and draw-spring. The great defect in these American couplings is that the carriage and the wagon couplings, instead of being completely interchangeable, as in English practice, are so entirely different that the coupling of a carriage to a wagon is only effected by an unsatisfactory make-shift; the projecting end of the carriage coupling-bar has a slot and pin-hole for attaching the wagon coupling link, but the only buffing provision then left is the pointed end of the carriage coupling-bar striking against the curved wagon buffer-face, the carriage buffer being at a different level above.

The English screw-coupling seems the most efficient means of tightening up the couplings of carriages, as it provides for giving an equally tight coupling with variations in the length between the carriages; but this efficiency only lasts complete whilst the train is standing, and in running it is seriously impaired by the stretching of the draw-springs, which is often so great in the forward portion of a heavy train as to leave the buffer-faces quite slack or separated. A perfect coupling requires to be quite independent of the pull, and to retain its original tightness under all circumstances; and this is only practicable with a solid coupling having no draw-spring. Now the present carriage draw-springs have really but little action in easing the starting of a train, being screwed up so tight that the whole train is started practically simultaneously; but with goods trains the case is different, the weight there to be started is so much greater that slack couplings are required in order to enable the engine to start the train in successive portions, and then draw-springs are requisite for easing the snatch upon each slack coupling-chain. The use of carriages without draw-springs and with centre-buffers has been already effected in this country, having been introduced on the Brighton line, and been worked satisfactorily there for many years on suburban trains that are not required to couple with ordinary carriages.

Automatic couplings of different kinds with centre-buffers are used in several countries, and various modifications of what is known as the 'Norwegian hook' are extensively used, in which the coupling-hook moves vertically, instead of horizontally as in the American carriage coupling, and on bumping the vehicles together the hook rises, and falls again into place by its weight. These couplings have, however, the defect of not having any means of tightening up to steady the carriage against side oscillation; and this objection has been met by introducing a cam movement on a tightening lever, and by a screw to tighten up the pin upon which the hook catches; but these plans involve the objection of not being in duplicate at the two ends of the carriages to allow of coupling indiscriminately.

Automatic coupling, although at first naturally appearing the most correct system, is found to involve in practice the sacrifice of other points that are of importance; and it has to be borne in mind that the desire for automatic couplings has arisen in this country mainly from the existence of the side-buffers and the dangerous obstruction that they cause in the access to the couplings. It becomes then a question for consideration whether an automatic coupling is really required, or whether a satisfactory solution of the question can be obtained by other means; and with the view of aiding in this matter the following suggestion is now offered for an improved coupling:—

In the proposed carriage coupling a screw-coupling is used as at present, but is attached to a rigid draw-hook on each carriage without any draw-spring, and placed just below the centre-buffers. The buffer-heads are coupled together by a link with drop-pin, in the centre of each buffer-face (as in the American wagons); and this link, which is of a strong square section, prevents either buffer rising beyond the limit allowed for variation in height of the carriage frames, and prevents any mounting of one frame upon the other, and telescoping of the carriages. In the act of coupling up, the screw-coupling is first hitched on to the draw-hook as usual and screwed up, and the buffer-link is then coupled, and takes the place of the present safety-chains.

In the proposed wagon coupling the coupling-chain is hitched on to a draw-hook as at present on running the wagons together; but this draw-hook is rigid without any draw-spring, and takes the place of the present safety-chain. The centre-buffers above this coupling-chain are then coupled by a link with drop-pin as in the carriages, only this link is made long enough to allow the required extent of slack between the buffer-faces; the buffers are made with a combined buffing and draw-spring as in the American wagons. In the proposed arrangement both for carriages and wagons, the two ends of each vehicle are kept duplicates, as in the present English practice, so that either end of any carriage can be coupled to either end of any other carriage or wagon.

In conclusion, it was suggested that the objects to be aimed at in the couplings and buffers of railway vehicles, are—

Central position for all connections between the vehicles.
Prevention of telescoping by having a rigid connection vertically.
Exact correspondence between carriages and wagons for mixed coupling.
Duplication of both ends of the vehicles in the couplings.
Avoidance of the shock of bumping carriages together for coupling.
Second safety coupling besides the main coupling for all vehicles.

It was suggested that these objects can be best obtained by a combination of the English and the American systems, selecting for this purpose the best points of each; this has been attempted in the plan here proposed, which can be applied as an addition to the present English stock, and worked in combination with the present couplings and buffers.

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3. *Hydraulic Attachment to Sugar Mills.*[1] *By* DUNCAN STEWART.

The object of this paper was to explain the application of hydraulic pressure to the rollers of sugar-cane crushing mills and their connection with a loaded accumulator giving the power to the planter or his manager to regulate the crushing of the canes to a pressure which will be known to him or them. In this arrangement the percentage of juice can be extracted equal on all the canes passing through the mill, whether the feeding be regular or not.

It will also act as a safety-valve on the working of the engine, gearing, and mill, and will not only allow the engineer to proportion the various parts of the plant to certain strains, but to scheme mechanical arrangements for feeding the mill which have hitherto been done by manual labour.

It will crush with such regularity that the megass may be used as fuel at once. The saving in money, besides the freedom from liability to breakage, has been reckoned at 20*s.* per ton of sugar made, and it is now at work in more than fifty sugar estates and factories.

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4. *Forced Draught.* *By* J. R. FOTHERGILL.

Forced draught, or mechanically supplying air above atmospheric pressure to the furnaces of steam boilers, has been the subject of many patents during the last fifty years, but it is only within the last two or three years, particularly in its application to merchant steamers, that practical success has been achieved.

The writer views the 'closed ash-pit' system as the best for merchant steamers.

After reviewing the chemical composition of average British steam coal and the oxygen required for the chemical combustion of its consumable constituents, the writer gave the quantity of air required at 62° Fahr. for 1 lb. of coal as follows:—

For the volatilised gases	50 cubic feet.
For the fixed carbon	90 ,,

or a total of 140 cubic feet, equal to 10·7 lbs.

In actual practice 22 to 24 lbs. of air are required, but with forced draught judiciously applied 16 to 18 lbs. prove sufficient; therefore the reduction of furnace temperature and loss of heat carried away by the use of 24 lbs. of air are avoided and a saving effected in proportion.

By the use of forced draught we are enabled to regulate the distribution of the air at will and by supplying the requisite quantities to the gases and fixed carbon we readily bring about the chemical union of the oxygen with the carbon to produce carbonic acid, giving 14,500 heat units, instead of only 4,400 by the formation of carbonic oxide.

The writer then proceeded to show in what manner and how the air supply should take place, pointing out the defects and difficulties in the regulation and distribution of air to the furnace under the ordinary conditions of natural draught.

In September 1884 the writer applied forced draught to the boiler of the s.s. *Marmora*, which steamer ran eleven consecutive voyages of sixteen days' steaming per voyage before she was wrecked, with a saving per voyage of 33*l.* 16*s.* 7*d.*, equal to 43 per cent. in the cost of the bunker coals, as compared with eleven voyages prior to the alteration.

Drawings in plan and section illustrating the arrangement fitted to the *Marmora* were shown and a general description given of the arrangement, indicating particulars as to the air admission and distribution, water-gauge pressure, grate area, and the necessity of a damper in the funnel, &c.

Utilising the heat of the waste gases to increase the temperature of the air

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[1] Published *in extenso* in *The Sugar Cane,* Dec. 1886.

supplied to the furnace unquestionably is a distinct saving, but the writer is of the opinion the cost of fitting an arrangement for such purpose when altering a boiler to forced draught will exceed the saving gained. When new boilers are supplied the increased cost will, however, probably be only small.

The application of forced draught to the *Marmora* proved so economical that it was decided when ordering the s.s. *Stella*, a steamer of 3,800 tons, having triple expansion engines, to apply forced draught to the boilers, which are subject to a pressure of 143 lbs.

Messrs. Wyllie & Morison's patent system was applied and the results have proved most successful.

The writer believes the *Marmora* was the first instance in which forced draught on the 'closed ash-pit' system was applied to a boiler which had been for some time in use under the ordinary conditions of natural draught, and ran the same for eleven consecutive voyages with considerable success, and he likewise believes the *Stella* is the first instance of a triple expansion engine having the boilers fitted with forced draughts.

5. *The Domestic Motor.* *By* HENRY DAVEY, *M.Inst.C.E.*

The Domestic Motor is really a steam engine working with negative pressure only, and therefore explosion is impossible. It is automatic in all its functions, and may therefore be left without an attendant for a considerable length of time.

There are two forms of the motor—one in which the engine and boiler are on one casting, the other in which the boiler is separate and made to contain from six to eight hours' supply of coke. This latter form has been specially designed for electric lighting purposes.

The engine part of the motor consists of a cylinder, piston and slide valve, similar to those of an ordinary steam engine.

The exhaust from the cylinder is discharged into a surface condenser consisting of a series of wrought-iron tubes. The condensed steam and air from the surface condenser are withdrawn by means of an extremely simple form of air-pump, discharging into a small water pocket, from which the water again enters the boiler, so that the water used for raising steam is used over and over again, thereby preventing a deposit in the boiler.

Any waste arising from leakage is automatically supplied from the condenser.

All the functions of the motor are automatic, except the firing, and the fire in the separate boiler type only requires attention once in from six to eight hours. The fuel used is gas coke. It has been found by careful experiments with the motor that the consumption of coke is from 6 to 7 lbs. per brake horse-power per hour in the self-contained type, and very much less in the separate boiler type. In general construction it is very similar to the boiler sometimes used for heating conservatories. The boiler contains a large vertical column of coke, which burns at the bottom, the coke above falling down by its own weight. As the bottom portion is burnt away, the weight of the column crushes the ashes through the spaces between the fire-bars, and the combustion is thereby maintained continuous. The column of coke is made sufficiently large and sufficiently high to keep up a constant rate of combustion for, say, six or eight hours.

It will be interesting here to notice that the total efficiency of the heating surface of the boiler is greater with this mode of firing than with any other. It has generally been well known that the fire-box of a locomotive boiler does by far the greater portion of the work in raising steam. The boiler under notice has no heating surface, except that of the fire-box, but the fire-box is so constructed that a great portion of the heat of the spent gases is trapped by the green fuel which is approaching the condition of combustion in the fire-box. So completely is the waste heat utilised that it is possible to put one's hand into the top of the boiler and take out lumps of coke, even when the coke is nearly half way down in the fuel space.

The author has not had time to make careful quantitative experiments as to the value of the heating surface and the economy of this kind of boiler, but he is convinced from general observation that it is far more efficient and economical than the ordinary form. One great reason lies in the fact that the heat is all imparted to the boiler surfaces by direct contact of solid fuel, or radiated from the solid fuel which is almost touching the plates. It is the author's intention to carry out careful experiments with this form of boiler.

6. *The Compound Steam Engine.*[1] *By* J. RICHARDSON.

After a brief introduction defining what is meant by a compound engine, and stating how the economy of one kind over another should be measured, the paper dealt with the various steps in the development of the steam engine so far as steam economy is concerned, and traced its progress up to the present date, giving illustrations of engines using low pressures non-expansively and expansively, high pressures non-expansively and expansively, and showing the use and value of the steam jacket and separate condenser. It was stated that though there is no theoretical limit to the economy to be obtained by extremely high degrees of expansion, yet there are practical limits which are soon reached for non-condensing engines. In these the steam must not be expanded below the atmospheric pressure, or back pressure and waste of power is the result. To prevent this a very high initial pressure must be used, and as with 140 lbs. boiler pressure, or 155 lbs. absolute, steam expanded ten times leaves only half a pound pressure in the exhaust, this is fixed upon as practically the most useful degree in non-condensing engines.

Reference was made to the use of steam at much higher pressures—500 lbs. and upwards—and used in three or more cylinders; yet the difficulties attending the production of steam at these high pressures and temperatures and the maintenance of the working parts of the steam cylinders are stated to be such as more than counterbalance the advantages to be obtained from their use.

It could be shown that expansion could be carried to such an extent that while the efficiency of the steam, considered merely as steam, would continue to be increased, a point would be reached at which it would be barely able to move the piston it was intended to propel, and when, therefore, the engine in which it worked would be practically useless.

A comparison was instituted between the single cylinder expansive engine and the various classes of compound, namely, those which have the low-pressure cylinder parallel with the high as in the Woolf engine, on the same centre line as in the tandem, and those with cranks at right angles, the advantages and disadvantages of each type being pointed out. The proportions to be maintained between the two cylinders were next considered, and the advantage of the intermediate receiver and heater were referred to; the advantage of expansion gear to the low-pressure cylinder, not merely for the purpose of securing greater economy, but also for the sake of securing uniform distribution of the load between the two cylinders, was pointed out. Illustrations and diagrams of the earlier types of engines were given, and indicator diagrams showing different methods of distributing steam, together with large diagrams showing modern tandem compound horizontal engine, coupled compound horizontal, and coupled compound with locomotive boiler combined, as well as details of the valve gear of each, and the method of automatically regulating the supply of steam.

The compound engine as now constructed is claimed to be the most perfect form of steam motor, comparatively small engines under 100 H.P., and without condensation, giving a horse power for somewhat under 20 lbs. of steam per hour, while large engines when fitted with condensers have been shown to use no more than 12 lbs. of steam per horse-power per hour; at the same time the construction of compound engines has been so simplified that they have no more parts, and are no more difficult to manage, than ordinary double-cylinder high-pressure engines.

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[1] Published *in extenso* in *Industries*, Sept. 10, 1886.

7. *On a New High-speed Steam or Hydraulic Engine.* *By* ARTHUR RIGG.

This paper described a new construction of high-speed engine, differing from all of the rotary types, inasmuch as it employs cylinders and pistons of ordinary construction. These cylinders are all arranged to revolve in the front of a fly-wheel, which is overhung on its bearings, much like the face-plate of a lathe. The pistons are connected to crank-pins projecting from the face of this fly-wheel, and the cylinders revolve round one centre, while the pistons revolve round a different centre, which is that of the fly-wheel. These centres, being in parallel lines and apart from each other, have a certain eccentricity, corresponding with half the stroke of cylinders and pistons.

The original crude idea of a revolving engine may be traced as far back as 1815, but little attention seems to have been given to its value, when developed into a workable engine. After discussing the insuperable difficulties against the attainment of very high speeds in ordinary engines, because of the reciprocations of their moving parts, and after showing how these difficulties are more masked than removed in three-cylinder engines of the triangular type, it is shown how the new revolving engine evades these difficulties altogether.

This is accomplished by a velocity being continuous in one direction, for the cylinders and pistons partake of a continuous revolution, each round its own centre: and the reciprocations are relative as between themselves, not absolute in relation to the earth.

In this construction a perfect statical balance is provided at first, and this becomes an equally perfect balance from a dynamical point of view; and, as a consequence, this engine requires no more foundation than suffices to carry its own weight, and it may be fixed upon upper floors, running even at very high speeds, when so required, without shock or perceptible vibration.

But economy in the production of power is a matter of prime necessity, and it was shown how easily this engine may be controlled by an automatic variable expansion governor, and how it may be driven by very high-pressure steam expanding in one or more cylinders successively.

But it is when arranged as a hydraulic engine that this type of construction possesses advantages even more conspicuous than those already described; for, besides being able to run much faster than has hitherto been considered possible, it is the only engine hitherto invented which can be governed at a regular speed, using only that amount of water which is required to produce the power given out. Hydraulic engines, it is well known, consume just as much water per revolution whether running empty or doing their full work, and it has long been a desideratum to discover a water motor that can run smoothly, and be governed in an economical manner.

Governing an inelastic fluid engine can only be accomplished by determining the total travel of its piston per minute, and this can be done by varying the rate of revolution with a stroke constant, or by varying the stroke with a rate of revolution constant.

It was shown by a model, and by diagrams, that the length of stroke is always twice the eccentricity, or the distance between those two centres around which the cylinders and pistons respectively revolve; and it is easy to alter this distance while the engine is running, so that the stroke of all the cylinders is under perfect control; and it may be changed either by hand or governors, the latter action being automatic. It is thus that a hydraulic engine of this type is under perfect control, and runs at a regular speed, however greatly the demand for power may vary.

Engines of this revolving type have been constructed and worked both by steam and water power; they run quietly and well, and seem to realise all the expectations foreshadowed by their designers.

8. *A new Method of Burning Oil for Lighthouse Illumination.*
By JOHN R. WIGHAM.

The author, with a view to avoid the breakage of glass chimneys, and the obstruction of light caused by their use, has adopted for oil lamps an arrangement analogous to that he previously applied to gas burners, the ordinary glass chimney being in both cases dispensed with. In the oil lamp described and exhibited a current of air is brought through orifices in the burner, and deflectors are so arranged as to oxidise the smoky oil flame, using an overhanging flue as in the gas burner. The flame is thus surrounded with a cylindrical wall of air in place of glass. The author referred to a somewhat similar lamp designed by Mr. Ross, of Dublin.

9. *A new Form of Light for Lighthouses.* *By* JOHN R. WIGHAM.

This paper described a special form of group-flashing light, Instead of the lenses revolving round the central light two or more lights are caused to revolve with the lenses. It is claimed that by such arrangement, while the full power of each light is taken advantage of, the cost of the optical apparatus is materially reduced. The author uses two instead of six or eight lenses, and by intermitting the lights obtains a combination of a novel and striking character.

10. *A new Illuminant for Lighthouses.* *By* JOHN R. WIGHAM.

After discussing the relative advantages of gas and electricity as a means of illuminating lighthouses, the author described the arrangement he has adopted for securing, when occasion requires it, a light having an intensity of illumination comparable with that of the electric light, but of much larger size. This consists in using, in connection with his multiple-jet gas burner, a solid carbonaceous body converted into vapour and made to produce intensely white light by compressed oxygen. It is claimed that the naked light of a triform on this principle would have an illuminating power quite equal to that of a powerful electric light, in addition to certain advantages arising from its larger size, while the cost would be little in excess of that of an ordinary gas light.

11. *A new Method of Arranging the Annular Lenses used for Revolving Lights at Lighthouses.* *By* JOHN R. WIGHAM.

The object in view in devising this new arrangement was to render the rotation of the lenses unnecessary, as by doing so the apparatus would be simplified and certain other advantages secured. Instead of superposing the burners and lenses in the same vertical plane, as in the ordinary triform and quadriform lights, the author proposed to place the lenses obliquely to each other, but in their focal position with regard to the illuminant; the beams of light emerging from each tier of lenses will thus overlap, illuminating the whole horizon, so that there will be no occasion for the lenses to revolve, while the increased amount of light transmitted by the annular lens compared with that by the refracting belt of the ordinary fixed light apparatus will be secured.

The paper further points out how, by automatically cutting off the gas at stated intervals, intermittent or flashing lights could be secured and a considerable economy of gas at the same time effected. A further advantage is claimed for the system in the fact that the full power of the light is available at any given point of the horizon instead of waxing and waning as in the revolving system.

SATURDAY, SEPTEMBER 4.

The following Papers were read:—

1. *On the Manufacture of Metal Tubes.* *By* JAMES ROBERTSON.

This paper described a novel method especially applicable to the manufacture of seamless copper tubes, which has been recently invented by the author and brought into practical use by Messrs. Ralph Heaton & Sons, of Birmingham.

By revolving a smooth steel rod, on which a gland was fitted that could be clamped more or less tightly and drawn along the rod by a weight passing over a pulley, it was shown that, whereas a weight of 60 lbs. was required to move the gland while the rod was in a quiescent state, on revolving the rod a single pound sufficed to produce this result. This circumstance depends on what the author calls the 'cross surface motion frictional contact of solid bodies,' and it was shown that by increasing the velocity of revolution the weight required to produce this end-movement may be still further reduced as compared with that in a state of rest, the practical limit being about one-eightieth.

In applying this principle to the manufacture of copper tubes a revolving mandrel (corresponding to the steel rod in the experiment described above) is forced by hydraulic pressure into a copper billet fixed coaxially with it. Round cast billets of 4, 5, and 7 in. in diameter and about 2 ft. 4 in. in length are employed, and, although not essential, it is found most economical first to pierce a hole $1\frac{1}{4}$ in. in diameter the entire length of the billet. This is done without removing metal, for it is 'laved' aside as the mandrel forces its way through the billet. On passing a three-inch mandrel through the billet in this form it is elongated to a length of about four feet, when it is known as a 'shell,' and passes to the draw-bench. The primary object of the initial hole is in order that the mandrel may be lubricated. This is done with oil so effectively that the mandrel never gets overheated, and the shell can be handled immediately after the operation.

The necessary end pressure of from 40 to 150 tons is given by a ram, and the water within the hydraulic cylinder is at the same time used as a back centre, thus avoiding excessive waste of power from friction. The ram, carrying the mandrel attached to its front face by a clutch-plate, is caused to revolve by gearing, the driven spur-wheel being also fixed to the front end of the ram.

The copper billet is held in a pair of half-round dies, while end-traverse is prevented by steel holding-dogs fitted in the front end of these dies. The mandrel is enlarged at its extremity in a bulbous form, having a sharp point and three cam-shaped inclined working edges on its surface. Each inclined edge as it revolves spirally causes a wave of metal to roll before it, and thus widens out the hole and elongates the billet, the direction of rotation being, of course, the converse of that which would be adopted in drilling. The mandrel revolves at a rate of about twenty revolutions per minute in making a hole three inches in diameter, and the traverse endwise is from six to ten inches in the same interval according to the temper or 'pitch' of the copper operated upon.

2. *On the Blackpool Electric Tramway.*[1] *By* M. HOLROYD SMITH.

3. *Automatic Pumping of Sewage by High-pressure Water.*
By BALDWIN LATHAM, *M.Inst.C.E.*, *F.G.S.*

The author in this paper shortly described a method of transmitting power from a central point by the use of high-pressure water, and using such power as a convenient mode for automatically raising sewage in any district. Two machines were placed vertically in one chamber, and so arranged by means of floats that when

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[1] Published in *Electrician*, Sept. 10, 1886.

one machine was overpowered by the volume of sewage, the second machine would come into action. By this method power could be transmitted more economically than by any other mode at present in use, and with the additional advantage that the water after use can be applied for flushing purposes.

4. *On the Birmingham, Tame, and Rea District Drainage Board.* *By* W. S. TILL.—See Reports, p. 499.

MONDAY, SEPTEMBER 6.

The following Papers were read :—

1. *Electric Illumination of Lighthouses.*[1]

By J. HOPKINSON, *M.A., D.Sc., F.R.S.*

The paper related to the cost of the electric light in lighthouses, and suggested a method of reducing the same. It has hitherto been supposed that it was not possible to establish and maintain an electric lighthouse at anything like the expense of a first-class light in which paraffine is used in the ordinary way. The high expense of the electric light arises in a great measure from the fact that the machinery is placed at a distance from the lantern, so that two attendants are always required on duty. The author suggested that a small gas-engine and dynamo machine should be placed in the room immediately below the lantern, and arrangements should be made whereby the lightkeeper, whether he is in the lantern or in the engine-room, could ascertain at a glance whether the arc is in its proper position. The attendance on the lamp, rotating apparatus of the lens (if a revolving light), engine and dynamo would be easy when the whole is brought together so as to be under observation at once; in fact, the gas-engine, dynamo, and lamp would constitute together a gas-burner, which, though consisting of many parts, is automatic throughout, and when at work requires nothing but the constant presence of a custodian, exactly as a gas lamp in a lighthouse requires a custodian as a guarantee against failure.

The plant would consist of a Dowson gas-producing apparatus and gas-holder, the generator and superheater being in duplicate, each capable of making 1,200 feet of gas per hour, the gas-holder having a capacity of 3,000 cubic feet; an eight-horse (nominal) Otto gas-engine and series-wound dynamo machine, placed in a room near the base of the tower and copper conductors to the lantern, the dynamo having magnet coils divided into sections so as to supply a small current when required; a one-horse (nominal) Otto gas-engine and dynamo machine, placed in the room immediately beneath the lantern floor, with gas-pipe from the gas-holder; one spare armature; the electric lamps to receive either carbons of 25 mm. or any lesser size, with complete adjustments for accurate focussing; one paraffine lamp as a stand-by; an optical apparatus of the second order, 70 cms. focal distance. The cost of this apparatus would depend upon the character of the light it was intended to exhibit. Provision would be made in the optical apparatus for giving the horizontal and vertical divergence desired by the methods successfully used in the lighthouses of Macquarie and Tino. Two focussing prisms would be fixed to form magnified images of the arc on pieces of obscured glass, let into the pedestal floor, so that the keeper, whether in the lantern or in the engine-room, could see at a glance the state of the arc, and observe whether it is of proper length, with the carbons in line, whether it is of exactly the right height and in the centre of the apparatus. An error of one millimètre would be glaringly apparent, and call for immediate adjustment, although its effect would only be a displace-

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[1] Published *in extenso* in the *Electrical Review*, Oct. 8, and the *Electrician*, Oct. 29.

ment of the beam five minutes of angle. The lantern would be 10 feet diameter, with bent plate glass. The cost of the whole described would be materially less than the cost of a first-order light and lantern with oil lamps and large burners. In fine weather the small engine would be used. Its effective power on the brake is fully $1\frac{1}{2}$ horse-power; from this $1\frac{1}{2}$ horse-power the dynamo machine produces considerably over 800 watts—say, 800 watts—in the arc itself, or 28 ampères, through a fairly long arc of 40 volts. Of course the value of this in candles depends upon the colour in which it is measured and the direction in relation to the axis of the carbons. In red light the mean over the sphere would certainly exceed 1,200 candles. In clear weather, or in slight haze or in rain, the beam of this light through the lenses would be much more powerful at the horizon and on the distant sea than any single-focus light in oil or gas, or at least would be fairly comparable with anything yet exhibited in oil or gas, whether triform or quadriform. But on the nearer sea the illumination would be reduced, so that no annoyance would be caused by dazzling flashes. In really thick weather, or, indeed, in any weather when there was a doubt as to the visibility at the horizon of the lower power, the larger engine would be used, under the superintendence of the second keeper. This engine will give 10 horse-power on the brake, and there is difficulty in getting 85 per cent. as useful electrical energy outside the machine—that is, 6,340 watts. From this deduct 10 per cent. for the leads and the lamp and for steadying the arc, leaving 5,710 watts in the arc itself, or 114 ampères, with a difference of potential of 50 volts. It hence follows from the South Foreland experiments that in any fog whatever, the flashes would penetrate farther than any existing gas or oil light. The increased size of crater compared with that produced by the current of 20 ampères will give increased vertical divergence, and so cause the maximum illumination to be attained at a less distance from the lighthouse. The attendance of two men would suffice for all the duties of a lighthouse, because, under ordinary circumstances, one only need be on duty, excepting whilst gas is being made. The usual course would be that, with the exception of from two to three hours at the beginning of the night, the gas-producer would be damped down, and when the small engine was at work the supply be taken from the gas-holder.

The consumption of coal would be 4 lbs. per hour of lighting, of water about half a gallon, of carbon about 4 inches per hour, allowing for ends wasted. Comparing with a first-order light illuminated with paraffine, the total charges for maintenance would not differ materially. The substantial advantage resulting would be that, at a trifling cost per hour, there is available at any moment a light of the greatest penetrative power.

2. *Multiplex Telegraphy.* *By* W. H. Preece, *F.R.S.*

The enormous increase of telegraphic business in England has necessitated new modes of working to increase the capacity of wires for the conveyance of messages. Delany's system enables six messages to be sent on one wire between London and Birmingham at the same time. It is based on a system of distributing the use of the wire for a very short interval several times a second to each telegraphist, so that the currents sent to each, though they are intermittent and very much broken up, are practically continuous. The distributors are maintained in absolute synchronism by a very ingenious system of correction. The instrument used for telegraphing is the ordinary apparatus already in use in England—the sounder. It is not a long-distance system, for the introduction of disturbances due to underground wires reduces its efficiency. Only four-way working is practicable between London and Manchester at present. It will be very extensively used by the Post Office.

3. *A portable Electric Lamp.* *By* W. H. Preece, *F.R.S.*

The demand for a new safety-lamp in mines has directed many minds to the application of electricity to this purpose. Some have proposed to use primary batteries; others utilise secondary batteries or accumulators. One of the most portable, compact, and convenient forms is that of Mr. Pitkin. It occupies a cubical space of 59 cubic inches for two cells, and 86½ cubic inches for three cells, weighing 5 lbs. 8 oz. and 7 lbs. 3 oz. respectively. The three-cell battery gives a light equal to 2·5 candles immediately after removal from the charging source, and lasts for nine or ten hours. It may also be used for other purposes that will readily suggest themselves, and makes a very convenient reading lamp for railway travelling, in conjunction with a small candle-power Edison-Swan lamp that concentrates upon a book all the light required. The lamp is fixed in the focus of a reflector whose surface is enamelled dead-white, instead of being bright-polished. The light is thus much more uniformly distributed. It is, moreover, soft, absolutely steady, and free from smell, or annoyance to one's fellow-passengers. It is lighted instantly without any match, and can be rapidly replaced by a small coil of fine platinum wire which, being raised to incandescence, serves for lighting a cigarette.

4. *On Improvements in Electric Safety Lamps. By* J. Wilson Swan, *M.A.* See Reports, p. 496.

5. *Primary Batteries. By* A. Réné Upward.

After briefly reviewing the forms of primary battery from the simple elementary cell to those of Daniell, Grove, Bunsen, &c., the author pointed out that the quantity of current given by the combustion of a given weight of zinc is the same in all batteries, but not the work done by the battery. The E.M.F. is proportional to the net gain of power in the chemical reactions.

The difficulties in the way of obtaining a perfect battery having been recapitulated, the author's battery, the chief characteristics of which are the use of free chlorine gas and the absence of polarisation in consequence of hydrogen not entering into the reactions, was described. The zinc being always in a solution of zinc chloride, no local action occurs; there is no fear of mixing of liquids, as only one liquid is used. The further advantages of this form of cell were enumerated as follows:

No fall in E.M.F., due to the solution becoming weaker, as the outer cells are always full of practically pure chlorine gas; no acids used in the cells (only pure water added); no liquids to remove; absence of smell or fumes; no amalgamation of the zincs; no destruction of the terminals; economy.

The chlorine generator and gasholders were described, as well as the chlorine cell itself, the battery, and the arrangements for the continuous automatic supply of gas to the cells.

6. *The recent Progress in Secondary Batteries.*[1]
By Bernard Drake *and* J. Marshall Gorham.

This paper gave an account of the various difficulties that existed some time back when the writers first became connected with the Electrical Power Storage Company, and dealt with the practical solution in each case. The writers stated that the three most common sources of trouble were, first, the destruction of the lead grid or conductor; second, the buckling or warping of the plates; third, the falling out of the active material, the above being almost entirely confined to the peroxide plates. The destruction of the grid both by local action and oxidisation could easily be prevented by overcharging the cells in the first instance, whereby a fine protecting coat of peroxide was formed on the surface of the conductor. If this coating were reduced by the total discharge of the cells, a fresh surface of the conductor would be attacked. The authors' experiments have shown that the life of the lead grid is not proportional to the ampère-hours either put in or taken out of

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[1] Published *in extenso* in *Engineering*, vol. xlii. p. 302.

a cell, but is dependent on the treatment the cell receives in use and the extent to which the above action is appreciated. The buckling of the plates was stated to be due to insufficient charging, which allowed a hard enamel of sulphate of lead to form on the surface of the active material. It was also found that charging tended to soften and remove this enamel. The falling out of the active material was generally due to the hard sulphate mentioned above, which caused the plugs of active material to split and come out of the plates entire. If, again, the discharge was too rapid there was a tendency for the active material to scale off, and a fine disintegration of the oxides showed that the plates contained insufficient sulphate, which acted as the binding agent. Some curves were exhibited showing the result of recent tests made with standard type 15-plate boxes, which gave a commercial efficiency of 90 per cent. in ampère-hours and 80 per cent. in watt-hours, allowing throughout the experiment about an hour's charge after gases were given off, so as to keep the plates in order. These figures were the mean of six consecutive charges and discharges at a constant current. It was found that with a drop of 10 per cent. in E.M.F. the capacity was over 400 ampère-hours, and a discharge of 9 hours at a rate of 25 ampères showed a drop of only ·02 of a volt. The maximum capacity claimed for these cells by the maker was found to be reached with a drop of E.M.F. of under 5 per cent. in the case of the cells under test. The instruments used were carefully calibrated, the ampères being measured by frequent readings from a Siemens dynamometer checked from time to time by a voltameter, which agreed within 1 per cent. The volts were taken with a high-resistance reflecting galvanometer calibrated by standard Clark cells and freshly made Daniel cells.

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7. *Electric Lighting at Cannock Chase Collieries.* *By* A. SOPWITH.

This paper must be considered as merely introductory to a visit which was proposed to be made by members of the Section to the Cannock Chase Colliery, and dealt in a general way with some special advantages and economies in connection with the electric lighting of collieries.

The author pointed out the convenience and economy in utilising the ventilating fan engines for working dynamos, on account of the regularity of speed (which apart from the requirements of an installation is kept within a limit of from 1 to 3 per cent., such variation being a gradual diminution or increase) and the fact that such engines run continuously night and day. The fan itself acts to some extent as a regulator, as the tendency to run away on switching out of lights is modified by the increasing resistance of the air; *vice versâ* the putting on of load and consequent tendency to slacken speed is reduced by the diminished work done by the fan at a few revolutions less; again the comparatively small proportion of power required for working the dynamo, amounting to from 7 to 12 per cent. of the usual working power of engine, may be considered an advantage.

The addition of counter-shafting in cases of slow running fans, or single pulleys in case of quick running fans, is an easy and inexpensive matter.

Allusion was made to the small extra consumption of coal in practice, and the merely nominal value of the slack which is consumed. In further connection with the working expenses, viz. replacement of lamps, it was mentioned that the underground workings in vicinity of shafts (extending to 200 or 300 yards) admit of lamps being worked considerably below power with sufficient effectiveness, and actual lives were given (including breakages) showing at one pit an average of 2,270 hours. The men who are required to act as examiners of machinery, and have no specifically regular work to do otherwise, replace lamps, and can attend to any occasional work connected with installation. As a matter of fact the three installations now working at Cannock Chase have not necessitated the employment of an extra man.

The only original feature—at least the author presumes it to be so—is the utilisation of old iron and steel pit ropes for main and branch cables. From four to five miles of rope are worn out annually, varying from $\frac{5}{8}''$ to $1\frac{1}{2}''$ diameter and over, and the conductivity of this has been proved to be about one-seventh that of a copper cable (of high conductivity) of similar dimensions. In the case of shafts, in order to avoid the injurious effects of water, the ropes are encased in wood boxes strung down the side of the shaft and roughly insulated on brackets. Underground, one of the ropes is simply wrapped with old brattice cloth or tarpaulin. On the surface the ropes are laid in brick channels filled in with gas tar and coal dust, but it appears from the last trials that it is sufficient to lay the ropes side by side in the same material; there is no appreciable loss of current. The fact that old ropes are only worth a few pounds per ton enables a profuse use of cables to be made, and at one of the installations the current is conveyed a distance of nearly 1,300 yards (double distance) with a resistance of only ·05 ohm, nearly one-half of which is due to the insertion of a length of $\frac{19}{9}$ high conductive copper cable.

A brief description of the last installation—which includes lighting of all surface works (extending over five acres), the underground workings in vicinity of the shaft, and, at a distance of 620 to 700 yards away, the church, schools, and houses—was given.

The author remarked upon the practicability of economical extension of installations by utilising old material such as ropes, old rails, water and gas mains, and gives the resistance of the latter as tried in one case, and concluded with a few general remarks.

8. *Dynamos for Electro-Metallurgy. By* Professor GEORGE FORBES, *M.A.*

The author wished to draw the attention of manufacturers and others to the enormous importance and the large field for new applications of the art of electro-metallurgy. The cost per pound of copper of finished articles, such as kitchen utensils, &c., neglecting cost of material, when these are electro-deposited instead of being manufactured as at present, is generally only 15 per cent., often 5 per cent., of the present cost of manufacture. When we possess machines capable of producing large currents of electricity at low pressure, an enormous industry will be immediately opened, and nearly all manufactures will be benefited by the new economical process. A few branches need alone be mentioned to show what may be hoped for, such as the production of sugar pans, copper fire-boxes, copper tubes, and even the coppering of ships' bottoms. These startling applications involve no new principle. The processes are as old and sure as could be desired. It is only the magnitude of the operation which is startling. The only cause of delay at present is the want of a suitable machine for supplying a large current.

It is now three years since the author realised that most dynamos as at present supplied have complications introduced with the one object of getting a high electric pressure. This is not required in electro-metallurgy, and for this purpose we can revert to the simplest modes of generating electric current. The author believes that the machine he has constructed is the most perfect, electrically and mechanically, of any that could be devised. The first large-sized machine consisted of a disc of iron capable of revolving on a spindle. Round its circumference are rubbing contact springs attached to a ring-casing which contains a coil of insulated copper wire. This casing, with the contained coils, is concentric with the disc. The whole is now encased in an iron mass, to which are attached the bearings. Contact makers or brushes are also attached to the ends of the spindle. These form, say, the positive terminal. The ring-casing thus forms the negative terminal. Independent excitement is given to the insulating coil of wire.

The advantages of such a machine are (1) its simplicity; (2) no wasted power in reversing the magnetism of the revolving part; (3) no reversal of current, as in the armature coils of ordinary dynamos; (4) its enormous current; (5) no Foucault currents.

The author made a machine, like the above, but double, with discs 11½ inches diameter. Its output was 18,000 watts, the energy required to magnetise it was 200 watts. Such a result has never been obtained with any other dynamo. Two difficulties were encountered. Firstly, the end-thrust was apt to be very great if the disc were not properly central. This was overcome by giving up the disc form and using a solid cylinder of iron, going right through the machine, for the armature. This had the further advantage of diminishing the internal resistance. The second difficulty was to prevent heating at the circumferential contact. A whole year was wasted in experiments on carbon contacts, which led to no results, and the author now proposes to run at a low speed and to use several brush contacts on the circumference, so arranged as to be easily accessible. This will surmount every difficulty.

In conclusion the author drew attention to the fact that the only reason why electric lighting is not cheaper than gas is that the machines, plant, and attendants are in use on an average only three or four hours per day. The electricity at any moment which could be generated, but which is not used, is a waste product. If this were used for the production of copper utensils, and the reduction of argentiferous copper ores and such purposes, the electric light could be supplied from central stations at less than the cost of gas and return a handsome dividend to the undertakers.

9. *On Distributing Electricity by Transformers.*
By CHARLES ZIPERNOWSKY.

After a brief reference to the several attempts that have been made to overcome the difficulties in the way of lighting a considerable area by means of electricity since the subdivision of the electric light has become an accomplished fact, the author pointed out that a practical system of distributing electric energy over a large area can only be based upon the use of high tension currents for conveying the energy from the generating centres, in combination with some mode of reducing the high tension to the limits of difference of potential which can be made use of without danger or difficulty. This limit is at present about 100 volts. Many methods have been suggested for meeting these conditions.

Thus a counter electromotive force can be introduced into the high tension circuit, as in the case of accumulators, and the terminals of such a device connected with the lamps, &c. The cost is, however, a grave defect of this system, and the high tension current which exists at each lamp might lead to fatal consequences.

After referring to the electric transmission of power as another means of overcoming the difficulty, the author discussed the use of induction coils or 'transformers' in some detail, tracing their use in the first instance to C. W. Harrison in 1857. Among subsequent workers Jablochkoff, C. T. Bright, Fuller, Varley, Haitzma Enuma, Gaulard, and Gibbs were mentioned; and he pointed out that the want of success was in great part due to the fact that the transformers were connected up in series, an arrangement which is only suitable for use with an invariable number of lamps in any one secondary circuit, or when each transformer supplies only one lamp.

Besides considerations in regard to cost, the conditions to be satisfied by a system of electric distribution were stated as follows:—

(1) Perfect independence of the several consumption devices.
(2) Absolute and relative economy so that the consumption of energy is in proportion to the number of lamps in use.
(3) All regulation to be concentrated at one central station.

The author then proceeded to describe the method he has devised in conjunction with M. Max Déri, and, with the assistance of M. O. T. Bláthy, to satisfy the above conditions.

This is based on the fact that, with a constant primary tension, the secondary one will vary only in proportion to the internal resistances of the coils; and as the resistance of each coil is less than 1 per cent. of the external resistance, the secondary tension will not vary more than 2 per cent., whatever be the intensity of current supplied to the consuming device. Constancy in the primary tension at the transformer terminals is secured by connecting them in multiple arc with the main line, and the arrangements are such that current and tension are distributed in the primary circuits, much as in a low tension direct supply system, the transformers simply acting as tension-reducing devices.

Instead of the old Ruhmkorff coil pattern of transformer a form is adopted such that the lines of magnetic force circulate entirely in iron, or as nearly so as possible, by which arrangement a considerable economy of magnetising force is effected and other advantages are at the same time gained. Two forms of transformer made on these principles were described, as well as the self-regulation of alternating current machines, which is especially valuable in installations of moderate size.

This system is at present in use in Gerona in Spain, Lucerne, Cologne, Berlin, Rome, Milan, Turin, and other towns, and has been temporarily erected for the Exhibitions in London, Budapesth, and Antwerp. The arrangements for Rome were explained in detail and illustrated by a diagram, and the author concluded by pointing out that, although the last word has not yet been spoken in relation to the distribution of electricity over large areas, the above system is the only one with which he is acquainted that approximates to the fulfilment of an ideal distribution.

TUESDAY, SEPTEMBER 7.

The following Report and Papers were read:—

1. *Report of the Committee on the Endurance of Metals under repeated and varying Stresses.*—See Reports, p. 284.

2. *The Water Supply of Birmingham.*[1] *By* C. E. MATHEWS, *F.R.G.S.*

3. *The Manufacture of Slack Barrels by Machinery on the English and American Systems.* *By* A. RANSOME.

The paper confined itself to such cask-making machines as have been most successfully applied to the production of slack barrels for holding dry goods, and as all the more satisfactory machines for this purpose are of English or American origin, the different systems of manufacturing slack barrels at present in use in this country and America were alone discussed.

The English cement barrel is made from fir staves sawn to length and parallel widths and thickness. The heads, which are also made of fir wood, are simply rounded, and held in place between two wooden hoops nailed inside the ends of the cask.

In the Universal Stave-jointing Machine a sufficient number of rough staves to make one cask are cramped side by side in a travelling box, and passed over a horizontal cutter, which rises and falls as the staves pass over it, and the amount of bilge given to the stave is governed by a template.

The staves, after being fired on a hot plate, pass to the trussing machine. This consists of a cast-iron cone, the inside of which corresponds with one half of the finished barrel; it has recesses turned in it to take the truss hoops, and is made in halves, hinged on one side, to facilitate insertion and removal. Immediately below the cone is a cast-iron table, caused to rise and fall by hydraulic pressure, applied through an accumulator. The attendant arranges a set of staves in a circle within the bilge truss hoop, which, for this purpose, is laid upon the rising table, the upper ends of the staves resting against a bevilled flange, formed on the lower edge of the trussing cone. The truss hoops being inserted in the recesses in the cone, the table is raised, and thus the upper ends of the staves are pressed tightly together in the cone, and the partially trussed barrel is withdrawn with two truss hoops driven firmly on it. Two more truss hoops are then inserted in the cone, and the cask is placed with its trussed end downwards, when a second rising of the table completely trusses it.

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[1] Published *in extenso* by the author.

The barrel is next taken to the chiming machine, where, while it is held in a horizontal position between two cones mounted on a lathe bed, cutters mounted on poppet heads and revolving at a very high speed are made to act simultaneously on both ends of the cask.

The heads are rounded on a special machine; the boards, having been first crosscut to length, are placed side by side between two circular cramp plates revolving at a high speed, a fixed cutter being made at the same time to act on the periphery.

The practical result of the introduction of the machinery above referred to is that a cement cask, which the hand cooper was formerly paid 8½*d.* for making, can now be produced for a total outlay in wages of about 2½*d.*, of which 2*d.* represents the cost of hooping and heading up after leaving the machines, and it is now probable that, by an invention just patented by Mr. Hewitt, foreman cooper at Messrs. Bazley, White & Bros.' extensive cement works at Northfleet, the cost of hooping and heading will be reduced by fully one half This invention consists in trussing the barrel in its permanent hoops, which are of steel, and four in number, leaving nothing to be done by hand but to fix the heads in place. A sample barrel trussed in this manner is exhibited.

The American slack barrel, a sample of which is also exhibited, is usually made of elm or some other comparatively hard wood, the staves being cut in such a manner as to make them, in section, curved to the approximate circle of the barrel. This is done by means of a slicing machine, in which the block, after being well steamed, is forced against a fixed knife, the wood being caused to describe a short arc of a circle as the knife passes through it. For stouter descriptions of casks the staves are sawn with a curved section by a cylinder saw, while for the lighter and smaller slack barrels a bilge saw is used, which not only cuts the staves to a curved section, but saws them curved in the direction of their length to the bent form which they would assume when made up into the cask. For flour barrels, however, the slicing machine is almost exclusively employed.

The staves for American slack barrels are jointed by two distinct kinds of machines. In one of these the joints are formed by a fixed knife being brought down upon the edge of the stave by a guillotine motion. In the other the stave, being bent over a horizontal saddle, is presented to the face of a disc armed with flat plane irons and running at a very high speed.

The staves, after being jointed, are set up in a circular form, and the open end is drawn together by means of a windlass.

As this operation tends to draw the cask out of truth, it becomes necessary to level it by compressing it endwise between two tables at right angles to its axis.

The barrel is then heated, and the remaining truss hoops lightly driven on by hand; it is then passed to the trussing machine, acting upon an entirely different principle from that already described.

These barrels are chimed and crozed at one operation: the barrel, being cramped between two chuck rings, is made to rotate, while rapidly revolving cutters of the requisite form for bevelling the ends and cutting the head grooves are brought into contact with its two ends.

The mode of manufacture of the heads of American slack barrels differs from that adopted in England mainly in the use of a dished saw, of a sweep corresponding to the diameter of the head in place of a fixed cutter.

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4. *The Sphere and Roller Mechanism. By* Professor H. S. HELE SHAW *and* EDWARD SHAW.—See Reports, p. 484.

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5. *On a new System of Mechanism for Imparting and Recording Variable Velocity. By* W. WORBY BEAUMONT, *M.Inst.C.E.*

In this paper the author described a new system of mechanism for imparting variable velocity to the recording parts of speed- and work-measuring instruments and to machinery. In the first part he described a new principle in the mechanical adaptation of a hollow cone mounted upon a revolving spindle with its centre at the smaller end coincident with that of the spindle, but with its axis inclined from that of the spindle, so that one side of the periphery of the cone remained continuously parallel to the axis of the spindle.

In the second part he described a new system of variable velocity gear in which motion was imparted or controlled by a conical roller or disc running upon this cone, or by a cylindrical roller or disc. To this is adapted a reducing gear, the wheel in which (carrying the idle pinion) is permissively rotative at a velocity variable by the longitudinal movement of the cone one way or the other, so as to bring the disc in contact with a larger or smaller part of the cone.

The author also described the exaxial cones as a means of transmission of different velocities by means of belts which would run upon them much as they would upon cylinders.

6. *On Balanced Locomotive Engines.* *By* T. R. Crampton.

The engine is driven by two pairs of adhesion wheels worked independently, dispensing with coupling rods or balance weights. It can be designed for ordinary high-pressure or compound. The four adhesion wheels are worked in pairs, two on each side (which may be made radial if desired), each pair being driven separately from one end of each axle only, by a pair of cylinders working on return cranks, attached close to the outside of one wheel as convenient; the crank pins being opposite each other, or 180° apart. The pistons, working in opposite directions, require no balance weights; the axles transmit the power to the wheels by torsion in one direction, there are no balance weights, in consequence there is no power generated in the working to produce oscillation. The axle-box guides receive no horizontal strains from the pistons, which amount, in an ordinary engine of the same dimension, to from 16 to 18 tons at each stroke, tending to break the frames.

The cylinders are placed so that the centre of the slide bars are nearly in a line with the centre of gravity of the engine. The connecting-rods are seven times the length of the crank—the vertical thrust, over the leading wheels, as in the author's original engine, is reduced to one-fifth of the ordinary system. There are large numbers of engines of the ordinary type having inclined cylinders at the smoke-box end, where the vertical action at each stroke of the piston varies the weight on the leading wheels three or four tons.

The whole of the working parts being outside the boiler, and nothing underneath it, as suggested by the author in 1846, enables the marine boiler to be used, which, in his opinion, is, under certain conditions, better adapted for locomotives than that in ordinary use; it is cheaper to make and more easily repaired, having no stays in the fire-box. Ordinary boilers can be used.

The total weight of engine is reduced, and greater heating surface obtained in a given distance between the axles. The absence of strains mentioned enables the whole structure to be made much lighter. A simple apparatus is employed for forcing the cranks off the dead centres when desired, which is applicable to all engines. Any known apparatus for manipulating the brakes can be placed on the foot-plate, the cylinder of such apparatus being utilised for moving the cranks off the dead centres if required. The tyres are formed to wear parallel, reducing the wear immensely as well as that of the rails. The details of the engine may be varied to suit circumstances. The position of the cylinders having no tendency to produce oscillation, they may be placed at any convenient position, consequently should assist in settling the vexed question of inside and outside cylinders.

When engines have all the moving parts on the outside, and are worked long distances by change of driver, the one driver, on giving up charge, can explain and point out to the one taking the engine on anything requiring attention, which is not so conveniently done when the machinery is underneath the boiler. The importance of locomotives constructed on the above principles may be shortly stated: the results of experiments made under precisely the same conditions with the ordinary locomotive gave the pressure of the steam in the boiler, on starting the improved engine from rest on a level, to be 30 per cent. less, and on severe curves 50 per cent. less than was required by the ordinary engine. This system is peculiarly suitable for colonial locomotives.

WEDNESDAY, SEPTEMBER 8.

The following Papers were read:—

1. *On recent Improvements in Sporting Guns and their accessories.*
By SAMUEL B. ALLPORT.

The writer justified the introduction to the Association of the subject of the manufacture of sporting arms, on the ground of the importance of the trade to the town of Birmingham, and further that the durability and performance of the guns produced depends largely on the application of scientific principles to their construction, to a knowledge of the theory of projectiles, and of the composition and force of explosive compounds. The danger and clumsiness of loading guns at the muzzle have given way to the safety and convenience of using cartridges composed of definite charges of powder and shot, made up in a portable form and containing their own means of ignition.

The safety and shooting power of the sporting breechloader are mainly consequent on the judicious design of its breech mechanism and the perfect fitting of the surfaces in contact when the barrels are closed. The method of tilting the breech ends of the barrels upwards on a hinge is most convenient to open them for loading, and for firmness when closed the original fastening principle of Lefaucheux has not been excelled. The 'snap bolt' system is, however, for home use, generally adopted, being more quickly manipulated and fairly durable when perfectly fitted. (These systems were illustrated by drawings.) The self-acting mechanism for forcing out the cartridge case was also explained.

The safety arrangement exhibited, known as 'the rebounding lock,' which, after the gun is fired, automatically restores it to a position that renders it absolutely safe from accidental discharge, was a marked advance in improvement.

External hammers were subsequently found to be needless, and to interfere with a free aim, and hence the so-called 'hammerless' gun was invented, wherein the hammers are concealed within the gun, and the mode of working simplified.

The 'Anson-Deeley,' and the 'Scott' hammerless guns are perhaps the best and most successful types of these guns. They possess special but different merits in their mechanism and automatic safety appliances, and the disposition of their moving parts is very judicious. The varieties of hammerless guns can only be glanced at, as so many patents have been taken out for them in the last ten years.

In noticing the performance of shot guns it has been found that by contracting or coning the bore of the barrel a little behind the muzzle, technically called 'chokeboring,' a direction of convergence can be conferred upon the charge of shot, whereby it can be concentrated upon the mark, and the tendency of the shot to spread, as compared with firing it from a true cylinder, is greatly restrained. The forces tending simultaneously to converge, and to disperse the charge of shot, are intricate and interesting. Much of the desired effect depends on the length and shape of the internal coning, for studying which the writer invented an expanding micrometer for minutely measuring the variations in the boring of tubes, whereby differences of calibre of half a thousandth of an inch are felt and visibly recorded. This instrument was exhibited and explained.

Latterly new gunpowders have been invented, having for their object the obtaining quickly a clear aim with the second barrel of a gun unclouded by the smoke from the first barrel which arises from using ordinary black gunpowder. These new powders are known as Schultze and E. C. (Explosives Company). They effect their purpose as they are nearly smokeless, and have been successful improvements. In their early manufacture they were imperfect and irregular in their force, and if heated to 80° Fahrenheit acted with great violence. Hence many guns were broken by them at first, and the need has been felt of some reliable instrument to measure the force which powders exert and its rate of development.

One of these, the Boulengé chronograph, indicates the velocity of a bullet during its flight between two targets 50 feet apart. These are respectively connected with suspended weights by an electric current. On the bullet piercing the targets the current is broken, the weights are set free, and hence the velocity and the projectile force employed are deduced. The gauze targets, however, appear likely to interfere with the velocity of small shot, and to affect the calculation for them.

The instrument known as the 'crusher gauge' is a cylindrical nozzle having an external screw to screw into any powder chamber. It is bored at one end to receive a perfectly fitting piston. On exploding powder in the chamber the piston delivers an impact upon a loose copper disc placed inside the crusher gauge, of which the rate of compressibility is ascertained previously. By carefully measuring the thickness of the copper disc before and after the experiment, the compression the disc has suffered is observed, and the powder force is deduced. Since the thickness of the barrel of a gun from breech to muzzle should diminish proportionally to the progressive decrement of gas pressure the lightest safe section can thus be found. This instrument has been screwed at equal distances along large guns for that purpose, and the principle seems capable of application to sporting guns. The paper then dealt briefly with the subject of impact.

The author exhibited a test gun of $\frac{73}{100}$ of an inch calibre, designed for testing the pressures exerted by different powders upon the barrels of guns. The upper side of the barrel is pierced with six tapped holes, into which gun-metal stop-screws are screwed. On removing either of these, an instrument for measuring the pressure may be screwed on. The stem of the piston in this instrument extends to the inner surface of the barrel, and its outer extremity carries a toothed rack. This engages with a pinion, the axis of which carries an index finger ranging over a graduated arc.

On firing the gun, a gas-check wad upon passing the end of the piston-rod exposes it to the pressure of the gas then generated, forcing the piston upwards against a spiral spring and compressing it. The compression is automatically recorded on the graduated arc in terms of hundredths of a ton per square inch. By interposing a different piston the gun becomes a crusher gauge at the same places along the barrel, whereby a second test is established.

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2. *Recent Improvements in the Manufacture of Rifle Barrels.*
By ARTHUR GREENWOOD, *M.Inst.C.E.*

The introduction of steel rifle-barrels some five and twenty years ago, and the gradual substitution of that material in place of welded wrought iron for the barrels of military rifles and arms of precision, have caused great changes in the machinery employed in their manufacture. A short description of such machinery may not be without interest in this great centre of firearms industry.

The barrels generally used for military rifles are made from mild steel rolled solid and the bore drilled out. This is necessarily a costly operation, and numerous attempts have been made at hollow rolling to avoid the expense of drilling.

To effect this barrel 'blanks' or short pieces of steel have been drilled and afterwards rolled on a mandril to the desired length, and many thousands of barrels have been made on this plan. Of late years, however, the military authorities have insisted upon barrels being first rolled solid to the desired form and afterwards drilled. At the Royal Small Arms Factory at Enfield a system of continuous rolling has been established, whereby the barrel has been rolled to its exterior form at one heat by passing it through a number of rolls placed one after the other. A barrel is thus rolled in about half a minute, which gives a great saving in time and cost of production, and the material is not harmed by re-heating, as was often the case in the old system.

When the rolled barrel has become cold it is passed through a straightening machine, which takes out any short bends, or 'kinks,' and is thus made ready for drilling.

Before going to the drilling machine the barrel goes to a machine which 'faces' or squares up the ends, and prepares a bearing at each end of it upon which it will rotate in the barrel-drilling machine.

The barrel-drilling machine has been specially designed to drill a perfectly true hole through the barrel, and to avoid straightening by means of external hammering, which is extremely harmful to the barrel. Three barrels are operated upon at one time and drilled simultaneously from both ends. The machine is horizontal, and the barrels rotate at from 700 to 900 revolutions per minute.

The drills are of the form technically known as D, or half-round bits, and are fed up automatically, a heavy pressure of water being injected up the barrels so as effectually to wash out the cuttings or 'swarth,' and thus ensure the free action of the drills.

About thirty barrels can thus be drilled in the working day by one attendant.

This system reduces the cost of drilling to little more than an eighth of the former system employed at Enfield, the results as regards excellence of work being at least equally good. The barrels are then rough or 'draw' bored, and then 'spilled up' or fine bored in horizontal machines by means of square bits: this system is well known and has undergone little change during recent years.

The exterior of the barrel is next turned, and ingenious arrangements have been made to secure the exterior being turned true or concentric with the bore.

The system at present at work at Enfield effects this with admirable precision, a 'bush,' or temporary bearing, being fixed to the barrel concentric with the bore.

This bush revolves in a stay, and steadies the barrel until 'spots' or bearings have been turned upon it, and from these spots the barrel is rough turned. It is afterwards finished in a copy turning lathe to the desired form, the result being a barrel with its exterior practically concentric with its bore, which is absolutely necessary for good shooting. In rifling, little change has been made in the system, but much attention has lately been given to reduce the cost of this delicate operation. The automatic rifling machine is coming generally into use, and now, with the automatic machine which rotates the barrel after each cut, gives the feed to the cutters, and finally rings a bell to summon the attendant when the barrel is completed, one man can attend to a number of machines producing as many as sixty or seventy barrels per working day, whereas on the old system one attendant was required for each machine producing on an average twenty barrels per day.

3. *The Birmingham Compressed-air Power Scheme.*[1] *By* J. STURGEON.

After pointing out the objects of the scheme, and showing that the large number of engines of moderate size used in Birmingham, often intermittently, renders some such system peculiarly applicable to the town, the author points out that, although each 1,000 horse-power at the Central Station may only produce 500 effective horse-power at the users' engines, it will displace considerably more than 1,000 horse-power of small boiler plant, furnaces, chimneys, &c., and the same engines can be used with compressed-air as with steam. The centralisation principle enables engines and boilers to be used of large power, with all the modern improvements, such as high-pressure triple expansion, gas firing, &c. At the pressure proposed (45 lbs.) the air-driven engines will indicate from 32 to 84 per cent. of the power developed at the main engines, according to the mode of using the compressed air. According to the investigations of Sir F. Bramwell and Mr. Piercy, on behalf of the Birmingham Corporation, the present consumption of fuel

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[1] Published *in extenso* by the Birmingham Compressed-air Power Company.

in small engines of from four to twenty-five horse-power varies from 36 lbs. to 8½ lbs. per horse-power per hour, and, as it is estimated that compressed-air power would reach the consumer at an expenditure of from 4·7 lbs. to 1·77 lbs. fuel per horse-power per hour, a saving of from 750 to 480 per cent. is effected.

The works will be situated on land fronting Garrison Lane. The first portion is laid out for the erection of fifteen engines of 1,000 horse-power each, to be worked by Lane's patent boiler and Wilson's gas-producers. As the Company have already received applications for over 3,600 horse-power, they have entered into contracts for the completion of 6,000 horse-power at the Central Station before May 31, 1887. The mains will all be of wrought iron, laid in concrete troughs near the surface of the road, so that they can be easily got at for examination and repairs. They will vary in size from twenty-four down to seven inches. Valves will be provided, by which, in case of damage to any portion of main, that portion will be automatically stopped off from the rest of the district, so as not to interrupt the general service. The compressed air will be sold to users at a price per 1,000 cubic feet of air of a standard pressure of 45 lbs., measured by a meter so constructed as to register the volume delivered at the value of the standard pressure, independently of any variations there may be in the main pressure. The meter consumption of the various users will be registered in the gross on a dial at the central works by electric apparatus, so that any waste or misuse of the air can be at once discovered and prevented.

The paper concludes with a discussion of the various economical aspects of the question, pointing out that compressed air can be used for all purposes for which steam is employed, except heating; air, on the other hand, has the advantage over steam that it is available for refrigeration.

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4. *The Welsbach System of Gas-lighting by Incandescence.*
By CONRAD W. COOKE.

This system, which is the invention of Dr. Carl Auer von Welsbach, of Vienna, consists in impregnating fabrics of cotton or other substances, made into the form of a more or less cylindrical hood or mantle, with a compound liquid composed of solutions of Zirconia and Oxide of Lanthanum (or with solutions of Zirconia with Oxides of Lanthanum and Yttrium), which mantle, under the influence of a gas and air flame, is converted into a highly refractory material capable of withstanding for long periods without change the highest temperatures that can be obtained from the most efficient form of atmospheric burners, and which, under the influence of such temperatures, glows with a brilliant incandescence, very white and perfectly steady, retaining, moreover, its woven or reticulated character; the organic volatile and carbonaceous matters being entirely burnt out and replaced by an incombustible and highly refractory residual skeleton, which becomes by its brilliant incandescence the source of light in the burner.

The light emitted is, at a distance, hardly distinguishable from a twenty-candle incandescence electric lamp, and by a modification of the composition of the impregnating liquid a yellower light is obtained, resembling that of the best gas lights, but much more brilliant, and with a saving of gas of from fifty to seventy-five per cent., and, being perfectly smokeless, it is incapable of giving off solid carbon, whereby ceilings or internal decorations are blackened.

The illuminating power of the lights may be taken at about ten candles per cubic foot of gas consumed per hour, and the mantles last from 800 to 1,500 hours.

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5. *Boiler Explosions.* *By* E. B. MARTEN.

After mention of the work of the British Association as to this subject at the Norwich, Exeter, Liverpool, Edinburgh, and Brighton meetings from 1868–1872, and also the Parliamentary Committee of 1869–1871, a paper by the writer at Liverpool in 1870 was quoted, recommending inquiries, independent of coroners' inquests, by competent engineers, whose published reports would probably be more useful than the verdicts of juries on such a complicated subject.

This scientific investigation is now undertaken by the Board of Trade, under the Boiler Explosion Act of 1882, who have already held 179 preliminary inquiries, with such useful result as to preclude the need of further legislation.

The work of the Midland Steam Boiler Inspection and Assurance Co. since 1862, chiefly among the hard-worked boilers in ironworks and collieries, was then described, the general result having been to lessen the frequency of explosions.

A table, abstracted from the writer's 'Annual Records of Boiler Explosions,' showed for twenty-four years 1,228 explosions (killing 1,476 and injuring 2,261 other persons), and was so arranged as to show at a glance the kind of boiler, and the cause of explosion, under the heads of Faults of Manufacture, Inspection, and Working.

Numerous sketches, photographs, and models illustrating some of the most important explosions were exhibited.

6. *South Staffordshire Mines Drainage:*
(1) *Surface Works.* *By* E. B. MARTEN.

After reference to a paper by the writer on the 'Drainage of the South Staffordshire Coal Field' at the last meeting in Birmingham in 1865,[1] which led to the obtaining of the South Staffordshire Mines Drainage Act, 1873, the works under that Act were described.

The area dealt with is 60 square miles, with 500 miles of streams passing over it, nearly all of which have been repaired where injured by mining. Also the 100 miles of canals have been repaired. Low-lying areas have been dealt with by surface pumps, so that the 50 million gallons per day of water found in the mines in 1865 has been reduced by about half.

For underground pumping the area was divided into six districts. The Bentley district in the north is not to be dealt with until the water finds its way through the Bentley Great Fault.

In the Bilston district pumping nearly ceased, and the water ran over into the Tipton district, so that they were afterwards dealt with as one, and all called Tipton. The struggle to overcome the difficulties in draining it forms the subject of the following paper by Mr. E. Terry, the mining engineer.

In the Oldbury district the mineowners voted themselves out of the underground clauses of the Act, so that the injustice remains that a few do the pumping while others get the coal unwatered. In the Kingswindford district the owners did the same without foreseeing that it would prevent the carrying out of arrangements by which one part was to be drained by a private individual, but he has erected a pumping-engine and drained mines which others work.

In the Old Hill district the system commenced by a private company has been successfully completed under the Act, as detailed in a paper following, by Mr. W. B. Collis, mining engineer.

(2) *The Drainage of the Tipton District.* *By* E. TERRY.

The arbitrators under the Act wished the surface works to be finished before the underground case was dealt with, but the Commissioners in the Old Tipton district urged that they should be allowed to work some of the engines lately stopped, which was done, and the arbitrators suggested putting up two new engines and temporarily working 38 others, with a capital expenditure of 70,000*l.* This was not accepted, and as an alternative owners were paid for pumping at the rate of 6½*d.* per lock (25,000 gallons) for each 100 feet raised, equal to about 20*l.* per annum per horse-power, but it resulted in the Commissioners being obliged to take most of the engines into their own hands.

In the Old Bilston district in the same way the arbitrators advised the erection of four new engines and the temporary working of 44 others, with a capital

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[1] Printed in the book on Hardware District, prepared for the 1865 Meeting.

expenditure of 46,000*l.*, making 116,000*l.* for the two districts; but this suggestion was not followed, and the Bilston water overflowed into Tipton, so that the Tipton people had to work the Bilston engines to save themselves, without rates for the coal raised there. In 1880 the districts were practically joined, and the arbitrators suggested a scheme for the whole, now called Tipton district, including the almost complete renewal of Stow Heath engine and putting down two large engines at Bradley and Moat, which are completed. The final result, as was shown in a table, is that the surface works have reduced the water to less than half, and the number of engines has been reduced from 77 to 12, and the annual cost from 76,000*l.* to 9,000*l.*, or $\frac{1}{8}$, and will this year be further reduced to 7 engines, and 7,000*l.*, or $\frac{1}{10}$ of what it was formerly, with a capital expenditure of 83,000*l.*, instead of the 116,000*l.* originally contemplated.

(3) *The Drainage of the Old Hill District.* *By* W. B. COLLIS.

The drainage of this district in 1871 was attempted by nineteen firms raising $1\frac{3}{4}$ million gallons per day, besides much water within 70 yards of the surface by small pumps. A limited company was formed for joint action, and when the Act passed, in 1873, their system was adopted. They took several old engines and put them in good order, and erected a very large one in the deep of the district, which has been at work for some time, and such levels are being driven as will soon enable it to do nearly all the pumping needed in the district. Interesting particulars of the engines were given. That at the Old Buffery had a wooden beam so trussed with iron that $3\frac{1}{2}$ tons were taken from it when a cast-iron beam was substituted. Another old engine at Windmill End has balloon boilers, the steam being very low pressure, and always on one end of cylinder. An engine used at the Fly (so called from a quick working whimsey once there) was a direct-acting bull engine, but is superseded by the new one at Waterfall Lane, an inverted Cornish, with beam below instead of above the cylinders.

SECTION H.—ANTHROPOLOGY.

PRESIDENT OF THE SECTION—SIR GEORGE CAMPBELL, K.C.S.I., M.P., D.C.L., F.R.G.S.

THURSDAY, SEPTEMBER 2.

The PRESIDENT delivered the following Address:—

I feel much diffidence in taking this chair, for, though in former days I used to pay a good deal of attention to what was then called ethnology, I have been for many years immersed in perhaps more exciting but, I am afraid, less satisfactory occupations; and I feel that I am very far behind in scientific knowledge and scientific methods. I only venture to address you because I take for my subject practical, rather than scientific, anthropology; the study and cultivation of the creature man as he exists, rather than that branch of the subject which seeks to inquire into his origin and development. Intensely interesting as are inquiries into the origin of man, it must be admitted that our knowledge on the subject is still very limited and our progress slow; that we have not yet got hold of the missing link, and scarcely know whether the flint implements are the work of man or of some earlier intelligent creature. We are hardly on firm ground till we come to man very much in the form in which we now have him, and even already divided into the principal varieties which exist to this day. I now then invite you to approach the subject rather as practical agriculturists deal with the subject of horses and cattle than as scientists who trace these animals to very ancient prehistoric types; and in dealing with man from this point of view I am emboldened by the consideration that here also science has not yet completely conquered the field, and that very much is open to those who bring to it only a quick eye and careful observation. I think it can hardly be doubted that, in distinguishing well-marked types of humanity, the eye is after all the easiest and perhaps the safest guide. With that alone one can recognise the unmistakable differences of colour, size, facial features, set of the eye, character of the hair, and one or two other features by which the physical characters of different types of humanity are varied. On the other hand, when we come to nicer and more subtile distinctions, especially among the mixed races which occupy most of the world, we must confess that anthropometric science as applied to craniology, &c. gives us results only partially conclusive. I have an unusually narrow head. I can hardly be fitted with a hat without making the hatter elongate it; my next brother has so remarkably broad a head that he cannot be fitted without altering a large hat the other way: and so I think it is in many families and races, as anyone who tries to puzzle out craniological results will find.

So again as regards other guides to race. It is admitted that language is not always a safe guide, but still it is a very important element in ethnological inquiries, especially among primitive races. I have paid some attention to that, and my impression is strong that language tests of race are to be found in the few simple elementary words and forms which any observer can easily master and examine, and not in the higher developments of the language, which are generally much intermixed with and influenced by foreign elements. I roughly put together a few dozen test words, &c. which we found very efficacious in India. Take English, too; the origin of the race is found in the lower and monosyllabic words, though the majority of the English words in a dictionary are Latin and French.

There is another race-guide which requires much care and some scientific accuracy, though not of what we should call a properly anthropometric character —I mean laws, customs, and habits. Like language these too may be varied by foreign influences, but I incline to think that they are more important for our purposes than has always been recognised, and are at least as persistent as, perhaps more persistent than, language. At any rate, they are certainly most important as affecting the modern history and cultivation of man; and while some laws and customs require scientific study, many habits and practices are on the surface, and open to the observation of every intelligent observer. I might class food and drink among such habits, as being those which bear most directly of all on physical development. For instance, one scarcely realises till one goes to China how important is the cow as pre-eminently an Aryan animal, the early sacredness of which was founded upon uses almost ignored by other great races such as the Chinese. The Chinese, again, who will not touch milk, and reject some other food which we think among the best (pheasants, for instance), make constant and large use of food which we reject, such as puppies and rats. It is most interesting to inquire whether there is any foundation for either class of prejudices.

Among other habits and institutions well worthy of observation I might cite marriage and the family, descent through the female or through the male, the forms of small self-governing communities, and the tenure of land. Animals of nearly allied species seem to be divided by curiously sharp lines into polygamous and monogamous races. It is hard to understand why hares should be strictly monogamous, rabbits polygamous, partridges monogamous, pheasants polygamous, geese monogamous, ducks polygamous. We have yet to discover to which class man belonged before laws divided the race into two opposite camps in this matter. When we come to institutions and land tenure we approach the region of politics, but for my part I must at once say that, if we avoid mere party in politics, we anthropologists are called on to perform most important functions in the social politics of the day. What can be more important than to ascertain the effect, on the race, of modern urban life, of the increased use of meat, of the diminished use of milk, of the enormously increased consumption of tea, of the more constant use of the eyes and the brain, viewing these subjects in their broad general results, rather than from a merely medical point of view?

My view of the good work that may be done by the more popular methods in anthropology may be somewhat consoling to our countrymen generally, for they seem as a whole to be too busy for much science, and to be deficient in it. I see it was stated that we have to get anthropometric instruments from abroad. But on the other hand our opportunities for observation far outrival all others. In our vast empire we have every race and every shade, every stage of progress, from the lowest to the highest; every institution and every method of living. As rulers, as explorers, as merchants, as employers of labour, as colonists, we come into the nearest contact, and have the most intimate relations with almost every people and every tribe on the face of the earth. We are indeed a people who, if we make but the most moderate use of opportunities, may bring together such a mass of knowledge of mankind as to leave nothing wanting. Surely then in this country anthropology is no mean subject.

Both in regard to the greatness of our dominion, the vastness of the population, and its infinite variety, India is by far the greatest of our fields, as it is that in which we have the most complete and effective official machinery. India is remarkable not only for its many countries, climates, and races, but also for the division of the populations into what one may call horizontal strata. There, under the caste system, every rank, occupation, and profession represents in some sort a race, and that in enormous variety. Whatever infiltration of blood there may be, every caste in India is at least as much a peculiar and separate race as were till lately Jews or gipsies in our own country, and more so. Every one of them has, too, its own institutions, its own rules of marriage and inheritance, its own laws and customs; and I need scarcely add that outside this Hindoo agglomeration of many races there are the various aboriginal races—also in great variety, and in a state of excellent preservation—tribes not of one family of the human race, but of almost every great family, from the purest Aryans of the north-west to what I may call extreme Mongolians in the east, and primitive blacks in the centre and south.

In truth, my experience of that great anthropological field India is my excuse for sitting here to-day. It has been my fortune to serve in very many parts of that great country, and, so far as my scanty acquirements permit, I have always taken great interest in, and inquired much about, the races and varieties of the peoples; and I think I may claim this, too, that ever since I have been a good deal absorbed in politics, in all the travels I have made in several parts of the world, in Eastern Europe, in America, and elsewhere, I have never wholly forgotten my ethnological proclivities, and have pried about a good deal to pick up information regarding the various races and tribes.

As India is in some sense an epitome of the world, so I may also say that the last provinces I administered, those forming the Government of Bengal, are or were an epitome of India. At that time the whole of Assam and the eastern frontiers were under Bengal, and we certainly had a very much greater variety of races than any other province in India—perhaps I may say than any other country in the world. Among the more advanced races, besides the whole of the well-marked Bengalee nationality we had some twenty millions of Hindustanis on the north, the Ooryahs on the west, and the Assamese on the east; then of the Indian aboriginal races, while in other provinces they have but scanty hill tribes, counted by thousands, we have in the western districts of Bengal many millions of these aborigines, settled, comparatively civilised, a fecund, colonising, and migratory people; we have them in endless variety of both the great aboriginal families, the Dravidian and that now generally known as the Kolarian. Partly in the Central Provinces and partly in Bengal, it has indeed been my lot to administer the whole of what I may call 'aboriginal India.' I may here mention that the several aboriginal Dravidian tribes of this tract speak languages clearly Dravidian in their roots and yet for the rest so distant from the cultivated Dravidian languages that the common origin must be very ancient indeed. But no one who sees these people can doubt their non-Caucasian character; and that may go far to settle the question whether the Dravidians of the Peninsula are of Caucasian origin, or non-Caucasians overlaid by an Aryan over-crust.

Again, on the north and east we have some forest tribes which may or may not be related to the aborigines of the interior of India. But as soon as we get into the hill country we meet with every form of what may be called the Indo-Chinese type—all the way from the frontiers of Nepal on the north, along the Eastern Himalayas, round both sides of Assam, and then on to Maneepore, the Chittagong hills, and the Burmese country. Here and there in this great extent of country we have many unclassed races with peculiar languages and institutions of their own—some very savage, others far advanced in civilisation. Among the latter I might mention, for instance, the Khassyahs, a very peculiar people with highly developed constitutional and elective forms of government, and also specially interesting as exhibiting far the best specimen of which I have anywhere heard of the matriarchal, or perhaps I should rather say matri-herital system fully carried out under recognised and well-defined law among a civilised people. The result of observation of the Khassyahs has been to separate in my mind the two ideas of matri-heritage and polyandry, and to suggest that polyandry is really only a local accident, the result of scarcity of women; as, for instance, in some parts of the Himalayas, where the hill women are in great demand in the adjoining plains, and the hill men are obliged to be content with a reduced number of women. Among the Khassyahs, on the other hand, there is no polyandry (so far as I have been able to learn) though there is great facility for divorce; and heritage through the female becomes quite intelligible, I may say natural, when we see that the females do not leave the maternal home and family and join any other family, as do the Aryans. They are the stock-in-trade of the family, the queen bees as it were; they take to themselves husbands—only one at a time—and if he is divorced they may take another—but the husband is a mere outsider belonging to another family. The property of the woman goes in the woman's family, the property of the man in his own maternal family. It should be added, however, that in these maternal families, though the heritage comes through the female, the males rule, as they ought to in all well-ordered communities.

When I administered the government of Bengal I did the best I could to obtain a classification of our many races, and a comparison of the languages brought together under my system of test words, and officially published in a large volume. We owe to the unrivalled experience of the late General Dalton a mass of information regarding the western aboriginal tribes, comprised in his great ethnological volume and many other publications; and more recently that very distinguished Indian officer, Mr. A. Mackenzie, partly a Scotchman and partly a Birmingham man, has brought together in his 'North-east Frontier of Bengal' a full and most interesting account of the eastern tribes. Now I am happy to say that one of my old fellow-workers in Bengal, who at present most worthily and well administers the government of that province, has undertaken, through Mr. Risley, a much greater work than any of us have yet attempted, viz., a general survey of the whole people, not only as regards their physical characteristics and languages, &c. but also (and this is the newest and most important part of the undertaking) as regards their institutions, laws, and social rules. It is hoped that, by obtaining accurate information of this kind regarding the many races, tribes, and castes of these great provinces, a flood of light may be thrown on the social history of the human race. It is a very great undertaking, but successfully carried out must have very great results. I can conceive nothing more important and interesting, and only hope that something of the kind may be attempted for India as a whole. Some of the most important castes, the Brahmins for instance, are so widely spread that we can hardly realise their position without extending the survey over India. In Bengal I think they are little agricultural, while in some provinces they are among the best of the agriculturists.

I could well wish that we had systematic inquiries of this kind nearer home. Europe is almost as good an anthropological field as India, and in our islands there is still very much room for investigation. In my own country of Scotland, after much asking, I have never been able to get any information who the Aberdonians are, and what is the language they speak, so different in its forms and intonations from the rest of Scotland. In England some most interesting maps might be made if it were only to trace the letter *h*, showing where it begins and where it ends. I have a belief that though languages may be changed and cease to indicate races, there is a great racial persistency in the letter *h* or the absence of it. The Scotch and the Irish have adopted the English language, but no Scotchman or Irishman was ever in the smallest degree wanting in aspirates—an Englishman might perhaps call them hyper-aspirators. The greater part of England, on the contrary, is equally persistent in the dropping of *h*'s. The whole subject is most interesting, not only in regard to the use or omission of the *h* by various races, but also on account of the very singular—I may say phenomenal—tendency of so many of the English neither to maintain nor to abandon the *h*, but simply to reverse the written language, omitting the *h* where it is written, and putting it in where it is not, in a peculiarly aggressive manner. It has been noticed, with truth, that we seem legitimately to drop the *h* in almost all words that come direct from the Latin, as 'hour,' 'heir,' 'honor,' yet in the Latin we pronounce the *h* fully. Is the spoken language the true tradition? Can it be that, while the Greeks spoke in aspirates which they did not write, the Romans clipped those which they did write, and that the modern Englishman combines the practice of these two famous races? Or is there any foundation for what I can call no more than a conjecture, viz., that the real English is that spoken by the Scotch, and that the corruption of the *h*'s is French brought in by the Normans? If a language map showed the clipping of *h*'s to be coincident with large Norman settlements, that might be so. Perhaps a few hundred years ago it was the aristocratic thing to clip the *h*'s, and the fashion may have gradually gone to the lower classes like the swallow-tailed coat worn by the typical Irish peasant, while the upper classes have been partially reformed back to true English by contact with the Scotch—only partially, though, for they still say 'wĕn' and 'wāle' instead of 'when' and 'whale,' to say nothing of 'idear' and 'Indiar.'

This, however, is a digression. I am afraid I have been long in coming to the main object of this address, viz. to recommend the systematic and scientific cultivation of man—what I may call 'homi-culture,' in the same sense as 'oyster-culture,' 'bee-culture,' or 'cattle-culture'—and that with a view both to physical and mental qualities. It seems very sad, indeed, that, when so much has been done to improve and develop dogs, cattle, oysters, cabbages, nothing whatever has been done for man, and he is left very much where he was when we have the first authentic records of him. Knowledge, education, arts he has no doubt acquired; but there seems to be no reason to suppose that the individual man is physically or mentally a superior creature to what he was five thousand years ago. We are not sure that under very modern influences he may not retrograde. No one doubts that, by careful selection and cultivation, cattle, vegetables, and many other things have been immensely improved. In regard to animals and plants we have very largely mastered the principles of heredity and culture, and the modes by which good qualities may be maximised, bad qualities minimised. Why should not man be similarly improved? It is true that the mind has a larger share in that which constitutes a man; but after all this is only a question of degree—the cultivation of the mind *does* enter very largely into animal-culture. I apprehend there is no doubt that the superiority for our purposes of shorthorns, black-polled, and other famous breeds of cattle is very largely due to placid and well-regulated minds, which enable them to take calmly a short and happy life, and to assimilate their food, differing in this very much from their restless and often vicious ancestors. Surely, then, if we only had the requisite knowledge, and, taking a practical view of life, could regulate our domestic arrangements with some degree of reason, rather than by habit, prejudice, and the foolish ideas cultivated by foolish novelists, man too might be greatly improved.

It may be admitted that we are not in a position to begin confident man-culture at once. Much study is first required and much knowledge must be accumulated before we can be confident in practice. The first thing that most strikes us in man, as compared with all domesticated and even most widely-spread wild animals, is the extremely small variation in man all over the globe. There are differences which seem large to us, but are extremely small from a more enlarged point of view. How enormous are the differences between different breeds of dogs, horses, and cattle! When we come to man the difference of which we make most is that of colour—a feature which we think quite trivial in animals. Who thinks very much more highly of a white than of a black cow, of a grey horse than of a black one? Our skilled eyes recognise variations of human feature, but they are so slight that the inhabitant of another planet would see no more difference than in the countenances of a flock of sheep. In size, compared to other animals, the differences are but slight. Probably there is no race whose average height really approaches six feet, and I doubt if any are on the average so small as five feet. In other physical features there are no considerable differences of formation whatever. Then as regards the mind we have yet to learn that there are very wide differences of mental capacity between different races. Very likely—probably, I may say—there are considerable variations, but they are not so wide as to be apparent without careful and accurate study. With the superficial knowledge we have, no one can say that Europeans, Hindus, Chinese, are born with brains superior or inferior to the other; and even in regard to the negro I do not know that it is yet shown that with equal advantages negro babies might not grow up nearly or quite as intelligent as Europeans. I do not say that it is so, but only that the question has not yet been sufficiently worked out. The difference is not so radical as to be self-evident from the first. Still, such experience as we have and the analogies derived from domesticated animals both tend to the belief that there *are* considerable, if not excessive, variations in the qualities and capacities of different races of men.

It seems to me, then, that the first object to which observation and experiment should be directed is to ascertain how far the qualities which distinguish different races, peoples, castes, and families are congenital and hereditary, and how far the result of education and surroundings. The distinguished President of the Anthropological Institute, Mr. F. Galton, has done much to make a beginning of the study of hereditary qualities in man, but there is still much to be done. To begin with very rudimentary facts we hardly know whether courage in man and absence of courage in women are natural or artificial qualities; whether right-handedness is natural or a very ancient fashion. Coming nearer to modern variations we do not know how far energy, enterprise, constructive power, and all the rest of it are qualities appertaining to particular breeds, like the qualities of pointers or greyhounds; or whether they are more the result of education and surroundings. What is the effect on mind or body of vegetable and animal food respectively, and of the use of one stimulant and another? Why do particular races affect particular stimulants? Why is the Northern European more especially given to spirits, and the Chinese and Indo-Chinese races to opium? Is there anything in the breed that enables Britishers to rule over Hindus, or is it only education? Why has a Chinaman some virtues which an Irishman has not, and *vice versâ*? All through the most important inquiry is to sift out those qualities in regard to which we must look to improvement in the breed, and those which more depend on education, so that power may not be wasted by efforts in the wrong direction—by breeding for qualities which already exist or educating where the breed renders a particular education hopeless.

We must try to learn the direction in which we are to work first, and then the methods by which we may effect improvements in the ascertained direction—whether it be in the direction of breed or in that of education.

Now to come to the practical modes by which effect might be given to some such ideas as I have ventured to suggest.

To begin at the beginning, I think that, while so much effort and so much science have been expended, perhaps not very fructuously, in inquiries into the origin of man, too little systematic attention has been given to the radical differences between the modern man and modern animals. For instance, in the matter of speech no one can doubt that dogs and elephants and seals understand a great deal of language. One cannot see the individuals of a pack of hounds answer to their names without being satisfied that they not only attach a meaning to a few rude sounds, but can distinguish niceties and refinements of language. Again, we know that parrots and other creatures can speak our language; but I have never seen the question whether any one creature can both speak and understand thoroughly worked out. Has it been carefully and thoroughly ascertained whether any animals really cry or laugh? Sir John Lubbock and others have given attention to the question whether, in habitation-building, and the like, bees and ants exercise an intelligent discretion or follow one unvarying hereditary instinct; but I do not think any distinct conclusion has been arrived at. Can any monkey or other creature be educated up to the point of putting sticks on a fire and cooking chestnuts? I am afraid that on all these subjects there has been nothing but very desultory individual effort.

Then as regards man-breeding. Probably we have enough physiological knowledge to effect a vast improvement in the pairing of individuals of the same or allied races if we could only apply that knowledge to make fitting marriages, instead of giving way to foolish ideas about love and the tastes of young people, whom we can hardly trust to choose their own bonnets, much less to choose in a graver matter in which they are most likely to be influenced by frivolous prejudices. As I am not preaching I need say no more on that—all that I could say is self-evident. But when we come to the very important question of the crossing of races there is very great need of scientific observation and experiment. Both the general knowledge that we have of humans and the analogy of animals tend to show the great benefit of the crossing of breeds. Anglo-Saxon is an awkward term. I do not stop to inquire whether it represents two races; whether the peasant of the Lothians is an Englishman and the peasant of the south of England a Saxon, or why one is superior to the other; but using the word English for the Teutonic inhabitants of these islands I think one can hardly doubt that the English breed crossed with a dash of Celtic blood produces a better animal than either of the parent races. Witness the people of many parts of Scotland, of Ulster, and, I believe I may also say, of Cornwall. It is the use of the Celtic blood as an alloy that makes me specially unwilling to see Highlanders, and even wild Irishmen, exterminated from these islands. It may be worse for all of us if that comes to pass.

There is a popular belief that the cross between an Englishman and a Hindu produces a race inferior to either. I very much doubt the fact. Owing to the caste system (and it prevails with us almost as much as with the Hindus) half-castes are placed at a very great disadvantage, but I doubt if they are naturally inferior; at any rate, the question requires to be worked out. I think we have the means of doing so if we systematically went about it. So again as regards the cross-breeds between whites and negroes. There is so much prejudice on the subject in the United States that it is very difficult to arrive at the truth. Some people think that the stimulating climate tends to make the white race in America wear itself out, and that (apart from the present great immigration from Europe) it would be a real improvement to the American race if the whites were crossed with the more phlegmatic blacks, say, in the proportion of six or eight of white to one of black, which now exists in the States. However, that is their affair, but a very important question for them.

And this brings me to the effect of climate. Is it the fact that in course of generations settled in America the climate alters the British race—or perhaps I should say European races? What is the tendency of the very peculiar Australian climate? It has passed into a popular proverb that the European race cannot survive in India beyond the second or third generation; and the result of that belief has been of enormous practical importance, for no sort of colonisation has been attempted. Yet I wholly doubt if the belief can be supported by any facts whatever; it is one of those things that are universally believed because they have never been tried, and therefore cannot be contradicted. Till little more than fifty years ago Europeans were not allowed to settle in India. To this day opportunities for education and good up-bringing are very much wanting—the surroundings are most unfavourable to European children; yet a good many instances could now be quoted of Europeans brought up in India who are physically just as good as their parents. The mortality in the European orphan asylums is extraordinarily low. It is not at all certain that the race might not be adapted to the climate, especially as the cool hill regions are those least occupied by the natives, and most fit for many lucrative industries introduced by Europeans.

Coming to physical and mental education, I have already alluded to some of the subjects which urgently require attention, the most important of which is, I think, the effect of what we call civilised life, and especially urban life. It is impossible to see the crowded and inferior dwellings in which so vast a population lives in towns, without room for the gardens which their fathers had, and without the space and recreations natural to man, and not to fear for the result on the race. I might also say more on the question of physical education and on that of a mental education so general as to leave no mere primitive jungle plants as a stock on which to graft improved varieties; a subject which is already engaging anxious attention. On many other questions to which I have briefly alluded I might enlarge, but I have detained you so long that I think you would prefer to get to business; and so I will conclude by recommending practical anthropology to your earnest attention.

FRIDAY, SEPTEMBER 3.

The following Papers were read:—

1. *On the Native Tribes of the Egyptian Súdan.* *By* Sir Charles Wilson, *K.C.B., F.R.S.*

The native races of the Súdan may be divided into four distinct groups—the Hamitic, Semitic, Núba, and Negro; but the first three only are dealt with in the present paper.

I. *Hamitic.*

The *Ababdeh* extend from the Nile at Assúan to the Red Sea, and from the Korosko desert northwards to the Keneh-Kosseir road. They represent the Blemyes of classical geographers. They speak Arabic, and have a large admixture of fellah blood; they claim Arab descent, and their sheikh families are descended from members of the Rabya Arab tribe. The sub-tribes are Ash-Shebáb, Abudyín, and Foggara; in all, 6,000 men.

The *Bisharín* stretch from the Nile, between the Atbara and Abu Ahmed, to the vicinity of Mount Elba on the Red Sea. They speak Tobedawiet, and are of purer blood than the Ababdeh. They are divided into several clans—Shentirab, Hamed-Orab, Aliab, Amrab, Hamar, Eireiab, Geihamab, &c., and number 20,000 men.

The *Amarar* extend from the Sawákin-Berber road, between Hamdab and Ariab, northwards to Mount Elba. They speak Tobedawiet, and claim descent from the Koreish of Mecca. They are divided into three groups—the Weled Gwilei, Weled Aliab, and Weled Kurbab-Wagadab, and several smaller clans, numbering 15,000 men.

The *Sawákinese* are not Hamitic, but of Hadramaut origin.

The *Hadendoa* occupy the country from Sawákin and Ariab to the vicinity of Kassala. They speak Tobedawiet, and are of pure blood, though one clan—Kamilab—claims descent from the Koreish. They are divided into twenty clans and number 30,000 men.

The *Artegas* speak Tobedawiet, but are of Hadramaut origin; they number 5,000 men and live at Tokar.

The *Kabbabish,* the largest tribe in the Súdan, extend from Dongola and Abu Gussi to the confines of Darfúr; they speak a pure Koranic Arabic, and have a tradition that they came from Tunis; they are possibly of Berber descent, but the sheikhs are apparently of Arab origin. They are divided into two great branches and several minor clans. One clan—Kawahleh—appears to be of Arab origin.

The *Bazi* are said by Selim el Assúani to be a Beja tribe.

The Beja, or Tobedawiet-speaking tribes, are probably the representatives of the people who erected the monuments at Meröe. The Arab conquerors seem to have established amongst them the patriarchal form of government, and to have constituted themselves the ruling families. There is a marked difference of type between the sheikh families and the common men.

II. *Semitic.*

The *Beni Amr* extend from the Khor Baraka to the sea-coast along the Abyssinian frontier. A portion of the tribe speak Gíz and a portion Tobedawiet; among the northern clans are many families of Beja origin.

The *Hallenga* speak Gíz and Tobedawiet; they claim descent from Ahmed ibu Hallag, the barber of the Prophet.

The *Habab, Bejuk, Mensa, Bogos,* &c., are allied to the Abyssinian families.

The *Ashraf,* near Sawákin, immigrated in 1550 A.D. They claim descent from the Prophet, and know Arabic, though their vernacular is Tobedawiet.

The *Raschaida* and *Zebada* are recent arrivals from Arabia; they live near Sawákin, and are not yet assimilated to Beja tribes. The tribes in the Nile valley, proceeding south from Wady Halfa, are:—

The *Gararish*, on right bank of Nile, from Wady Halfa to Merawi; they are allied to the Foggara Ababdeh, but are a very mixed people, with much Arab blood, and have lost the Beja type.

The *Hauwawir* extend along the desert road from Debbeh to Khartúm as far as Bir Gamr. They are nomads of fairly pure blood, and related to the Huweir of Lower Egypt. Divided into several clans and number 2,000 men.

The *Shagiyeh*, partly nomad, partly agricultural, on both banks of the Nile from Korti to Birti, claim descent from the Beni Abbas, but are of mixed blood from intermarriage with the Núba, whom they dispossessed; they preserve, however, their Semitic type. They are divided into twelve clans; language, Arabic.

The *Monassir*, partly nomad, partly agricultural, on both banks of Nile in the cataract country above Birti. They are of mixed Arab, Núba, and Beja blood, and claim descent from Mausúr, brother of Abad, the grandfather of the Ababdeh.

The *Robatab* are semi-nomads, and occupy the country in the bend of the Nile at Abu Hamed. They are of mixed Arab and Núba blood, and claim descent from the Beni Abbas.

The *Hassaníyeh* are pure nomads in the desert between Abudom and the Nile, opposite Shendi; a small tribe given to robbery.

The *Jáálin* on both banks of the Nile from Abu Hamed to Khartúm; of Arab origin, claiming descent from Koreish; partly nomad, partly agricultural; some of the clans have largely intermarried with the Núba. The Semitic type is clear, though different from the Shagiyeh. They are divided into a large number of clans. The Jáálín and Shagiyeh have adopted the non-Semitic custom of cutting the face.

The *Battahín*, on the Blue Nile near Khartúm, appear to be of mixed Arab and Núba blood.

The *Shukríyeh* are nomads between the Atbara and the Blue Nile, and apparently of Arab origin.

The *Baggara* tribes of Kerdofan are true nomad Arabs; the date of their arrival in the Súdan is uncertain, but they appear to have gradually drifted up the Nile valley. They are little known, but amongst the tribes are the Duguaim, Jawameah, Hamr, Jalaydat, Hawazim, Bedayriah, Kenana, Howara, and Beni Gerar.

III. *Núba.*

The Núba are an essentially agricultural people and indigenous to the country. They form the population of the Nile valley from Assúan to Korti, and are widely scattered over Sennár, Kordofan, and Darfúr. They speak a language called Rotana. In Kenús they are much mixed with Arab blood, and some families claim descent from the Koreish. The purest Núba blood is found in Jebel Daïer, Jebel Takalla, and Dar Núba, where the people have maintained their independence.

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2. *On the Dutch in South Africa. By* Miss F. S. ALLIOTT.

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3. *On the Celtic and Germanic Designs on Runic Crosses.*
By Professor BOYD DAWKINS, *M.A., F.R.S., F.S.A.*

In dealing with the ornamentation of Runic crosses it is very generally assumed by archæologists, that the early Irish MSS., such as the Book of Kells and the illuminated gospels of St. Cuthbert and St. Chad, are of pure Irish art, and that consequently the interlacing 'rope' or 'basket' work pattern is distinctly Irish and Celtic. It is, however, an assumption which may readily be disposed of by an appeal to the distribution of the designs on ornaments and monuments in the British Isles, and in France, Scandinavia, and Germany. We will consider them under two heads. 1st. The scroll, spiral, and flamboyant work, consisting of graceful combinations of curves; and, secondly, the interlacing work, more or less square and angular—the 'rope' or 'basket.' The first of these two styles first appears in the British Isles, Scandinavia, France, and Germany, in infinitely remote Prehistoric times, in the Bronze Age, and subsequently became more and more elaborate in the Prehistoric Iron Age, constituting the late Celtic art of Mr. Franks. This may be proved by the examination of the various collections in those countries. This art was probably ultimately derived from the centres of civilisation in South Europe, principally Greek and Etruscan, and has clearly been proved by Chantre to have been introduced into France from Italy.

From its prevalence among the Celts of the British Isles and of France it is justly termed Celtic, and it was dominant in these regions down to the time of the retreat of the Roman legions before their Germanic foes. I do not know of a single case of its association with the interlacing pattern in those regions in any design of a date before the time of the Germanic invasion.

The interlacing pattern of Class II. is conspicuous by its absence from Irish art until the days of early Irish Christianity. It may be traced far and wide over Europe, and among warriors who owed nothing to Irish art. It occurs in finds proved beyond controversy to be Germanic or Teutonic, using the term to include also the Scandinavians. In Britain it is the ruling design, in Anglian and Saxon finds, in cemeteries and in barrows, such, for example, as that recently explored at Taplow. In France it is associated with the remains of the Germanic invaders, Merovingian, Frankish, and others. It has been met with both in Switzerland and Italy, and generally on the Continent in those regions into which the German tribes penetrated. It does not occur in France or the British Isles in association with any remains of a date before the Germanic tribes had begun to move to the attack of the Roman Empire. From these facts it may be concluded that it is distinctly Germanic, and not Celtic, and still less 'pure Irish.' Whence it was ultimately derived is a question which need not be discussed in this place.

The association of the Celtic graceful spiral and flamboyant with the Germanic design, not only in the early Irish MSS., but in Irish chalices and ornaments, may readily be accounted for by the influence of the Germanic tribes (including Scandinavians) not only in Ireland in the eighth and following centuries, but in those parts of Europe traversed by the Irish missionaries. It is only reasonable to suppose that the men who introduced Christianity into Scandinavia and North Germany, and founded the great abbey of St. Gall in Switzerland, should have fallen under the influence of Germanic art, and have combined the native Celtic with the foreign Germanic designs. As a matter of fact the two styles were so combined not only in Ireland but in Scotland and England, and generally on the Continent wherever the Celtic and Germanic peoples lived side by side. It may, therefore, be concluded that the Irish illuminated MSS. cannot be taken as the tests of pure Irish, or even of Celtic art, but that a large part of the ornamentation is due to contact with Germanic art.

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4. *Notes on Natives of the Kimberley District, Western Australia.*

By EDWARD J. HARDMAN, *F.R.G.S.I.*

During two visits to the Kimberley District in the years 1883 and 1884 the author had opportunities of studying the characteristics and customs of the Aborigines. The district is in the extreme tropical portion of Western Australia. The natives, however, differ but little in appearance from other tribes of the Australian continent, except that they are somewhat superior in physique, and appear to be, on the whole, rather more intelligent than the southern races. The initiatory rites of the young men and the marriage laws are peculiarly interesting, and exhibit many differences from those hitherto observed upon. Circumcision and other similar but more severe operations are undergone by the youths, and the females in some parts also submit to painful initiatory rites. There are four marriage sects—Paljari, Kimera, Bannighu, and Boorungoo—and no member of any one of these sects can marry into it. He or she must marry into another sect, concerning which there are rigid rules laid down. Thus Paljari marries Kimera, Bannighu marries Boorungoo, and in both cases the children belong to one of the other sects, not those of either of the parents. These matters were entered into in some detail, together with a description of general habits and customs, native weapons, implements, &c. The author exhibited some photographs of the native men and women, and also four skulls of the Kimberley natives, which he had brought home, and which have been measured and described by Dr. Phin. S. Abraham, F.R.C.S.I.

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5. *Observations on Four Crania, from Kimberley, West Australia (Mr. Hardman's Collection).* *By* P. S. ABRAHAM, *M.A., M.D., B.Sc., F.R.C.S.I.*

For convenience of reference, the specimens are marked A, B, C, and D. The measurements have been taken in accordance with the rules laid down by Broca, Flower, Topinard, and other modern anthropologists. In estimating the capacities, with No. 8 shot, I had the kind assistance of Mr. Oldfield Thomas, of the Natural History Department, British Museum.

The skulls present many of the typical Australian characters: they are dolicocephalic and micro-cephalic, and with prominent supra-orbital ridges in the males; they are remarkable, however, in being by no means prognathous or platyrhine. A and C are without doubt the crania of adult males, and D is the skull of a female, probably past middle life. In its slight development of supra-orbital and muscular ridges, B has a strong resemblance to a female skull; but from the fact that its last molars have not yet appeared, and that the cranial sutures (except the basilar) are not united, it may possibly have belonged to a young male. This is the more likely, for, as in the case of the undoubtedly male skulls A and C, one or more of the incisor teeth have been removed. A and B have thus had the two inner incisors, and C only the right inner incisor, extracted in early youth. The corresponding alveoli have, in consequence, so closed up that the basi-alveolar length in A and B could not be taken with accuracy. It is clear, however, that C is, for an Australian, remarkably orthognathous, while D is mesognathous.

As in the skulls of other low races, the cranial sutures are in all the specimens comparatively simple. Wormian bones are present in A and C, and an epipteric in A. In B, on the right side, the frontal and squamosal bones nearly meet at the pterion. The nasal indices are all mesorhine, while the orbital index is mesoseme in A, B, and D, and microseme in C.

The forehead in A, B, and C is low and very receding, and the brain-case is arched and very narrow above, so as to be actually scapho-cephalic. In D, on the other hand, the forehead and the vault of the cranium are of a much higher type. In the smallness and flatness of its nasal bones, however, and in some other facial points, D exhibits lower characters than the others. An imperfect lower jaw belongs to D—of a very low type, its most striking feature being the little development of a mental prominence.

MEASUREMENTS.

	A	B	C	D
Length, L.				
Glabello-occipital	179	177	186	182
Ophryo-occipital	176	175	183	182
Breadth, B	127	129	135	127
Cephalic index, B I	709	729	726	698
Height, H	130	132	135	128
Height index, H I	726	746	726	703
Basi-nasal length, B N	98	97	101	103
Basi-alveolar length, B A	(?) 99 [1]	(?) 95 [1]	98	105
Alveolar index, A I	(?) 1010 [1]	(?) 979 [1]	970	1019

[1] In consequence of the early extraction of the middle incisors these numbers are only approximate.

MEASUREMENTS—*continued.*

	A	B	C	D
Nasal height, Nh . .	50	48	52	49
Nasal width, Nw . .	26	24	26	26
Nasal index, Ni . .	520	500	500	531
Orbital width, Ow . .	43	36	43	40
Orbital height, Oh . .	37	32	35	35
Orbital index, Oi . .	860	889	814	875
Pre-auricular circumference	270	253	265	270
Total circumference, C .	485	405	518	496
Capacity, Ca . . .	1263	1247	1415	1276
Stephanic breadth . .	92	113	100	98
Mid-frontal breadth .	94	90	95	93
Biasteric breadth . .	100	101	114	104
Biauricular breadth .	121	114	123	116
Foramen magnum, length	39	36	38	33
„ „ breadth	32	30	33	30
Transverse arcs, frontal .	270	263	275	275
„ „ bregmatic	280	285	295	277
„ „ parietal .	289	294	300	280
„ „ occipital .	250	248	255	230
Longitudinal arc, frontal .	120	128	129	129
„ „ parietal	128	126	135	120
„ „ occipital	98	104	106	107
Bijugal breadth . .	119	109	121	108
Bizygomatic breadth .	133	130	141	128
Palatal length . . .	55 } int. 56 } ext.	50 } int. 51 } ext.	52 } int. 55 } ext.	53 } int. 62 } ext.
Palatal breadth . .	43 66	38 65	41 65	37 61
Bimalar	103	96	105	98
Naso-malar . . .	110	105	115	105
„ „ index . .	1068	1073	1085	1071
Length, molar series .	42	—[1]	40	—[1]

6. *The Scientific Prevention of Consumption.*[2]

By G. W. HAMBLETON.

We are so familiar with consumption, it has, indeed, become so much a part and parcel of our daily life, that few only are aware of the number of its victims or the amount of suffering and misery it entails. To many it will be a painful surprise to learn that nearly 70,000 deaths are recorded, and that there are some 200,000 persons suffering from it in Great Britain during the course of a year. Yet, notwithstanding its practically unchanging rate of mortality, consumption is recognised as a preventable disease, and the evidence that demonstrates this is complete and conclusive. The lungs of persons who have died from some other disease are frequently found to contain the remains of an attack of consumption, that has been overcome. In some there is no previous history of the symptoms or signs of that attack, but in others such a history has, in their youth, been clearly obtained. Sheffield grinders, those following sedentary occupations, and members of consumptive families, presenting the signs and symptoms of the disease, have been known, on obtaining a complete change of surroundings and residence to completely recover.

As the result of my experimental investigation on the ætiology of consumption, I have shown that the disease is due to those conditions that reduce the breathing surface of the lungs below a certain point in proportion to the rest of the body.

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[1] This measurement cannot be taken, from imperfection of the alveoli.

[2] Published, with diagrams, by J. & A. Churchill, 11 New Burlington Street, W.

Experimentally by such conditions I have produced the disease. Wherever these conditions are, there consumption is found: wherever these conditions are absent, there the disease is unknown: and upon the introduction of the former into the latter the disease makes its appearance. Evidence given to prove these points.

The causal conditions are those that habitually tend to disuse of the lungs and those that habitually compress or inflict direct injury upon the lungs. Examples given.

There are therefore two distinct objects to be accomplished in the prevention of consumption. On the one hand we have to secure an adequate amount of breathing capacity in proportion to the rest of the body, and on the other to prevent either compression of the chest or injury to the lungs. This can be done by adopting those measures that tend to the development of the breathing capacity and suppressing or obviating those conditions that compress or injure the lungs. By adopting measures is meant placing men, women, and children under conditions of habitation, clothing, education, and urging upon them habits that tend individually and collectively to develop the lungs. Some details on these points and on the prevention of inhalation of small particles of various substances and compression of chest were also given.

Diagrams showing the effect on the proportion of the chest to the rest of the body due to various conditions from health to consumption were shown.

7. *Dragon Sacrifices at the Vernal Equinox.* *By* GEORGE ST. CLAIR, *F.G.S.*

The object of this paper was to show that human sacrifice, which prevailed extensively in early times, was a custom connected especially with the Vernal Equinox, and that the offerings were made to appease a mythical dragon which made its demand at that time. The Dragon of mythology is identified and defined, and it is shown in what sense he opened his jaws at the spring season of the year.

Human sacrifices have been offered from motives which ought to be respected. In Egypt they had been abolished at an early period; but in Greece we have historical instances. By-and-by substitution came about, and took various forms, one form being to offer one victim when danger threatened (and the gods demanded) a multitude. Death or the Grave was propitiated in this way, and it came to be symbolised by Darkness, because the heavenly bodies went down into darkness in the course of their revolution. The Darkness was symbolised by a Dragon. In eclipses the darkness devours the sun or moon; nocturnal darkness swallows the sun and stars; but the chief antitype of the Dragon is the winter half of the great year of the precession cycle. By the rule of reversal which belongs to the great year the darkness encroaches on the eastern side of the heavens, and the dragon opens its jaws at the vernal equinox.

Human sacrifice was practised more especially at the spring of the year, or (in other instances) in honour of deities who once presided over equinox constellations. Artemis and Cronus, to whom this homage was chiefly shown, were both connected with the zodiacal sign Scorpio: and, according to M. Ernest de Bunsen, Scorpio was the starting-point of the primitive calendar. If the festival of Saturn did not get displaced or misplaced through the precession movement, it was still a festival in honour of the god of the under world—and that meant death and the grave.

Tradition says that human sacrifices were abolished by Hercules. As Scorpio rises with Hercules, and ceases to be a dark sign, the mythology is consistent with itself.

The paper might end here, but a paragraph is added to show that the Hebrew Passover may be explained as an equinox festival, at which a lamb was offered as a substitute mercifully provided in the later legislation, in place of an earlier sacrifice corresponding to that of Phœnicians and Greeks. But the tradition of child-sacrifice was kept up by the enemies of the Jews, and is the origin of the false and cruel blood-accusation made so often in the Middle Ages, and occasionally still on the Continent.

SATURDAY, SEPTEMBER 4.

The Section did not meet.

MONDAY, SEPTEMBER 6.

The following Papers were read:—

1. *Evidence of Pre-glacial Man in North Wales.*
By HENRY HICKS, *M.D., F.R.S.*

The author described the conditions under which some flint implements had been discovered during the researches carried on by Mr. E. B. Luxmoore and himself in the Ffynnon Beuno and Cae Gwyn caves, in the Vale of Clwyd, in the years 1884–86. These caverns were explored by them for the first time in 1884, and some of the results were given by the author in a paper at the last meeting of the British Association. The facts then obtained had led him to the conclusion that Pleistocene animals and man must have occupied the caverns before the glacial drifts which occur in the area had been deposited, as it had been found that, although the caverns are now 400 feet above ordnance datum, the materials within them had been disturbed by marine action since the Pleistocene animals and man had occupied them. Moreover, glacial deposits, with foreign pebbles, were found in the caverns overlying the bones. Last year a grant was made by the British Association for the purpose of carrying on the explorations, chiefly with the object of obtaining further evidence as to the age of the deposits in the caverns. The results obtained this year are highly confirmatory of the author's views, and have a very important bearing on the antiquity of man in Britain. It was found that a hidden entrance to the Cae Gwyn cave had been blocked up by a considerable thickness of glacial deposits which must have accumulated subsequently to the occupation of the cave by the Pleistocene mammals. A shaft was dug through these deposits, in front of the entrance, to a depth of over 20 feet, and in the bone earth which extended outwards under the glacial deposits on the south side of the entrance a small well-worked flint flake was discovered, its position being about 18 inches beneath the lowest bed of sand. It seems clear that the contents of the cavern must have been washed out by marine action during the great submergence in the glacial period, and then covered by marine sand and an upper boulder clay. The author believes that the flint implements—lance-heads and scrapers—found in the caverns are also of the same age as this flint flake, hence that they must all have been the work of Pre-glacial man.

2. *On the recent Exploration of Gop Cairn and Cave.*
By Professor BOYD DAWKINS, *M.A., F.R.S., F.S.A.*

The exploration of Gop Cairn and Cave near Gop Hall, Newmarket, St. Asaph, now being carried on by Mr. Pochin, Mr. P. G. Pochin, and Professor Boyd Dawkins, has up to the present time yielded the following results:—

The cairn commonly known as 'Queen Boadicea's Tomb,' and commanding a magnificent view over the Vale of Clwyd, and to the Snowdonian range, over the Irish Sea, and the plain of Lancashire and Cheshire, is composed of blocks of limestone, and is about 40 feet high and about 300 long and 200 broad. We sunk a shaft near the centre 26 feet deep, down to the limestone rock, and drove an adit from the bottom in an N.E. direction and 30 feet long, both of which had to be heavily timbered, and carefully carried out by experienced miners. In following the surface of the rock the only remains met with were a few refuse-heap bones of hog, sheep, or goat, and of ox or horse—too fragmentary to be accurately determined. These are, however, of the usual kind found almost universally in Britain in burial-places of the Neolithic and Bronze ages. The cairn itself is similar in character to that near Mold in the same district, in which a skeleton was discovered in 1832, lying at full length, clad in a golden corselet, now in the British Museum, and adorned with 300 amber beads. An urn, full of ashes and other remains, was also met with. Its large size implies that it was raised in honour of some chieftain conspicuous above his fellows. The trifling results of this exploration, carried on at the cost of Mr. Pochin, are due to our not having as yet hit upon the interment, which we hope to do by further operations.

While the cairn was being attacked Mr. P. G. Pochin discovered a cave 141 feet to the south-west of Gop Cairn, which had been known many years as a fox's earth, and the entrance of which was completely blocked up with earth and stones. On digging it out we found it to consist of a rock shelter, ending in two horizontal passages blocked up either completely or within a few inches of the roof. In the lowest strata of red and yellow clays, mixed with stones, some of which were derived from the boulder clay of the district, were the gnawed and broken bones and teeth of the woolly rhinoceros, bison, horse, reindeer, stag, roe, and cave-hyæna, which belong to the Pleistocene Age, and are similar to those which have been discovered by Dr. Hicks, Prof. Hughes, myself, and others in various caverns in the Vale of Clwyd.

Above this was a deposit containing fragments of charcoal and large quantities of broken bones of animals wild and domestic, comprising the badger, fox, marten, the sheep, or goat, the *Bos longifrons,* horse, and the hog. These were mingled with round stones which had been used as pot-boilers, and a few flint splinters. Near the entrance of the rock-shelter the charcoal was very abundant, and slabs of limestone, burned on their upper surfaces, pointed out the position of the fire-places. This upper accumulation is mainly an old refuse-heap, and its date is fixed by some of the fragments of pottery, one of which bears the rim and ornamentation so commonly met with in pottery of the Bronze Age. This refuse-heap may, therefore, be referred to a period of occupation by them during the Bronze Age.

Besides the above-mentioned remains in the refuse-heap, there were human bones, which increased in number as we dug our way to a square sepulchral chamber, 4 feet 10 inches × 4 feet 10 inches × 3 feet 10 inches, three sides of which were formed of walls of slabs of limestone, the fourth by the inner side of the rock-shelter, and the top by the limestone roof of the cave. It was packed with human skulls and bones of all ages, in the greatest confusion, and evidently interred from time to time. From the association of the bones, however, it was clear that it had not been used merely as an ossuary, but that the bodies themselves had been placed there with the bones in their proper positions, those of the ankle, for example. Along with these were two jet links, shaped like gimblet-handles, a beautifully polished flint flake, ground down to the thinness of $\frac{1}{10}$ of an inch, and with the edges carefully bevelled; and some fragments of rude pottery, ornamented with chevrons, and with the moulding round the rim of the pattern usually met with in sepulchral urns of the Bronze Age. The sepulchral character may, therefore, be referred to the same relative date as the refuse-heaps, and we may conclude that caves were used in North Wales for habitation and for sepulture in the Bronze Age, as I have already proved them to have been so used in the Neolithic Age in this district.

The numerous human remains throw great light on the ethnology of this district in the Bronze Age. The sepulchral caves near Ruthin, and the sepulchral caves and tombs of the Vale of Clwyd prove, as I pointed out many years ago, that in the Neolithic Age the population of this part of Wales was of the Iberic type so widely spread through Europe. In Gop Cave the oval-headed Iberic type is traceable in all the skulls but one. This exception, from its compactness and absence of strong muscular ridges, may be inferred to have belonged to a woman. It is round, prognathous, and with largely developed cheek-bones, and presents all the characters which are usually found in the round-headed Celt—a race which invaded Gaul and Spain in the Neolithic Age, but which was unknown in Britain until the age of Bronze. It is interesting to note that men of the Iberic race were greatly preponderant in the Vale of Clwyd in the Bronze Age. The presence of one Celtic skull in their sepulchre marks the beginning of the fusion of the two races in this district—a fusion which has been going on ever since, and by which the Iberic type is at the present time being slowly obliterated. The Iberic type still lingers in the Vale of Clwyd, but even within my memory it has become rarer than it formerly was.

3. *On the recent Exploration of Bowls's Barrow.* *By* W. CUNNINGTON.

Mr. Cunnington described some further explorations he and his brother have recently made of Bowls's Barrow, near Heytesbury, in South Wilts. The researches have been made at the east end of the barrow, where the original cist has been found empty, but with a skull near it; several other skulls were also found in a more or less broken condition. Facing the floor of the barrow, near where the skeleton was found, was a black unctuous earth which, on recent examination, has been found to contain a large quantity of ammoniacal salts. Separated from the cist, at the east end of the barrow, several horns of oxen have been found, in addition to those already found some years ago. The skulls and other human remains which have been found are primary burials, and were covered by large blocks of Sarsen stone, some weighing from 200 lbs. to 300 lbs.

4. *On Crania and other Bones, from Bowls's Barrow, in Wiltshire.*
By J. G. GARSON, *M.D.*

The skulls recently obtained by Mr. Cunnington from Bowls's Barrow are of large size, and long and narrow in form. The average proportion of the breadth of the skulls to their length is as 72·1 to 100. Two of the skulls are *hyperdolichocephalic*, that is to say, they have a cephalic index laying from 65–70; three are *dolichocephalic*, 70–75; and one is *mesaticephalic*, 75–80. In general outlines they present two distinct forms, namely, elongated oval, and what is called coffin-shaped. The ridges above the nose and eyes are fully marked and the skulls have generally a smooth appearance. The nose is straight and the teeth are much worn. They also conform in every respect to the Long Barrow type, and are all those of adult males. Many of them bear the marks of sharp-cutting instruments. These circumstances seem to point out the probability of the barrow being the burial-place of those who have fallen in war. Besides the skulls there were numerous bones of the extremities found. These were generally strong, and the muscular ridges well marked, showing the people to have had good muscular development. Of the existing inhabitants of this country the Iberian race inhabiting parts of Wales and the West of England seem to be the descendants of this Long Barrow race.

5. *On a Scrobicularia Bed containing Human Bones, at Newton Abbot, Devonshire.* *By* W. PENGELLY, *F.R.S.*, *F.G.S.*

This communication consisted of a description of a bed of fine sandy mud, 11 feet thick, crowded from top to bottom with shells of *Scrobicularia piperata*, and recently discovered near the head of the tidal estuary of the River Teign, Devonshire. Its top was 1 foot above the level of the highest spring tides in the estuary, and its bottom 3 feet above the level of low water. At a depth of 10 feet in the bed were found the following human bones: a skull, part of the left superior maxilla containing two teeth, a right scapula, and a right femur—all believed to be of the age of the deposition of the part of the bed in which they lay. There is apparently no doubt, from the presence of the *Scrobiculariæ*, that since the era of the deposition the entire district has undergone an upheaval not less than 14 feet, nor more than 27 feet; the same upheaval, in all probability, which elevated the raised beach of Hope's Nose—about 7 miles S.E. of the *Scrobicularia* bed—as well as those extending thence, at intervals, to the Land's End of England.

6. *Papuans and Polynesians.* *By the* Rev. G. Brown, *F.R.G.S.*

After more than fourteen years spent in the Samoa Group amongst a true Eastern Polynesian people, the writer resided for some years in the New Britain Group, amongst a pure Melanesian or Papuan people. There was no white man in the group at the time of his arrival, and the people were quite unaffected by foreign intercourse. Whilst engaged in reducing this language to a written form, and studying its grammatical construction, Mr. Brown was led to alter or very much modify his previous opinion that the Polynesian and Papuan languages were radically separate and distinct from each other, and to conclude that they are both of one common origin, the Papuan representing now the more archaic form. Mr. Brown, in his paper, gave a detailed account of the principal theories on the subject of the origin of the different Polynesian tribes, as advanced by Messrs. Wallace, Vaux, Ranken, Keane, Fornander, Staniland Wake, and other writers, and expressed his own opinion that the Papuans and Polynesians were of one common stock, of which the former was the least affected by immigration from the mainland. This opinion the writer attempted to justify by a comparison of the two languages and the manners and customs of each race. The customs at birth, the class relationships of the Papuans, and the survival of them in Eastern Polynesia, the marriage customs, etiquette, the social and religious customs of both peoples, were compared, and in the opinion of the writer the comparison justified the opinion which he had formed.

TUESDAY, SEPTEMBER 7.

The following Papers and Reports were read:—

1. *What is an Aryan?* *By* Sir George Campbell, *K.C.S.I.*

The question is—What are the traits to distinguish an Aryan? He is seldom pure. He seems to have been a sort of monster, developed in comparatively recent times, who has conquered and absorbed older races. He is easily distinguishable from Turanians and Negroes (*e.g.*, a Constantinople Turk is an Aryan), but it is very difficult to distinguish between Aryan and Semitic, craniology notwithstanding.

Let us deal with—1, colour; 2, features.

There are two great branches of Aryans—dark branch in India; fair branch in Europe, including Asia Minor. Part of Western Asia (*e.g.*, Hindoo Koosh) may be classed as intermediate. Seeing various castes of Hindoos and Aborigines together, one cannot doubt that besides climate Hindoo Aryans get dark colour from the Aborigines. So also the Celts have derived a dark tinge from the Iberians, &c. The fairest Aryans are in north of Europe, but they also are not pure. Was the original Aryan white, or has he been blanched in the North? I incline to think that he was light brown in his original state, and has been blacked or blanched in the South-east and North-west.

Next as to features. What are the true Aryan features? God finished the Celt by running His hand up the face; the Teuton by stroking him down. That means that the Celt has lost some of the high, prominent features of the purer Aryans. The idea is, the large high features are the real Aryan. But the greatest development and exaggeration of that sort of feature is found in the races of Western Asia—notably the Jews whom we deem Semitic—where flux and reflux of conquest have mixed Aryans and Semitics; but high features prevail among Jews and Syrians, Northern Arabs, Persians, Affghans, and Kaffirs of the Hindoo Koosh. The Southern Arabs are very different—small, dark, more snub-featured men; and the Arab language has more African than Aryan affinities. I suspect these are true Semitic, and not the Northern Arabs of Persian affinities.

I incline to believe that what we call Jewish features as seen in Persians, Affghans, &c., are the real Aryan features, and that they have been toned down by intermixtures in India and Europe.

We find a remarkable similarity of feature in the fair and dark Aryans if we compare European and Indian features. But I confess that the subject is very puzzling. I should be glad of light on the questions: What are the true Aryan features? What the Semitic? And how are we to distinguish between the two?

2. *The Influence of Canadian Climate on European Races.*
By Professor W. H. Hingston, *M.D., D.C.L.*

A few preliminary observations were made on the physical geography of Canada and its influence in controlling climate. Its extent was shown by its boundaries: the Arctic Ocean on the north; Baffin's Bay and Davis' Straits on the north and north-east; the Atlantic on the east; the Pacific on the west; and line 45° and the Great Lakes on the south. Of the interior valley of North America Canada occupied the greater part—a valley which passes through the entire northern zone. The contents of this valley, and it contains the St. Lawrence basin, were described —the watersheds of which cover 130,000 square miles. The Lawrentides on the north, and the hills of Notre-Dame on the south, were alluded to, and their moderating influence on climate, their extent, the form, extending from the coast of Labrador to the Arctic Sea, and varying in height from 1,000 to 4,000 feet. The low altitude of Canada (300 to 500 feet) greatly modified its climate, and gave to Canada a great range of animal and vegetable life.

The climate of Canada is regular and is influenced by position alone. A knowledge of the climate of two distant places led to a knowledge of the climate of intervening places. Its dryness was proverbial, but more rain falls usually than in Great Britain, but at longer intervals, and more at a time. The different seasons were described; their great regularity, and the regularity of advent and departure of animals and birds. The difference in vegetation was hastily considered; and lastly, the influence of the climate on man. The effects of heat and of cold were according as they were immediate, remote, or continued. Heat was much more easily and comfortably borne than the same temperature in Great Britain, as the dryness of the atmosphere favoured evaporation from the surface of the body and produced sensible coolness. Cold in winter is stimulating, and Europeans become quickly inured to it without suffering inconvenience in the meantime, provided they took indigenous customs as their guide in the selection of food and clothing.

The tables of mortality were considered. The death-rate was not large, except in early life; but the death-rate among children is high *because* the birth-rate is enormous. The natural increase is the best proof of the healthiness of the climate. There are *no* diseases indigenous to Canada, but diseases of all kinds, as met with elsewhere, are considerably modified in course and duration. Deaths from remittent fever are less frequent than in any other portion of America. The ephemera are trivial, and intermittent fever, which is almost unknown in the eastern portions of Canada, is becoming rapidly dissipated in its more western parts. Great stress was laid on the importance of Canada to the consumptive and the dyspeptic, and a few remarks on the habits of the people were made, and experiments were alluded to which went to show that in height, weight, and lumbar strength the residents of Canada had given unmistakable signs of advancement over the peoples from which they are sprung.

3. *Traces of Ancient Sun Worship in Hampshire and Wiltshire.*
By T. W. Shore, *F.G.S.*

The outlying stone towards the north-east from the so-called Altar Stone at Stonehenge has long been considered to have been so placed to denote the line of the midsummer sunrise. If a tangential line be supposed to be drawn from the northern part of the outer circle of stones to the outlying stone above referred to, this line will denote the line of sunrise at the beginning of May. The three chief Celtic festivals were those of the Summer Solstice, the Winter Solstice, and that of Spring, from which the comparatively modern May-day festival is a survival.

Another outlying stone at Stonehenge marks the line of the mid-winter sunrise along a tangential line drawn to it from the outer circle of stones.

Some ancient Celtic earthwork lines in Hampshire and Wiltshire are in the same directions, and in some instances as many as three sides of such earthworks are in lines which mark the lines of sunrise or sunset at the dates of the Celtic festivals. The gates in some of the Celtic oppidi in these counties are also situated on the same lines. The same reverence for the east-north-east line, or about 20° N. of E., seems to have prevailed in Romano-British time. At Itchen Abbas there is a pavement having on it a figure, considered to be the head of Osiris, the Sun God, the line of which, drawn through the head of the figure parallel with the sides of the pavement is to the E.N.E. The sun reverence of the Celts appears to have been transmitted to Anglo-Saxon times in Hampshire. There must have been a very great intermixture of race in this part of Britain after the Saxon Conquest, as is shown by the survival of a large number of Celtic place and water names, and also by the existence of a large number of slaves through the period of the West Saxon history down to the date of the Domesday Book, at which time the proportion of slaves in Hampshire was as one to five of the population. As many as 132 churches in Hampshire are mentioned in the Domesday Book, and a few of these buildings survive in whole or in part. As many as from eighty to one hundred of the ancient churches in Hampshire have an orientation closely approaching the E.N.E., generally 20° N. of E., and two of the undoubted Saxon structures still remaining in part have this orientation. No church which was built in Norman time has any orientation towards the E.N.E., the general line of the Norman buildings being E. and W. The reverence for the E.N.E. line appears to have disappeared in Hampshire at the time of the Norman Conquest.

4. *The Life History of a Savage. By the* Rev. GEORGE BROWN, *F.R.G.S.*

Commencing with the birth of the child, when a warm banana leaf was placed against him, and he was fed with the juice of the cocoa-nut, and left to be ever after 'dressed in pure sunshine,' the author described the games of his boyhood, his initiation into certain secret rites, the ceremonies at the feasts—particularly at the one at which he was taught to curse his enemies—and his marriage. At that time there was an interchange of goods and a distinct payment for the wife. Presents were also given by the women to the bride, and by the men to the husband, and after a spear had been given to the latter, and a broom to the former, a stick was given to the husband. The spear meant that the husband was to protect his wife, and the broom that with that the wife was to do her household work, and the stick was a symbol of his authority—or, in plain English, 'here's the stick with which to whack her if she does not.' At the time of death the cries of the friends were very piteous and touching. The dead was cried to to come back, was expostulated with for having left his friends, was entreated to say how his friends had offended him, and so on, the mourners seeming to be speaking in the very presence of the spirit of the dead person. Among these black races he had many dear friends, men who could be talked to with pleasure, and from whose conversation benefit could be got. The more they studied the life and character of these people whom they thought so degraded, if they would only come down to their level, talk to them, and try to get out of them what they knew, the more it would be found that there was more poetry and common sense in their ideas than they had been given credit for. They had intuitive perceptions of right and wrong according to their lights; many of the things which his hearers would call good they called good, and they had a definite idea of a future state, and also of a definite punishment, for one offender—the niggardly man. When the old man came near death he was put upon a litter and carried round to see the old scenes amid which he had passed his life, his canoe, the sea, all the old familiar subjects; and then he was taken back to wait his time. After death, he was placed in a sitting posture, and taken into the public square, with his weapons by his side, and before him the people placed offerings of their valuable goods and money. The idea was that the spirit was near, but about to go, and that he must be provided for his journey; and here they found something like the old Greek practice of placing a coin in the hands of the dead to pay the ferryman.

5. *Note on Photographs of Mummies of Ancient Egyptian Kings, recently unrolled at Boulak.* *By* Sir J. WILLIAM DAWSON, *C.M.G., F.R.S.*

These photographs, representing the mummies of Seti I., Rameses II., and Rameses III., have been kindly communicated by Dr. Schweinfurth, of Cairo. They are of great interest as enabling us to see the actual features of these ancient Egyptian kings, and to compare them with their representations in the monuments, and with modern Egyptians. It appears that the features of Seti are scarcely of Egyptian type, as represented either by the monuments of the older dynasties or by the present Egyptians; though, as Dr. Schweinfurth shows in a drawing accompanying the photographs, a similar style of countenance still exists among the Copts. It also appears that the features of Rameses II. strongly resemble those of his father, and are very like those on some of his statues. Both Seti and Rameses have narrow and somewhat retreating foreheads and strongly developed jaws, indicating men of action rather than of thought, and both were men of great stature and bodily vigour, and seem to have lived to advanced ages.

Dr. Schweinfurth, in a letter accompanying the photographs, invites especial attention to the fact that mummies when unrolled speedily decay, and thinks that the Association should exert its influence in behalf of the preservation of these precious relics, either by restoring their wrappings or by placing them in air-tight cases, so that they may escape the destruction which has fallen on so many mummies in European museums.

6. *On the Anatomy of Aboriginal Australians.*
By Professor A. MACALISTER, *F.R.S.*

7. *Notes on a Tau Cross on the Badge of a Medicine Man of the Queen Charlotte Islands.* *By* R. G. HALIBURTON.

The author said this badge was interesting, as Queen Charlotte Island is one of the most isolated of the Northern Pacific islands. It lies off the west coast of British Columbia. This symbol was used by the Indians on large sheets of copper, to which they assigned a high value, and each of which they called a 'tau.' The connection of that name with the symbol is world-wide. Our T is simply the tau symbol, and is called 'tee' or 'tau.' The medicine men represent the tau sometimes on the forehead. The ancients used to mark the captives who were to be saved with a tau or cross. Ezekiel refers to this, and the word he uses for 'the sign' to be marked on the foreheads of them that are to be saved, really is 'the tau' or 'cross.'

No one has divined why the *scarab* was so sacred. He was led to a solution by seeing an exaggerated *tau cross* on the back of a scarab. On looking into the Egyptian name for the scarab he found it to be *tore*, and that the sutures on the beetle form a tau cross. But the same name is applied to the same beetle by our peasantry, 'tor-beetle,' or 'dor-beetle.' Wilkinson represents a god with a scarab for a head—and one of the names of which was *tore*. The use of the prehistoric or pre-Christian cross is world-wide, and a puzzling problem which he would not enlarge upon.

8. *Remains of Prehistoric Man in Manitoba.*
By CHARLES N. BELL, *F.R.G.S.*

The author in this paper announced the existence in the Canadian North-west of sepulchral mounds, and pointed out the hitherto unknown fact that there is a continuous line of mounds from the mound centres of the Mississippi River down the Red River to Lake Winnipeg. Human remains, much decayed, are found in the mounds, all buried by being placed on the surface under heaps of earth in which patches of charcoal and ashes frequently occur, though no remains of funeral feasts, as bones, &c., are met with. Indians, when first met with, buried weapons with warriors, but none are found in these mounds, though implements and ornaments of shell, bone, and stone are common, as well as pottery, which last was unknown to Indians of North-west Canada on arrival of whites. One mound has burnt clay and boulder floor similar to the 'Sacrificial Mounds and Altars' of Ohio. Ornaments of sea-shells, which must have been carried fully 1,200 miles from their native waters, have been found by the author and others in the mounds. Traditions prevalent amongst Indians were given and proved to be not founded on fact. An ancient camp site had been discovered and explored by the author on the bank of Red River, near the group of mounds. A description was given of burial customs of North-west tribes as practised when first visited by whites, and comparison drawn between those customs and the mound form. Mounds from Lake Winnipeg to the Gulf of Mexico have been found of the same character, and were probably made by one race, though the whites found great diversity of mortuary customs prevailing amongst Indian tribes inhabiting this great tract of country. Little exploration has yet been made in the Canadian North-west, which offers a wide and productive field to archæologists. The mounds are very ancient and are situated in what were the best game districts.

9. *Report of the Committee for investigating and publishing reports on the physical characters, languages, and industrial and social condition of the North-western Tribes of the Dominion of Canada.*—See Reports, p. 285.

10. *Report of the Committee for investigating the Prehistoric Race in the Greek Islands.*—See Reports, p. 284.

APPENDIX.

Second Report of the Committee, consisting of Messrs. R. B. Grantham, C. E. De Rance, J. B. Redman, W. Topley, W. Whitaker, *and* J. W. Woodall, Major-General Sir A. Clarke, Sir J. N. Douglass, Admiral Sir E. Ommanney, Capt. Sir G. Nares, Capt. J. Parsons, Professor J. Prestwich, Capt. W. J. L. Wharton, *and* Messrs. E. Easton, J. S. Valentine, *and* L. F. Vernon-Harcourt, *appointed for the purpose of inquiring into the Rate of Erosion of the Sea-coasts of England and Wales, and the Influence of the Artificial Abstraction of Shingle or other Material in that Action.* (C. E. De Rance *and* W. Topley, *Secretaries.*) *The Report edited by* W. Topley.

The descriptive papers printed by the Committee last year referred entirely to the south and south-east coasts of England—Devonshire to Kent. The information now given includes some then in hand referring to other districts, and also some which has been contributed since.

Reference may be made to the introductory remarks in last year's Report for an explanation of the general scope of the Committee's inquiry. The final Report is deferred until fuller details are obtained respecting the north-western coasts.

The Committee would again ask for the assistance of any who, by long residence or by other means, have special knowledge of changes on any part of the English and Welsh coasts. Printed forms of questions can be obtained from the Secretaries or from any member of the Committee.

The various Reports and Papers are printed on the authority of the respective authors.[1]

COPY OF QUESTIONS.

N.B.—Answers to these questions will in most cases be rendered more precise and valuable by sketches illustrating the points referred to.

1. What part of the English or Welsh Coast do you know well?

2. What is the nature of that coast?

- **a.** If cliffy, of what are the cliffs composed?
- **b.** What are the heights of the cliff above H.W.M.?
  Greatest; average; least.

3. What is the direction of the coast-line?

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[1] Of the following Reports, &c., Nos. 2, 3, and 4 are supplied through Sir A. Clarke; No. 5 through Mr. J. B. Redman.

4. What is the prevailing wind?

5. What wind is the most important—

- **a.** In raising high waves?
- **b.** In piling up shingle?
- **c.** In the travelling of shingle?

6. What is the set of the tidal currents?

7. What is the range of tide?

(1) Vertical in feet. (2) Width in yards between high and low water.

(**a**) At Spring tide; (**b**) at Neap tide

8. Does the area covered by the tide consist of bare rock, shingle, sand, or mud?

9. If of shingle, state—

- **a.** Its mean and greatest breadth.
- **b.** Its distribution with respect to tide-mark.
- **c.** The direction in which it travels.
- **d.** The greatest size of the pebbles.
- **e.** Whether the shingle forms one continuous slope, or whether there is a 'spring full' and 'neap full.' If the latter, state their heights above the respective tide-marks.

10. Is the shingle accumulating or diminishing, and at what rate?

11. If diminishing, is this due partly or entirely to artificial abstraction? (*See* No. **13**).

12. If groynes are employed to arrest the travel of the shingle, state—

- **a.** Their direction with respect to the shore-line at that point.
- **b.** Their length.
- **c.** Their distance apart.
- **d.** Their height—
  - (1) When built.
  - (2) To leeward above the shingle.
  - (3) To windward above the shingle.
- **e.** The material of which they are built.
- **f.** The influence which they exert.

13. If shingle, sand, or rock is being artificially removed, state—

- **a.** From what part of the foreshore (with respect to the tidal range) the material is mainly taken.
- **b.** For what purpose.
- **c.** By whom—Private individuals. Local authorities. Public companies.
- **d.** Whether half-tide reefs had, before such removal, acted as natural breakwaters.

14. Is the coast being worn back by the sea? If so, state—

- **a.** At what special points or districts.
- **b.** The nature and height of the cliffs at those places.
- **c.** At what rate the erosion now takes place.
- **d.** What data there may be for determining the rate from early maps or other documents.
- **e.** Is such loss confined to areas bare of shingle?

15. Is the bareness of shingle at any of these places due to artificial causes?

- **a.** By abstraction of shingle.
- **b.** By the erection of groynes, and the arresting of shingle elsewhere.

16. Apart from the increase of land by increase of shingle, is any land being gained from the sea? If so, state—

- **a.** From what cause, as embanking salt-marsh or tidal foreshore.
- **b.** The area so regained, and from what date.

17. Are there 'dunes' of blown sand in your district? If so, state—

- **a.** The name by which they are locally known.
- **b.** Their mean and greatest height.
- **c.** Their relation to river mouths and to areas of shingle.
- **d.** If they are now increasing.
- **e.** If they blow over the land; or are prevented from so doing by 'bent grass' or other vegetation, or by water channels.

18. Mention any reports, papers, maps, or newspaper articles that have appeared upon this question bearing upon your district (copies will be thankfully received by the Secretaries).

19. Remarks bearing on the subject that may not seem covered by the foregoing questions.

1. The Sea-Coast from Westgate to Margate, Kent.

By RICHARD B. GRANTHAM, M.Inst.C.E., F.G.S.

Northumberland Chambers, Northumberland Avenue, London, W.C.
August 1886.

In continuing the Report of the Committee of the British Association on the 'Erosion of Sea-Coasts' for this meeting, I have selected a part of the coast of Kent which is remarkable for the manner in which it has been affected by the action of the sea, namely, the Chalk Cliffs between Westgate-on-Sea and the Infirmary at Margate.

The country inland is composed of clay and loam overlying the chalk formation, and the line of cliffs referred to is about a mile in length, and, as shown on the diagram on page 850, runs east and west from the roadway at Westgate on the west to the Infirmary at Margate on the east.

My object in selecting this line of coast is to show the peculiar manner in which the sea has eroded it. The cliffs vary from 25 to 40 feet in height above the shore, or a mean of 30 feet, and average about 35 feet in height above ordnance datum, and they are based upon the chalk rock of the shore. The sea has perforated them in places by excavating caverns in the manner shown on the enlarged portion of the plan, some being as much as 20 to 25 yards in depth. The sides of these caverns are generally perpendicular, supporting the roofs, the height varying from 12 to 25 feet, but diminishing very much at the backs. They decrease in width from the entrances. The direction of the caverns is generally N.W. to S.E., but some are N.E. to S.W., and two, which take these different directions, sometimes meet. They are generally at an angle of 30° with the coast line.

The prevailing winds are from the N.E. and S.W., but the N.W. wind here causes the highest waves, and is the principal cause of the perforations of the cliffs.[1]

The assumption is that the velocity of the waves is increased as they enter the caverns, and thus strike the sides and roofs with great force, excavating the softest portions of the chalk. The chalk is bedded horizontally in places, and is interspersed by beds of rubbly chalk which is not stratified, and appears to have been thrown in or forced between the solid beds, and the washing out, as above described, loosens the solid chalk, and finally brings it down in masses. The enlarged plan shows how projecting points are cut through and detached from the mainland, becoming islands, which are, however, soon washed away.

The lines on the enlarged plan illustrate the extent of the erosive action on the whole line of the cliffs, the fine lines showing the top and bottom boundaries as they existed in 1880 when a survey was made, and the thick lines the boundaries at present existing, as found by a re-survey. In places upwards of 20 feet in width of cliff have been lost in this period; the average loss, however, over the whole length is not so much.

A sea-wall was built in 1878 at the Westgate end as a commencement of a terrace-road under the face of the cliff, and another was built in 1884 to protect the portion near the Infirmary at Margate, and further works of a similar kind are in progress. The main object of these walls is to prevent the wearing away of the cliffs and loss of land, but they will afford the means of constructing sea-terraces both under and upon the cliffs.

The whole shore consists of chalk with masses of rocks covered with sea-weed in places, the remainder being open stretches of chalk covered more or less with sand. There are no groynes and no shingle, so that there is no protection against the erosion. The sand is shifting in nature, and the quantity varies at different seasons.

The tides recede from the cliffs at low spring tides from 800 to 1,000 feet. At Margate the tides rise 13 feet at neaps and 15½ feet at springs.

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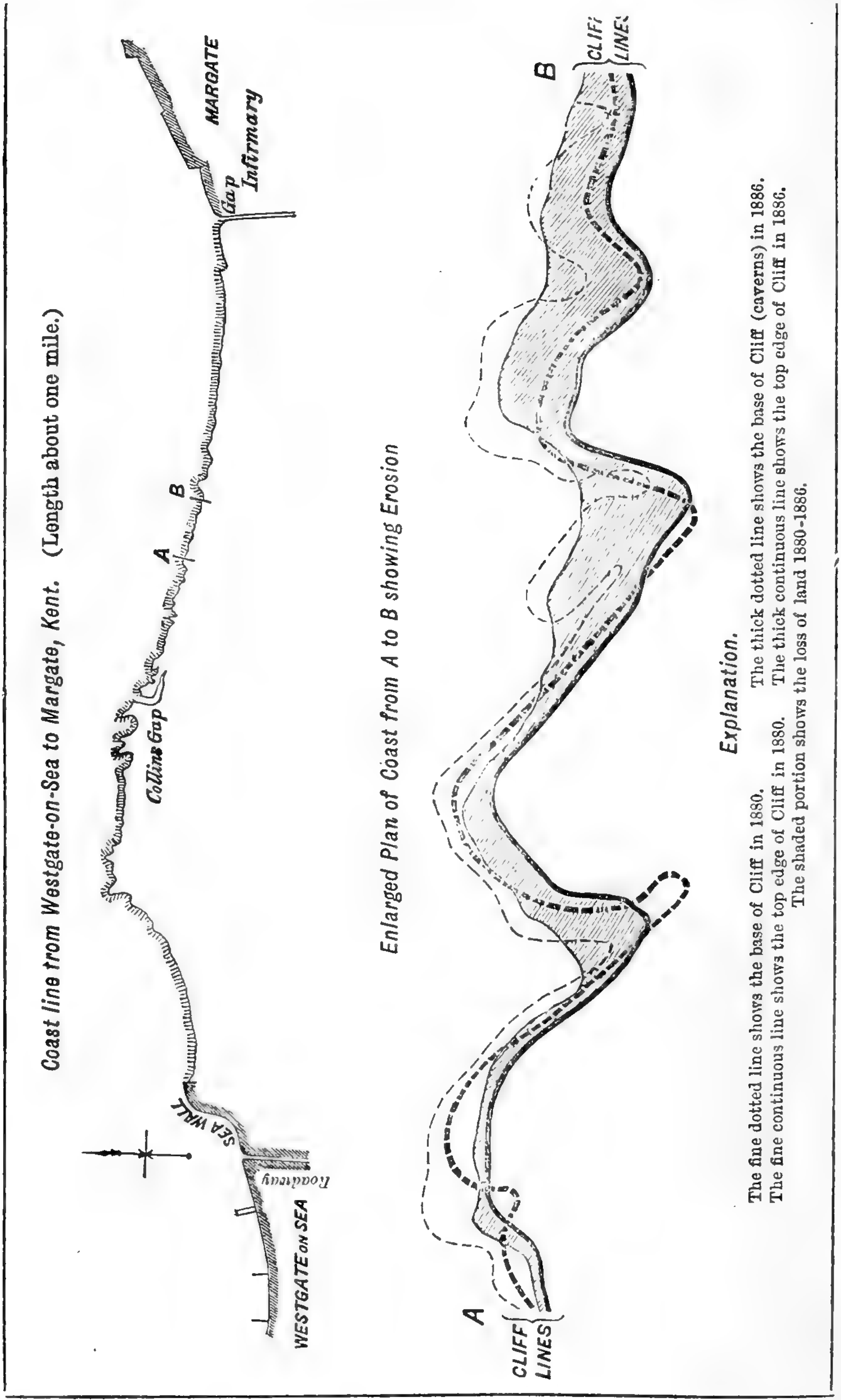
[1] Acting along divisional planes or lines of jointing in the Chalk, the more important lines running to south-east from north-west.—W. T.



Coast line from Westgate-on-Sea to Margate, Kent. (Length about one mile.)

Enlarged Plan of Coast from A to B showing Erosion

Explanation.

The fine dotted line shows the base of Cliff in 1880. The thick dotted line shows the base of Cliff (caverns) in 1886.
The fine continuous line shows the top edge of Cliff in 1880. The thick continuous line shows the top edge of Cliff in 1886.
The shaded portion shows the loss of land 1880-1886.

2. The Estuary of the Colne.

By JOHN BATEMAN, Brightlingsea.

1. The estuary of the Colne.

2. A fringe of flat salt-marshes overflowed at high tides. They form small cliffs of about 5 feet, and then soft mud reaches to low-water mark.

3. N.E. to S.W.

4. S.W.

5. a. East. **b.** and **c.** No shingle.

6. Same as at mouth of Thames.

8. Mud entirely.

14. Yes. **a.** Almost without exception from mouth of Thames northwards, and eastwards certainly at Mersea, Brightlingsea, St. Osyth, and Clacton. **b.** Cliffs only commence at Clacton. **c.** The area of one salt-marsh of about 10 acres has diminished by nearly one-third in twenty years. **d.** Tithe Commutation Map of Brightlingsea, 1832 (?) shows 'West Marsh Point' to have been something like 100 yards seaward of its present situation. **e.** Yes; just locally.

16. Something like 700 acres of Brightlingsea were enclosed from the salt-marshes, 1700–1800. No record is preserved of exact dates, but a map of 1780 shows much now enclosed to have been then subject to occasional tidal overflow. There are also curious isolated 'hills' of shingle and clay on some of the enclosed marshes, evidently washed together by sea action.

17. Dunes fringe the coast of St. Osyth for 2½ miles, infringing perhaps 50 to 150 yards on the marshes. **a.** St. Osyth beach, locally 'T'oosy beach.' **b.** 12 to 15 feet. **d.** No. **e.** A long salt-water 'crik,' locally so called, runs close behind them inland.

3. The Deben to the Colne.

By PETER S. BRUFF, M.Inst.C.E., Engineer Harwich Harbour Conservancy Board, Ipswich.

1. Suffolk and Essex Coasts, from River Deben to near River Colne.

2. Various; cliff, flat 'denes,' and embanked marshes. **a.** London Clay, sometimes capped with Crag, gravel, or sand. **b.** (1) 68 feet. (2) 37 feet. (3) 6 feet.

3. N.E. to S.W.

4. S.E. to S.W.

5. a. N.E. to S.W. **b.** Varies locally from E. to W. (N. to W. at Walton.) **c.** N.E. to E.

6. N.E. to S.W.

7. (1) **a.** 11 feet 6 inches. **b.** 8 feet. (2) **a.**[1] Deben to Orwell, 25 yards. Walton-on-the-Naze, 230 yards. Clacton, 150 yards.

8. From Deben to Orwell, sand and shingle with occasional layers of cement stone at foot of beach. From Orwell to Colne there is a clay flat at foot of beach uncovered at low water.

9. a. About 30 to 40 yards at Felixstowe and Clacton. **b.** Sometimes evenly distributed, sometimes in patches with sand between. **c.** N.E. to S.W. **d.** A small proportion as large as hens' eggs, the majority much less. **e.** There is a ridge formed by the spring tides, and also by the neaps; the heights above the respective tide-marks vary according to the state of wind. The average height would be about 2 feet above the tide-marks.

10. Where not protected by groynes the shingle is diminishing.

11. No.

12. a. Generally at right angles. **b.** From 30 to 40 yards. **c.** Various. **d.** Too varied to summarise. **e.** Timber-piles and planks. There are some stone groynes at Walton-on-the-Naze. **f.** Between Deben and Orwell they arrest the shingle very effectually, and prevent the loss of foreshore and land. At Walton-on-the-Naze the same in a less degree.

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[1] At a part of this there are rocks of 'septaria,' uncovered at low water, extending some distance beyond the average of 25 yards.

13. a. A considerable quantity of shingle has been taken from the beach at Clacton, at about high-water mark, for road-making, and for concrete for building. **d.** It is said that some forty or fifty years ago cement stone was dredged and otherwise removed in front of Felixstowe, which removal had an injurious effect upon the coast, but the practice has long been discontinued.
14. Yes. **a.** At Felixstowe, between the 'Lodge Point' and Martello Tower P. At Walton-on-the-Naze and Frinton. **b.** At Felixstowe the greatest loss was where there was 'flat' 'Benthill' at the foot of cliffs. At Walton and Frinton, London Clay cliffs 40 to 68 feet above high water. **c.** In places as much as 100 feet in ten years, but a fair average would be about half that amount. The loss at Felixstowe is practically stopped by groynes on beach. **d.** The tithe maps of the parishes in question should be compared with the $\frac{1}{2500}$ Ordnance Survey of 1874. **e.** At Walton and Frinton it is, practically. The existence in the cliffs of potholes of sand and gravel containing water is also a cause of subsidence; the water breaking out on the base, carrying the sand with it, loosens large masses of the upper part of cliff.
15. The loss of land at Walton and Frinton has gone on from time immemorial; but it has been noticed that since the construction of the Harwich Harbour Conservancy Board's works at Landguard Point there has been a greater scarcity of shingle on the beach at Walton and Frinton.
16. No.
17. Part of Landguard Common and the land at the mouth of the Deben is formed of 'blown sand' covering the top of a shingle beach. **a.** Locally called 'Benthills.' **b.** From 3 to 10 feet above high-water mark. **d.** That at Landguard Point is increasing, in consequence of the Conservancy Board's jetty. **e.** No; prevented by the 'bent grass' or 'marram.'
18. Tracing accompanies this paper, showing Harwich Harbour Conservancy Board's works at entrance of harbour, and the scouring away of Landguard Point to the S.W., and accumulation of beach to the N.E. of same. As to which, see also various Reports presented to and published by the authority of Parliament.

4. Great Yarmouth.

By Major A. G. Clayton, R.E., Norwich.

1. Great Yarmouth, Norfolk.
2. Flat sand.
3. North and south.
4. Variable.
5. a. North-west. **b.** West-north-west. **c.** Shingle does not travel.
6. North and south.
7. (1) **a.** 4 feet. **b.** 3 feet. (2) About 50 yards.
8. Sand, but at certain periods, generally spring and autumn, banks of shingle are thrown up.
9. d. About the size of a walnut. **e.** The shingle is in detached banks only.
10. Apparently diminishing.
11. Yes.
12. There are no groynes.
13. a. Between high and low water. **b.** Ballast for fishing smacks and for roads. **c.** Chiefly private individuals. **d.** No.
14. No.
16. No.
17. Yes. **a.** 'Denes.' **b.** 5 feet—8 feet. **d.** No. **e.** No.

5. Aldeburgh to Cromer.

By W. Teasdell, C.E., Yarmouth, Norfolk.

1. English coast, from Aldeburgh to Cromer.
2. a. Sandy hills and cliffs. **b.** (1) About 80 or 90 feet. (3) From 10 to 30 feet.
3. From south-east to north-west.

4. South-west.
5. **a.** North-east to south-east. **b.** East.
7. Width is from 100 to 200 feet at spring tides; up to about 150 feet at neap tides.
8. Sand and shingle.
12. Groynes are employed in Norfolk and Suffolk. **a.** At right angles. **b.** From 80 to 150 feet. **c.** Varying from 40 to 300 feet. **e.** Pitch-pine generally. **f.** In some cases raising the beach 4 feet.
14. At Gorleston, Suffolk, the cliff has gone back from 200 to 300 feet within the last forty years. **b.** Sand, height 80 to 90 feet. **c.** Within the last six years gone back 60 feet. **e.** No.

6. Weybourn to Happisburgh.

By Alfred C. Savin, Church Street, Cromer, Norfolk.

1. Norfolk, from Weybourn to Happisburgh, a distance of about twenty-five miles.
2. A flat foreshore, backed by lofty cliffs. **a.** Sand, gravel, and clay. **b.** (1) About 250 feet; (2) about 150 feet.[1] (?) From Cromer they decline on both sides until at Hasbro' and Weybourn they disappear altogether.
3. South-east to north-west
4. East and north-east.[1] (?)
5. **a.** North-east. **b.** It varies, but as all the large beds of shingle are to the north of Cromer, a gale from that direction is the best. **c.** North, as the set of the tide is from that direction.
6. About north-west.
7. (1) **a.** About 18 feet. **b.** About 8 or 10 feet. (2) Sometimes as great as 500 yards, but is very variable, as it greatly depends on the state of the beach, the wind, &c., so that it is impossible to state correctly the distance.
8. Shingle and sand.
9. Shingle :—**a.** In scattered beds, except at West Runton, Sherringham, and Weybourn. **b.** From high-water mark to about half low. **c.** North-easterly.[1] (?) **d.** From the size of a goose egg to that of a pigeon. **e.** At Weybourn, Sherringham, and West Runton it is piled up in regular steps, and protects the cliffs from the sea; but at Cromer and at all the villages to the east it occurs in small detached beds of no great size.
10. There is no perceptible decrease at Weybourn, Sherringham, and West Runton; but at Cromer it is steadily diminishing.
11. Entirely due to artificial abstraction.
12. Yes, at nearly all the villages on the coast. **a.** At right angles. **b.** From 50 to 100 yards. **c.** Some half a mile, others about a quarter of a mile, and all intermediate distances. **d.** (1) First built at Cromer about fifty years ago. (2) Sometimes about 6 feet, at another time not so much; very variable. (3) It greatly depends on which portion you measure, as against the cliff it is level with the top, but down by the sea both sides will be of the same level. **e.** Pine and fir. **f.** I think if it had not been for the groynes Cromer would have been washed away years ago, for when a hole is made in a groyne it rapidly lowers the level of the beach.
13. [The following statements **a** to **c** refer to Cromer.—W. T.] Yes. **a.** From high-water mark to about half low-water mark. **b.** For road-metal and building; but by far the larger quantity is sent by rail to Runcorn for china-making, &c. **c.** By men who get their living by carting shingle, sand, &c. Lord Suffield and B. Bond Cabbell, lords of the manor. **d.** Yes; but only at Cromer and East Runton, as they are the only places where the beach is removed to any extent.
14. Yes, on the whole coast, excepting parts protected by a sea-wall. **a.** At Cromer, Overstrand, Sidestrand, Trimmingham, Mundesley, Bacton, and Happisburgh; all the villages named are on the east side of Cromer. **b.** Clay, sand, and gravel; from 250 feet at Cromer to about 4 feet at Hasbro', where the *cliffs end.* **c.** It is stated on good authority at about 2 yards per year. **d.** Such

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[1] [These statements do not quite agree with those given by Mr. C. Reid.—W. T.]

data are chiefly confined to work on the geology of the coast, &c. **e.** Yes; for on the north side of Cromer the loss is comparatively small, which is no doubt due to the large beds of shingle which occur from Cromer through East Runton, West Runton, Beeston, Sherringham, and Weybourn, where the cliffs end and are replaced by large beds of stones.

15. Yes, at Cromer a bed of shingle is of rare occurrence, for as soon as it is seen it is carted away. **a.** Yes. **b.** I do not think that the groynes stop the shingle, for as soon as they are full on the north side it washes over the top and so travels along.

16. **a.** No, only now on the Lincolnshire coast.

17. Only at Hasbro', where they replace the cliffs and extend up to Yarmouth. **a.** Marram Hills, so called from the species of grass which grows upon them and binds the loose sand together. **d.** I believe they increase near Yarmouth, as the water is gradually receding at that place. **e.** They very rarely shift, and are kept in their places by the marram grass.

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7. Weybourn to Palling.

By Clement Reid, Geological Survey Office, 28 Jermyn Street, London.

1. Norfolk, between Weybourn and Palling (23 miles).

2. Cliffy, except about three miles of alluvium protected by sand-dunes. **a.** Boulder clay and gravel, but for four miles near Weybourn the base of the cliff is chalk (soft, with many flints). **b.** (1) 250 feet. (2) 80 feet. (3) 0 or 3 or 4 feet below high water at Hempstead Marshes.

3. E. and W. at Weybourn, but curving near Cromer to the E.S.E., which direction it retains for 16 miles of the distance.

4. South-west.

5. **a.** N.E. to N.N.W. **b.** Gentle southerly or south-westerly. **c.** N.N.W.

6. Flood tide strong, close in shore, from the N.N.W. Ebb weaker and in the opposite direction. At Cromer there is about three hours' difference between the time of high water and the change in the direction of the current.

7. (1) 18 or 19 feet at spring tides.

8. For about 8 miles there is a foreshore of chalk, more or less covered with shifting sand and banks of loose unworn flints. The rest of the coast has a foreshore of sand, generally resting on clay. Everywhere there is a shingle beach extending from above high water to about the level of mean tide. The beach becomes more sandy southward.

9. **a.** Constantly varying according to the direction of the wind and the denudation of the coast. **b.** Between mean tide and extreme high water. **c.** To the E. and E.S.E. **d.** Very various; they are stones washed out of the boulder clay. **e.** Usually in one continuous slope, but varies with the wind.

10. Constantly shifting, and moving back with the denudation of the cliff, but nowhere greatly accumulating or diminishing.

12. **f.** Prevent the beach travelling to the S.E. *N.B.*—Under the higher cliffs the old groynes have been crushed by landslips, and it is useless to erect fresh ones unless the cliffs are sloped at a very low angle; the cliffs are full of land-springs.

13. Only at Cromer and Runton. **a.** Large flints are taken, principally from the lower part of the beach. **b.** and **c.** Building (private individuals), road-making (local authorities), and pottery (companies). The amount removed has as yet been too small to make any appreciable difference, especially as it is immediately replaced.

14. Yes. **a.** Along the whole coast. **b.** See **2.** **c.** About 2 yards annually. **d.** See Redman's paper on the 'East Coast.' **e.** No.

15. Yes. **a.** No. **b.** At Sherringham there is a short space bare of beach beneath the new groyne, and the cliff has been denuded much faster, east of the village, since the groyne was erected. The erection of groynes at Cromer caused the clay foreshore and base of the cliff to be exposed for many years at Overstrand, but the denudation of the clay has now allowed a new beach to form, adjusted to the new conditions. The groynes near Eccles seem to have effectually stopped denudation, and do not appear ever to have caused a scour.

16. No.

17. Yes; but they are of more importance further south, at Yarmouth, &c.
a. Marram Hills.

19. The greatest denudation is caused by N.N.W. gales. On-shore winds do comparatively little. The tides scour, during gales, to so great a depth that no groynes can permanently protect this coast; probably they cannot even alter the *average* rate of denudation during a long period.

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8. The North-West Coast of Norfolk.

By J. S. VALENTINE, M.Inst.C.E., 6 Queen Anne's Gate, Westminster.

1. The north-west coast of Norfolk.

2. The coast from King's Lynn to Wells is flat, with the exception of Hunstanton Cliff, which extends from the village of Hunstanton St. Edmund's on the south to the old village of Hunstanton on the north, a distance of about 1½ mile.

a. The cliff is composed of Lower Greensand and the lower beds of the Chalk, separated by a band of Red Chalk about 3 feet thick. The dip of the strata is to the north and east.

b. The greatest height of the cliff is 60 feet above high-water mark at the lighthouse, decreasing to the level of the beach at each end.

There are dunes of blown sand at Holme, and at Holkham, near Wells.

3. From Lynn to St. Edmund's Point about E.N.E.; thence to Gore Point trending towards the east; from Gore Point nearly due east.

4. North-west and south-west.

5. **a, b, c.** North-west.

6. The flow of the tide is to the south.

7. Spring tides in Lynn Roads range 23 feet 3 inches; neap tides 14 feet 2 inches.

Opposite Hunstanton Cliff the width from high- to low-water mark in spring tides is 600 yards.

8. The area covered by the tide is principally sand.

Along the base of Hunstanton Cliff, when the sand is swept away during north winds, the Lower Greensand (which contains a considerable amount of iron) forms the foreshore. The rock is divided by joints running seawards at right angles to the cliff.

The greatest accumulation of shingle is between Hunstanton Cliff and Wolferton Creek, seven miles; south of which there is none or very little.

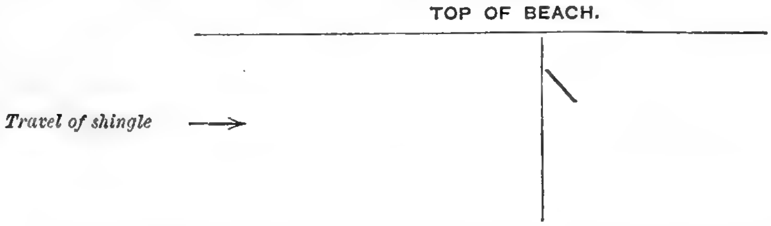
9. **a.** Various. **c.** North to south. **d.** Generally small.

10. There has been no apparent diminution during the time I have noticed it—say twenty-five years.

11. See **13.**

12. The groynes are generally at right angles to the shore; but in some instances I have erected short spur-groynes on the leeward side, which have collected shingle in larger quantities, and so stopped the cutting away of the top of the beach, which occurred before these spur-groynes were erected.

In 1862 the sea broke through the Heacham Beach. I then erected a number of groynes, as described above, which have accumulated a strong beach. (See examples near the Rifle Butt.)



The groynes are constructed of timber.

13. a. The principal part of the shingle removed artificially is taken from Snittesham Beach, about five miles south of Hunstanton. It is there that the shingle accumulates.

b. For road-making in Marshland and the Fens, and for concrete for public works along the coast.

c. It is sold by the lord of the manor to road surveyors, contractors, &c.

14. a. The coast is wasting at Hunstanton Cliff, where large falls occur every winter.

b. Lower Greensand capped by the lower beds of the Chalk. Height of cliffs vary from 0 to 60 feet.

c. I should say that during the last forty years from 20 to 30 feet have been lost—perhaps more in some places.

e. The loss is confined to the cliff, at the base of which there is very little shingle.

15. No.

16. The eastern side of The Wash and the north coast of Norfolk as far as Wells have generally a margin of land, of varying width, which has been gained from the sea, and which is retained by artificial means, such as embankments, groynes, &c.

Some enclosures are ancient. Two—the Holme Marshes, north of the village of Hunstanton, and Lord Leicester's enclosures near Wells—have been made within the last thirty years. Both enclosures were made by carrying an embankment on the north side from the high land to the 'dunes,' which protected the land from the west.

17. There are 'dunes' protecting the lands enclosed at Holme and near Wells. (See **16.**)

b. Greatest height perhaps 20 feet.

e. They are covered with marram grass, and do not blow over the land.

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9. The Coast of Pembrokeshire—Southern Part.

By KENNETH W. A. G. MCALPIN, Assoc.Inst.C.E., Pembroke Dock.[1]

1. The coast of Pembrokeshire and Milford Harbour.

2. Rocks principally, having frequent bays of sand where the continuity of the rock-line is broken.

a. The cliffs are composed of Old Red Sandstone, Carboniferous Limestone, of slate,[2] and anthracite coal-measures with grey sandstone.

The Old Red Sandstone, as a rule, is not in large blocks suitable for masonry, or even rubble-walling, and is not well able to resist the exposure to weather. It is much protected by the growth of lichens, mosses, &c., above water mark, which defend it from the rays of the sun and frost, and make the cliffs appear of a greenish grey colour. The hardest specimens of the red sandstone, however, retain their redness, as at St. Ann's Head. The area between high and low water is greatly protected from erosion by being almost hidden by the numerous shells of the limpet tribe that are everywhere to be found; also mussels in great abundance, and the varied forms of sea-weed.

The limestone cliffs are light-blue in colour, like the colour of a wild pigeon; the stones are in most cases of large size, great soundness and strength, suitable for engineering—dock or fort works for example. Notably large and good blocks are to be obtained from the Pen-y-holt and adjacent cliffs, Caldy Island, and Lydstep; at other places the limestone is much the same in appearance, but is composed of smaller blocks and rubble, well and solidly packed together. These limestone cliffs form a noble escarpment against the sea; the same face is now presented to the weather that has borne the storms of many centuries, as is clearly to be seen all along the limestone coast, but most notably at the Elegug Stack and St. Govan's Head, where the face is weathered in a most

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[1] Communicated by Lieut.-Col. A. W. Mackworth, R.E., through Major-Gen. Sir A. Clarke, R.E. The MS. of this Report is illustrated by a map and seven photographs.

[2] Cambrian and Silurian shales and sandstones.—W. T. (See Report on p. 859.)

remarkable manner, like a honeycomb, sometimes perforated as if by large boring drills, evidently the work of hundreds of years.

The stone when burned in kilns makes excellent white lime for building and agricultural purposes, and there are a few quarries for these uses.

In some places the large courses are quite horizontal; at other places the beds are pitched on end vertically. They also lie at every possible angle, sometimes grading off from one angle to another, and are sometimes abruptly broken.

The slate cliffs of North Pembrokeshire do not stand up bold and upright, like these of limestone; but at the distance look like the red sandstone cliffs, viz., rounder, bluffer, and more receding in figure. In colour and vegetable covering they much resemble the red sandstone.

It remains to tell of the coal-measures where they meet the sea. The water works out the bottom, the top falls down, the loose stones make a beach wearing into pebbles, and the finer material becomes sand on a flat slope to seaward: this is the case at St. Bride's Bay, and at Amroth, between Tenby and Caermarthen. These coal strata are mostly mixed with grey sandstone, clay, and various loose materials over which the sea has made considerable advances. There can be no doubt but that St. Bride's Bay has surrendered much of its land to the water in years gone by; but the progress of the sea appears now to be arrested by the rocks that take the wash at the south end of the bay, and also by a remarkable ridge of pebbles at Newgale Sands, which has been driven before the waves, and thus made a barrier against themselves. This pebble-ridge is of great size, about a couple of miles long, great width and height, the individual pebbles being of all sizes up to about 12 inches diameter, and of various kinds of rock

b. Greatest height of cliff about 200 feet. Least, a wash at high water. Average about 150 feet.

3. Coast line very irregular; there is no considerable length of any given direction.

4. The prevailing wind is *westerly*, but not due west. It varies from south-west to north-west.

Storms (when it blows hard) invariably begin from the E.S.E. and work round by west to north-west, from which quarter they finish or blow themselves out. Our principal gales always come from this westerly direction, viz., from off the Atlantic, and the south-west coast bears the brunt of these gales.

5. **a.** South-west wind raises high waves.

b. West.

c. Our shingle does not travel [beyond the bays in which it occurs].

6. There is a strong tide passing the coast six hours northward and six hours southward alternately. As it affects the coast it is most felt at St. Govan's Head, the sound between Skomer and Skokham and the mainland, and about Ramsey Island and its sound. Where the current is running contrary to a strong wind a very heavy sea is raised: this is often the case off St. Ann's Head when the tide out of Milford Haven runs out against a westerly gale, and produces high and broken waves.

7. At spring tides 21 feet 6 inches; at the equinoxes often up to 26 feet.

At neap tides about 14 feet.

No figures can be given for width in yards from high to low water, as it differs from 0 to, say, half a mile in width.

8. The area covered by the tide in the harbour of Milford is mostly shingle or mud. Mud of a slimy nature is formed in the upper reaches. The area on the sea-coast is bare rock or sand. No mud there.

9. **a. & b.** The shingle is generally found from high water to about half tide of very various breadths.

c. It does not travel.

d. About a hen's egg is the largest size of pebble in the harbour. Outside at Newgale about 12 inches diameter.

e. Shingle is always in one continuous slope—not a 'neap full' and a 'spring full.'

10. Stationary, to all human observation.

11. Very little is removed from the coast; some is from the harbour, but only in small quantities. Inappreciable results.

12. No groynes on any part of the Pembrokeshire coast.

13. In general terms it may be stated that there are no removals of stone, sand, or shingle from our coast. These when wanted are obtained from inland quarries, for roads, buildings, &c.

14. No doubt the coast is being worn back, but at a very slow rate indeed. That it has been much worn is certain by the rugged outline.

It seems as though the outline of the rocky coasts will be for centuries as they are now, they having arrived at the maximum resistance and being well able to hold their own. The same cannot be so confidently stated with respect to the coal and shingle shores.

a. *Newgale and Amroth.*—It is said that when the tide is very low, and there happens to be then a storm that washes the sand away, there have appeared at both these places stumps and roots of ancient trees, and in the case of Newgale Sands there have been exposed stone pavements and walls which were witnessed by reliable men in the last century (see Fenton's 'Pembrokeshire'). Traditions are told in the county of forests occupying these two bays. It is obvious that the sea has not finished its advances at these parts of the coast.

b. Where there are cliffs there is no perceptible erosion.

c. Its rate is very slow, and may be said to be imperceptible.

d. Not known.

15. Not applicable to Pembrokeshire.

a. Shingle not abstracted.

b. No groynes.

16. No reclamations of land.

17. There are very considerable dunes of blown sand.

a. They are locally known as the 'Burrows'; most likely by that name because rabbits burrow in them and live in them in great numbers.

b. Mean height about 40 feet; greatest about 60 feet from their own base.

c. Not connected at all with river-mouths, nor with areas of shingle; in all instances they appear to have been blown up from the sand on the sea-shore; the grains are very fine and regular. It is remarkable that some of these hills of blown sand are at a great distance from the shore, sometimes a mile, and the base of the sand-hill 200 feet above sea-level; and yet there is no doubt that they came from the sea.

d. They are probably increasing, but not in an observable degree.

e. They do not blow over the land, but retain their mound-like shape always. As suggested in the question, they are much prevented from blowing away by the presence of vegetable growth, of which there is a good covering and a great variety, comprising *Juncus acutus* (great sharp sea-rush); its roots form a matted mass that aid much in consolidation; *Carex arenaria* (sea-sedge), abundant on the sand, where it is of great service in preventing the shifting; *Convolvulus Soldanella* (sea bind-weed), very common on the sand-hills; *Eryngium maritimum* (sea-holly). A dwarf wild rose, resembling the Scotch rose, is also common on the sand. The purple sea-rocket, stork's bill, sea-milkwort, the yellow horned poppy, and such like flowers, with wire-haired grasses in great variety. Another reason why the sand does not blow away is that most of the high winds are accompanied by rain, except the east wind, so that little would blow away when wet; and the east wind would only have the effect in blowing the top dry grains to the westward, which would only be a superficial action, and not go below the roots of the herbage.

19. There are pebbles at Freshwater West Bay about the size of those at Newgale, but not anything like the extent or variety of stones; when the waves are very high these are rolled violently against one another, and produce a deafening noise that is lost in the general roaring of the storm; but it happens sometimes that huge waves, locally called the 'ground swell,' come in and break on the shore, when there is no wind. They are the effect of storms that have blown themselves out at sea, and the waves rolling in break on the coast, sometimes with great violence, when there is no wind. These agitate the pebbles, so that they can be heard distinctly in Pembroke and Pembroke Dock, a distance of eight or nine miles. The attrition thus caused must wear the pebbles considerably. It is probable, however, that new loose stones are being washed in to repair this loss. In this way in low places on this coast the sea has before it the well-assigned duty of washing up and piling up a barrier against itself.

10. The Coast of Pembrokeshire—North-Western Part.

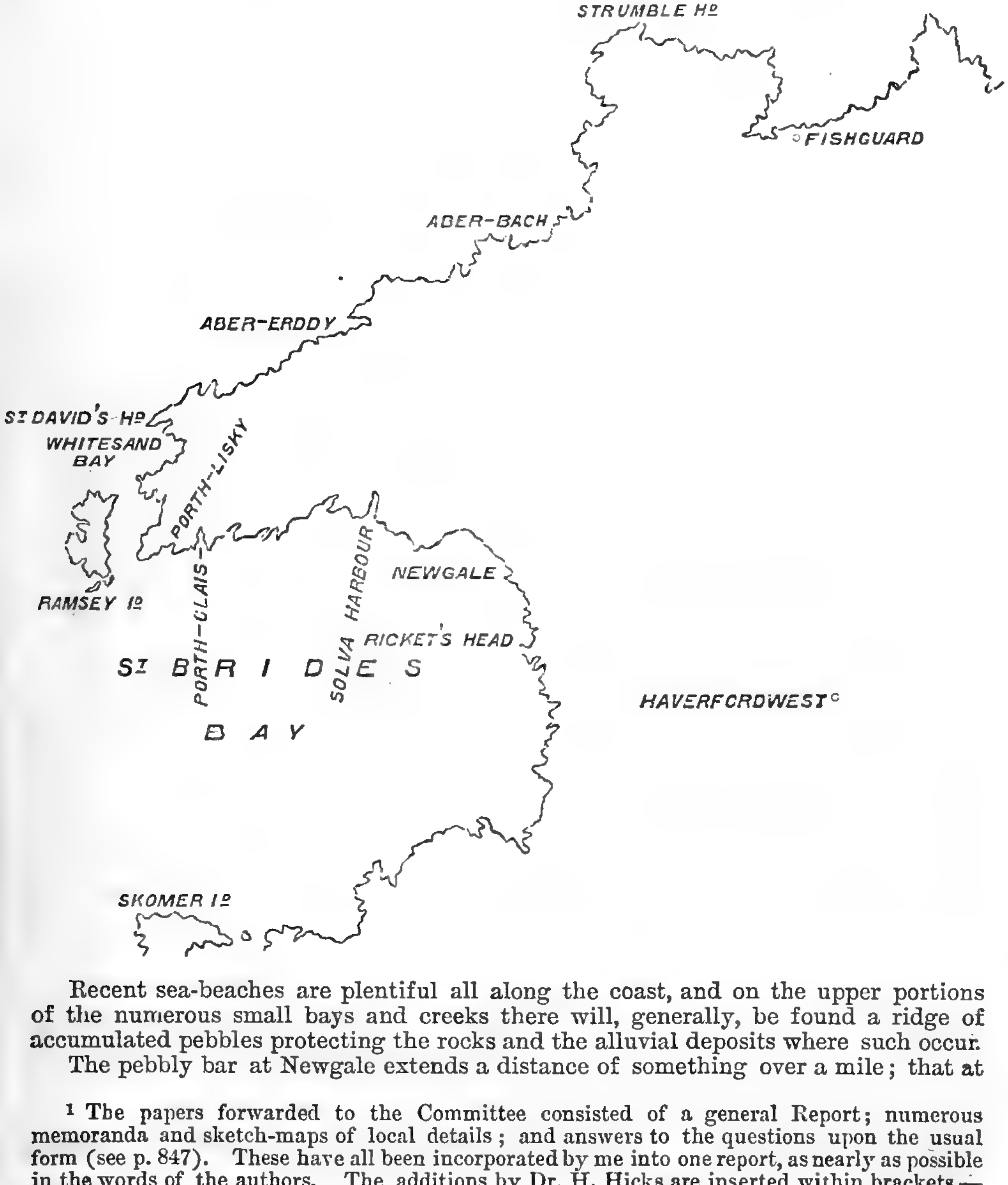
By Capt. THOMAS GRIFFITHS and H. WHITESIDE WILLIAMS, F.G.S.

(Communicated by HENRY HICKS, M.D., F.R.S., F.G.S.)[1]

This report refers to that portion of the coast of Pembrokeshire situate between Aberbach, on the northern coast, and Ricket's Head, in St. Bride's Bay.

The cliffs in this coast line vary in height from 50 to 250 feet, with an average height of about 100 feet. [The rocks forming the coast-line belong to the Archæan, Cambrian, Ordovician, and Carboniferous series, with intrusive and contemporaneous volcanic rocks.—H. H.]

MAP OF THE COAST OF PEMBROKESHIRE.



Recent sea-beaches are plentiful all along the coast, and on the upper portions of the numerous small bays and creeks there will, generally, be found a ridge of accumulated pebbles protecting the rocks and the alluvial deposits where such occur.

The pebbly bar at Newgale extends a distance of something over a mile; that at

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[1] The papers forwarded to the Committee consisted of a general Report; numerous memoranda and sketch-maps of local details; and answers to the questions upon the usual form (see p. 847). These have all been incorporated by me into one report, as nearly as possible in the words of the authors. The additions by Dr. H. Hicks are inserted within brackets.—W. TOPLEY.

Whitesand Bay about 1,000 yards; that at Abermawr about 800 yards. All the other bars are under 500 yards in length, measuring along the ridge.

There are evidences that nearly all these bars are increasing in height and base.

The pebbles are principally fragments from the local rocks, and the pebbles are usually well rounded.

There are no groynes on this coast. Generally speaking, the shingle does not travel in any direction except landwards. At Newgale and Whitesand Bay the shingle travels slightly in a N.N.W. direction.

It is a common practice amongst local farmers to take the sea-sand in large quantities for mixing with manure for agricultural purposes. The gravel and pebbles are also taken, where available, for road-making.

The range of tide is generally about 17 feet at spring tide, about 11 feet at neap tide. The tides run six knots at spring tide through Ramsey Sound with strong eddies near all the points. Flood to the north, ebb to the south, curving round St. David's and into St. Bride's Bay, where they get very weak.

The prevailing winds are south-west to north-west, and these are of most importance in raising high waves.

North-east of St. David's Head.—At Abermawr the sea has driven back the shingle very considerably in recent years. A limekiln at the eastern end of the bay and a roadway which was carried round a point to the adjacent creek of Aberbach have been washed away. About an acre of land, a large portion of which was under cultivation, has been eroded in the course of 60 years. In the winter of 1885, during a heavy gale from the northward, the sea drove back the shingle all along its line, but chiefly in its centre, partly filling up a roadway at the back and damming up a stream, causing it to flood the adjoining meadows, and necessitating the closing of the highway. Here, as at Newgale and Whitesand Bay, submerged trees have been seen after a gale. In the memory of a resident, now about 80 years of age, the trees thus exposed in his earlier days were used for firewood and other purposes, and he remembers a sleigh, for use on a farm, being made from the wood. All the wood obtained was in a good state of preservation.

The beach at Abercastle has been cut into by the sea about 50 yards during the last 50 years.

At Abereiddy the beach has been increased to the extent of about 50 yards on the sea side, the additional shingle having accumulated from the waste of a neighbouring slate quarry.

The beach at Aberpwll has been eroded to the extent of 10 yards within the memory of the present residents.

Whitesand Bay.—This bay is mainly excavated in drift, the bounding cliffs on the north and south being formed of Cambrian rocks. [The drift consists of an earthy boulder clay containing ice-scratched boulders, mainly fragments of local rocks; many of these boulders lie along the shore.—H. HICKS.]

The shingle beach is about 1,000 yards long, with a maximum width of about 50 feet, and a mean width of about 40 feet. The seaward face has many small irregular ridges. The shingle travels slightly towards the north end of the bay, and in this direction therefore the beach is widest.

The sand on the foreshore is 208 yards wide—from low-water mark to the beach.

Blown sand covers the ground inside the beach, in little hillocks of from 12 to 15 feet high, each having a seaward slope of from 23° to 25°. The land thus thinly covered with sand-hills rises to about 100 feet above the sea, but the sand is sometimes carried inland as far as the stream which runs to St. David's, about a mile from the shore. This blown sand does not affect the coast-line, except in such places where it is exposed to the direct action of the waves, by which it is easily eroded, and is then carried out to sea (subsequently to undergo re-deposition) by the rapid eddies formed by the swift tidal current finding its way through Ramsey Sound.

The sea has made considerable inroads at Whitesand Bay, the shingle moving landwards. A rock now 20 yards from the beach marks the site of the road forty years ago, the shingle beach being then on the seaward side of the road. The new road, made twenty years ago, was protected by a sea-wall; but this has been in part destroyed and great gaps cut into the road. At the north-east corner of the bay there is a field which has lost a width of about 34 yards in fifty years.

In the northern part of the bay stumps of trees and peat are laid bare during westerly gales, when the sand of the foreshore is cleared away.

Porth-seli is a small inlet on the southern side of Whitesand Bay, separated from the main bay by cliffs about 100 feet high. The sea is encroaching here, some 40 yards of land having been lost during the last fifty years.

Coast from Porth-lisky to Newgale Sands.—Porth-lisky is a small inlet excavated in the softer beds of the Pebidian series; it is bounded by the harder beds of the Pebidian on the west and by the hard granitoid or Dimetian rock on the east. The cliffs in the bay are about 90 feet high. [They consist of a series of nearly vertical beds, belonging to the Pebidian groups. Some have an ashen-like appearance; others are felsitic breccias, which decompose very readily.—H. HICKS.] The shingle in the bay varies in size from gravel up to pebbles 18 inches in diameter. Old inhabitants believe that it has moved up the bay about 10 yards within their memory.

Porth-clais Creek is the outlet of the river which drains the St. David's area. The banks on each side run up from a cliffy base in a sharp slope to a height of about 100 feet.

During the last fifty years the sea has cut away about 40 yards of the upper part of the harbour, and also some of the cliff on the west side. This is partly due to vessels which carry away ballast, but also to the wash from a heavy run in the creek during S.W. gales. The pier near the mouth of the creek has been breached by the sea during the last few years, thus accelerating the cutting process.

Along the cliffs from Porth-clais eastwards to Carbwddy there have been some heavy slips, but there is nothing to enable one to judge as to how much has fallen within recent years. The alterations which have been made in the pathways show that the loss must have been considerable in some places.

In Carbwddy the shingle has moved seaward 22 yards; the slope of the new ridge is about 23°. This gain is due to the waste from a large quarry which is worked here. This shingle, being the recent waste from the quarry, is hardly formed into pebbles.

From Carbwddy to Porth-y-rhaw the waste from the cliffs appears to be less than further west. [These cliffs consist of Cambrian rocks, chiefly sandstones and flaggy beds.—H. HICKS.]

In the cliffs under Llanunwas, extending from Porth-y-rhaw to Solva, there have been very heavy slips. In one place, between a rock called the Cradle and one called Gewny, the entrance of Solva Creek, the slips of the cliff have cut back fully 10 feet in gaps along a distance of 500 feet in about thirty years. Solva Creek has not undergone any noticeable change in that time. To the east of Solva Creek there are heavy slips every winter. Between the point called Dinas Mawr and Pencwm at the north end of Newgale Sands the slips have been few and of no great extent.

This bay is excavated in Carboniferous beds, the Cambrian rocks forming the north-west margin. At Cwy Mawr, where the Carboniferous rocks commence, about 20 yards have been eroded during the last fifty years. The cliffs at the south-eastern side of the bay are also of Carboniferous rocks. Between these cliffs there is a shingle beach, rather more than a mile long, with an extreme width of about 110 feet and a mean width of about 90 feet; the landward slope from the summit is about 46 feet long. The seaward slope, about 64 feet long, has an intermediate full, which does not seem to be caused by the neap tide, as it is too wavy and irregular: it changes with every gale. The pebbles vary from 3 to 14 inches in diameter; they are sometimes mixed with patches of small gravel.

The spring tides range 17 feet; neap tides 11 feet.

Some people believe that the beach has travelled landwards to a considerable amount, but there seems no evidence of any important change during the last eighty years. The amount of shingle is said to be increasing, and it has a slight tendency to travel from S.S.E. to N.N.W.

Behind the northern part of the shingle beach there is a marshy alluvial flat, about 10 feet below the summit of the shingle.

Seaward of the shingle beach there is sand, 230 yards wide at low water; trunks of trees have been seen here when the sand has been cleared away by heavy storms.

Giraldus Cambrensis states that in the winter of 1234, by reason of a violent storm, 'the surface of the earth [at Newgale], which had been covered for many ages, reappeared, and discovered the trunks of trees cut off, standing in the very sea itself, the strokes of the hatchet appearing as if made only yesterday. The soil was very black and the wood like ebony. By a wonderful revolution the road for ships became impassable, and looked, not like a shore, but like a grove cut down, perhaps, at the time of the Deluge, or not long after, but certainly in very remote ages, being by degrees consumed and swallowed up by the encroachments of the sea.'

Edward Llwyd, a Welsh historian, also states that the trees, 'which retained manifest signs of the strokes of the axe at the falling of them,' were again seen and noted in the year 1590, and the trunks of the fallen trees are said to have been seen by various persons in recent years.

The foregoing evidence appears to support the theory of submergence, rather than that of simple encroachment of the sea.

There is an old tradition, still current locally, that previous to the year 520 a large tract of land existed on the present northern shore of Pembrokeshire, extending from Ramsey Island (off St. David's) to Bardsey Island (off the coast of Caernarvonshire). This supposed tract of land was known as *Cantref y Gwaelod* (i.e. the Lowland Hundred), and is said to have been inundated about the year A.D. 520.

We have not been able to discover any reliable proofs that the land inundated was ever connected with the coast to which this report refers. On the contrary, nearly all the evidence, either physical or historical, opposes the local tradition referred to. The authorities we have consulted differ very greatly in their statements regarding the extent and locality of the inundated lowland. [See accompanying copy of chart on previous page.]

Theophilus Jones, of Brecon, 'a very celebrated Welsh herald,' writes:—'History as well as tradition agree in stating that *Cantref y Gwaelod*, . . . of which my ancestor Gwyddno Goronhir . . . was the king or reigning prince, reached all the way to the Irish coast; that it was only a river that divided them till it was inundated.'

Carlisle, in his 'Topographical Dictionary,' says:—'*Cantref y Gwaelod* is supposed to have occupied that portion of St. George's Channel which lies between the mainland and a line drawn from Bardsey Isle to Ramsey, in the county of Pembroke, and the proprietor is called in ancient authors Lord of Cantref y Gwaelod, in Dyfed—Dyfed in old records always meaning the county of Pembroke. Mr. Edward Llwyd greatly corroborates this tradition, having observed roots and stumps at a low ebb in the sands between Borth and Aberdyfi, in the county of Cardigan. And Giraldus says that St. David's Head extended farther into the sea, and that trunks of trees with fresh marks of the axe were apparent.'

Carlisle had, evidently, no acquaintance with the coast of Pembrokeshire. In quoting Giraldus' remarks it is plain that he supposes Newgale to lie to the north of St. David's Head. We cannot find that Giraldus anywhere states that St. David's Head extended farther into the sea.

Carlisle, in another place, says:—'History informs us that all the bay between the Causeway [St. Patrick's Causeway] and the county of Cardigan was formerly dry land, called *Cantref y Gwaelod*.'

In Camden's 'Britannia,' p. 632, we are informed:—'And that saying of William Rufus shews that the lands were not here [? St. David's Head] disjointed by any great sea, who, when he beheld Ireland from these rocks, said he could easily make a bridge of ships whereby he might walk from England into that kingdom.' In the foregoing Camden evidently misquotes *Giraldus Cambrensis*, who, in his 'Itinerary through Wales,' tells us that 'in clear weather the [Irish] *mountains* are visible' from St. David's, 'and the passage over the Irish Sea may be performed in one short day.' Ireland is to be seen even nowadays from this coast in clear weather.

In Meyrick's 'History of Cardigan,' in his references to *Cantref y Gwaelod*, we find:—'The boundary of this [*Cantref y Gwaelod*] on the north-west was, we are told, Sarn Badrig, or St. Patrick's Causeway, which runs out to sea in a serpentine manner, about two-and-twenty miles from the coast of Merionethshire, about halfway between Harlech and Barmouth. The coast included between this causeway and Cardigan bounded it on the north-east and south sides, and a supposed line from Cardigan to the extremity of Sarn Badrig formed its western limit.'

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[*An asterisk* (*) *signifies that no abstract of the communication is given.*]

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Together with the Transactions of the Sections, Sir R. I. Murchison's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE SEVENTEENTH MEETING, at Oxford, 1847, *Published at* 18s.

CONTENTS:—Prof. Langberg, on the Specific Gravity of Sulphuric Acid at different degrees of dilution, and on the relation which exists between the Development of Heat and the coincident contraction of Volume in Sulphuric Acid when mixed with Water;—R. Hunt, Researches on the Influence of the Solar Rays on the Growth of Plants;—R. Mallet, on the Facts of Earthquake Phenomena;—Prof. Nilsson, on the Primitive Inhabitants of Scandinavia;—W. Hopkins, Report on the Geological Theories of Elevation and Earthquakes;—Dr. W. B. Carpenter, Report on the Microscopic Structure of Shells;—Rev. W. Whewell and Sir James C. Ross, Report upon the Recommendation of an Expedition for the purpose of completing our Knowledge of the Tides;—Dr. Schunck, on Colouring Matters;—Seventh Report of the Committee on the Vitality of Seeds;—J. Glynn, on the Turbine or Horizontal Water-Wheel of France and Germany;—Dr. R. G. Latham, on the present state and recent progress of Ethnographical Philology;—Dr. J. C. Prichard, on the various methods of Research which contribute to the Advancement of Ethnology, and of the relations of that Science to other branches of Knowledge;—Dr. C. C. J. Bunsen, on the results of the recent Egyptian researches in reference to Asiatic and African Ethnology, and the Classification of Languages;—Dr. C. Meyer, on the Importance of the Study of the Celtic Language as exhibited by the Modern Celtic Dialects still extant;—Dr. Max Müller, on the Relation of the Bengali to the Aryan and Aboriginal Languages of India;—W. R. Birt, Fourth Report on Atmospheric Waves;—Prof. W. H. Dove, Temperature Tables, with Introductory Remarks by Lieut.-Col. E. Sabine; —A. Erman and H. Petersen, Third Report on the Calculation of the Gaussian Constants for 1829.

Together with the Transactions of the Sections, Sir Robert Harry Inglis's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE EIGHTEENTH MEETING, at Swansea, 1848, *Published at* 9*s.*

CONTENTS:—Rev. Prof. Powell, A Catalogue of Observations of Luminous Meteors;—J. Glynn, on Water-pressure Engines;—R. A. Smith, on the Air and Water of Towns;—Eighth Report of Committee on the Growth and Vitality of Seeds; —W. R. Birt, Fifth Report on Atmospheric Waves;—E. Schunck, on Colouring Matters;—J. P. Budd, on the advantageous use made of the gaseous escape from the Blast Furnaces at the Ystalyfera Iron Works;—R. Hunt, Report of progress in the investigation of the Action of Carbonic Acid on the Growth of Plants allied to those of the Coal Formations;—Prof. H. W. Dove, Supplement to the Temperature Tables printed in the Report of the British Association for 1847;—Remarks by Prof. Dove on his recently constructed Maps of the Monthly Isothermal Lines of the Globe, and on some of the principal Conclusions in regard to Climatology deducible from them; with an introductory Notice by Lieut.-Col. E. Sabine;—Dr. Daubeny, on the progress of the investigation on the Influence of Carbonic Acid on the Growth of Ferns;—J. Phillips, Notice of further progress in Anemometrical Researches;—Mr. Mallet's Letter to the Assistant-General Secretary;—A. Erman, Second Report on the Gaussian Constants;—Report of a Committee relative to the expediency of recommending the continuance of the Toronto Magnetical and Meteorological Observatory until December 1850.

Together with the Transactions of the Sections, the Marquis of Northampton's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE NINETEENTH MEETING, at Birmingham, 1849, *Published at* 10*s.*

CONTENTS:—Rev. Prof. Powell, A Catalogue of Observations of Luminous Meteors;—Earl of Rosse, Notice of Nebulæ lately observed in the Six-feet Reflector; —Prof. Daubeny, on the Influence of Carbonic Acid Gas on the health of Plants, especially of those allied to the Fossil Remains found in the Coal Formation;—Dr. Andrews, Report on the Heat of Combination;—Report of the Committee on the Registration of the Periodic Phenomena of Plants and Animals;—Ninth Report of Committee on Experiments on the Growth and Vitality of Seeds;—F. Ronalds, Report concerning the Observatory of the British Association at Kew, from Aug. 9, 1848 to Sept. 12, 1849;—R. Mallet, Report on the Experimental Inquiry on Railway Bar Corrosion;—W. R. Birt, Report on the Discussion of the Electrical Observations at Kew.

Together with the Transactions of the Sections, the Rev. T. R. Robinson's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTIETH MEETING, at Edinburgh, 1850, *Published at* 15*s.* (Out of Print.)

CONTENTS:—R. Mallet, First Report on the Facts of Earthquake Phenomena;—Rev. Prof. Powell, on Observations of Luminous Meteors;—Dr. T. Williams, on the Structure and History of the British Annelida;—T. C. Hunt, Results of Meteorological Observations taken at St. Michael's from the 1st of January, 1840, to the 31st of December, 1849;—R. Hunt, on the present State of our Knowledge of the Chemical Action of the Solar Radiations;—Tenth Report of Committee on Experiments on the Growth and Vitality of Seeds;—Major-Gen. Briggs, Report on the Aboriginal Tribes of India;—F. Ronalds, Report concerning the Observatory of the British Association at Kew;—E. Forbes, Report on the Investigation of British Marine Zoology by means of the Dredge;—R. MacAndrew, Notes on the Distribution and Range in depth of Mollusca and other Marine Animals, observed on the coasts of Spain, Portugal, Barbary, Malta, and Southern Italy in 1849;—Prof. Allman, on the Present State of our Knowledge of the Freshwater Polyzoa;—Registration of the Periodical Phenomena of Plants and Animals;—Suggestions to Astronomers for the Observation of the Total Eclipse of the Sun on July 28, 1851.

Together with the Transactions of the Sections, Sir David Brewster's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-FIRST MEETING, at Ipswich, 1851, *Published at* 16*s.* 6*d.*

CONTENTS:—Rev. Prof. Powell, on Observations of Luminous Meteors;—Eleventh Report of Committee on Experiments on the Growth and Vitality of Seeds;—Dr. J. Drew, on the Climate of Southampton;—Dr. R. A. Smith, on the Air and Water of Towns: Action of Porous Strata, Water, and Organic Matter;—Report of the Committee appointed to consider the probable Effects in an Economical and Physical Point of View of the Destruction of Tropical Forests;—A. Henfrey, on the Reproduction and supposed Existence of Sexual Organs in the Higher Cryptogamous Plants;—Dr. Daubeny, on the Nomenclature of Organic Compounds;—Rev. Dr. Donaldson, on two unsolved Problems in Indo-German Philology;—Dr. T. Williams, Report on the British Annelida;—R. Mallet, Second Report on the Facts of Earthquake Phenomena;—Letter from Prof. Henry to Col. Sabine, on the System of Meteorological Observations proposed to be established in the United States;—Col. Sabine, Report on the Kew Magnetographs;—J. Welsh, Report on the Performance of his three Magnetographs during the Experimental Trial at the Kew Observatory;—F. Ronalds, Report concerning the Observatory of the British Association at Kew, from September 12, 1850, to July 31, 1851;—Ordnance Survey of Scotland.

Together with the Transactions of the Sections, Prof. Airy's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-SECOND MEETING, at Belfast, 1852, *Published at* 15*s.*

CONTENTS:—R. Mallet, Third Report on the Facts of Earthquake Phenomena;—Twelfth Report of Committee on Experiments on the Growth and Vitality of Seeds;—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1851–52;—Dr. Gladstone, on the Influence of the Solar Radiations on the Vital Powers of Plants;—A Manual of Ethnological Inquiry;—Col. Sykes, Mean Temperature of the Day, and Monthly Fall of Rain at 127 Stations under the Bengal Presidency;—Prof. J. D. Forbes, on Experiments on the Laws of the Conduction of Heat;—R. Hunt, on the Chemical Action of the Solar Radiations;—Dr. Hodges, on the Composition and Economy of the Flax Plant;—W. Thompson, on the Freshwater Fishes of Ulster;—W. Thompson, Supplementary Report on the Fauna of Ireland;—W. Wills, on the Meteorology of Birmingham;—J. Thomson, on the Vortex-Water-Wheel;—J. B. Lawes and Dr. Gilbert, on the Composition of Foods in relation to Respiration and the Feeding of Animals.

Together with the Transactions of the Sections, Colonel Sabine's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-THIRD MEETING, at Hull, 1853, *Published at* 10*s.* 6*d.*

CONTENTS:—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1852–53;—James Oldham, on the Physical Features of the Humber;—James Oldham, on the Rise, Progress, and Present Position of Steam Navigation in Hull;—

William Fairbairn, Experimental Researches to determine the Strength of Locomotive Boilers, and the causes which lead to Explosion;—J. J. Sylvester, Provisional Report on the Theory of Determinants;—Professor Hodges, M.D., Report on the Gases evolved in Steeping Flax, and on the Composition and Economy of the Flax Plant;—Thirteenth Report of Committee on Experiments on the Growth and Vitality of Seeds;—Robert Hunt, on the Chemical Action of the Solar Radiations;—Dr. John P. Bell, Observations on the Character and Measurements of Degradation of the Yorkshire Coast;—First Report of Committee on the Physical Character of the Moon's Surface, as compared with that of the Earth;—R. Mallet, Provisional Report on Earthquake Wave-Transits; and on Seismometrical Instruments;—William Fairbairn, on the Mechanical Properties of Metals as derived from repeated Meltings, exhibiting the maximum point of strength and the causes of deterioration;—Robert Mallet, Third Report on the Facts of Earthquake Phenomena (continued).

Together with the Transactions of the Sections, Mr. Hopkins's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-FOURTH MEETING, at Liverpool, 1854, *Published at* 18*s*.

CONTENTS:—R. Mallet, Third Report on the Facts of Earthquake Phenomena (continued);—Major-General Chesney, on the Construction and General Use of Efficient Life-Boats;—Rev. Prof. Powell, Third Report on the present State of our Knowledge of Radiant Heat;—Colonel Sabine, on some of the results obtained at the British Colonial Magnetic Observatories;—Colonel Portlock, Report of the Committee on Earthquakes, with their proceedings respecting Seismometers;—Dr. Gladstone, on the Influence of the Solar Radiations on the Vital Powers of Plants, Part 2;—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1853–54;—Second Report of the Committee on the Physical Character of the Moon's Surface;—W. G. Armstrong, on the Application of Water-Pressure Machinery;—J. B. Lawes and Dr. Gilbert, on the Equivalency of Starch and Sugar in Food;—Archibald Smith, on the Deviations of the Compass in Wooden and Iron Ships;—Fourteenth Report of Committee on Experiments on the Growth and Vitality of Seeds.

Together with the Transactions of the Sections, the Earl of Harrowby's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-FIFTH MEETING, at Glasgow, 1855, *Published at* 15*s*.

CONTENTS:—T. Dobson, Report on the Relation between Explosions in Coal-Mines and Revolving Storms;—Dr. Gladstone, on the Influence of the Solar Radiations on the Vital Powers of Plants growing under different Atmospheric Conditions, Part 3;—C. Spence Bate, on the British Edriophthalma;—J. F. Bateman, on the present state of our knowledge on the Supply of Water to Towns;—Fifteenth Report of Committee on Experiments on the Growth and Vitality of Seeds;—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1854–55;—Report of Committee appointed to inquire into the best means of ascertaining those properties of Metals and effects of various modes of treating them which are of importance to the durability and efficiency of Artillery;—Rev. Prof. Henslow, Report on Typical Objects in Natural History;—A. Follett Osler, Account of the Self-registering Anemometer and Rain-Gauge at the Liverpool Observatory;—Provisional Reports.

Together with the Transactions of the Sections, the Duke of Argyll's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-SIXTH MEETING, at Cheltenham, 1856, *Published at* 18*s*.

CONTENTS:—Report from the Committee appointed to investigate and report upon the effects produced upon the Channels of the Mersey by the alterations which within the last fifty years have been made in its Banks;—J. Thomson, Interim Report on progress in Researches on the Measurement of Water by Weir Boards;—

Dredging Report, Frith of Clyde, 1856;—Rev. B. Powell, Report on Observations of Luminous Meteors, 1855–1856;—Prof. Bunsen and Dr. H. E. Roscoe, Photochemical Researches;—Rev. James Booth, on the Trigonometry of the Parabola, and the Geometrical Origin of Logarithms;—R. MacAndrew, Report on the Marine Testaceous Mollusca of the North-east Atlantic and neighbouring Seas, and the physical conditions affecting their development;—P. P. Carpenter, Report on the present state of our knowledge with regard to the Mollusca of the West Coast of North America;—T. C. Eyton, Abstract of First Report on the Oyster Beds and Oysters of the British Shores;—Prof. Phillips, Report on Cleavage, and Foliation in Rocks, and on the Theoretical Explanations of these Phenomena, Part 1;—Dr. T. Wright, on the Stratigraphical Distribution of the Oolitic Echinodermata;—W. Fairbairn, on the Tensile Strength of Wrought Iron at various Temperatures;—C. Atherton, on Mercantile Steam Transport Economy;—J. S. Bowerbank, on the Vital Powers of the Spongiadæ;—Report of a Committee upon the Experiments conducted at Stormontfield, near Perth, for the artificial propagation of Salmon;—Provisional Report on the Measurement of Ships for Tonnage;—On Typical Forms of Minerals, Plants and Animals for Museums;—J. Thomson, Interim Report on Progress in Researches on the Measurement of Water by Weir Boards;—R. Mallet, on Observations with the Seismometer;—A. Cayley, on the Progress of Theoretical Dynamics;—Report of a Committee appointed to consider the formation of a Catalogue of Philosophical Memoirs.

Together with the Transactions of the Sections, Dr. Daubeny's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-SEVENTH MEETING, at Dublin, 1857, *Published at* 15*s.*

CONTENTS:—A. Cayley, Report on the recent progress of Theoretical Dynamics;—Sixteenth and Final Report of Committee on Experiments on the Growth and Vitality of Seeds;—James Oldham, C.E., continuation of Report on Steam Navigation at Hull;—Report of a Committee on the Defects of the present methods of Measuring and Registering the Tonnage of Shipping, as also of Marine Engine-Power, and to frame more perfect rules, in order that a correct and uniform principle may be adopted to estimate the Actual Carrying Capabilities and Working-power of Steam Ships;—Robert Were Fox, Report on the Temperature of some Deep Mines in Cornwall;—Dr. G. Plarr, de quelques Transformations de la Somme $\Sigma_{t_0}^{-a} \frac{a^{t|+1}\beta^{t|+1}\delta^{t|+1}}{1^{t|+1}\gamma^{t|+1}\epsilon^{t|+1}}$ a étant entier négatif, et de quelques cas dans lesquels cette somme est exprimable par une combinaison de factorielles, la notation $a^{t|+1}$ désignant le produit des facteurs $\alpha\ (\alpha+1)\ (\alpha+2)$ &c.... $(\alpha+t-1)$;—G. Dickie, M.D., Report on the Marine Zoology of Strangford Lough, County Down, and corresponding part of the Irish Channel;—Charles Atherton, Suggestions for Statistical Inquiry into the Extent to which Mercantile Steam Transport Economy is affected by the Constructive Type of Shipping, as respects the Proportions of Length, Breadth, and Depth;—J. S. Bowerbank, Further Report on the Vitality of the Spongiadæ;—Dr. John P. Hodges, on Flax;—Major-General Sabine, Report of the Committee on the Magnetic Survey of Great Britain;—Rev. Baden Powell, Report on Observations of Luminous Meteors, 1856–57;—C. Vignoles, on the Adaptation of Suspension Bridges to sustain the passage of Railway Trains;—Prof. W. A. Miller, on Electro-Chemistry;—John Simpson, Results of Thermometrical Observations made at the *Plover's* Wintering-place, Point Barrow, latitude 71° 21′ N., long. 156° 17′ W., in 1852–54;—Charles James Hargreave, on the Algebraic Couple; and on the Equivalents of Indeterminate Expressions;—Thomas Grubb, Report on the Improvement of Telescope and Equatorial Mountings;—Prof. James Buckman, Report on the Experimental Plots in the Botanical Garden of the Royal Agricultural College at Cirencester;—William Fairbairn, on the Resistance of Tubes to Collapse;—George C. Hyndman, Report of the Proceedings of the Belfast Dredging Committee;—Peter W. Barlow, on the Mechanical Effect of combining Girders and Suspension Chains, and a Comparison of the Weight of Metal in Ordinary and Suspension Girders, to produce equal deflections with a given load;—J. Park Harrison, Evidences of Lunar Influence on Temperature;—Report on the Animal and Vegetable Products imported into Liverpool from the years 1851 to 1855 (inclusive);—Andrew Henderson, Report on the Statistics of Life-boats and Fishing-boats on the Coasts of the United Kingdom.

Together with the Transactions of the Sections, the Rev. H. Lloyd's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-EIGHTH MEETING, at Leeds, September 1858, *Published at* 20s.

CONTENTS:—R. Mallet, Fourth Report upon the Facts and Theory of Earthquake Phenomena;—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1857–1858;—R. H. Meade, on some Points in the Anatomy of the Araneidea or true Spiders, especially on the internal structure of their Spinning Organs;—W. Fairbairn, Report of the Committee on the Patent Laws;—S. Eddy, on the Lead Mining Districts of Yorkshire;—W. Fairbairn, on the Collapse of Glass Globes and Cylinders;—Dr. E. Perceval Wright and Prof. J. Reay Greene, Report on the Marine Fauna of the South and West Coasts of Ireland;—Prof. J. Thomson, on Experiments on the Measurement of Water by Triangular Notches in Weir Boards;—Major-General Sabine, Report of the Committee on the Magnetic Survey of Great Britain;—Michael Connel and William Keddie, Report on Animal, Vegetable, and Mineral Substances imported from Foreign Countries into the Clyde (including the Ports of Glasgow, Greenock, and Port Glasgow) in the years 1853, 1854, 1855, 1856, and 1857;—Report of the Committee on Shipping Statistics;—Rev. H. Lloyd, D.D., Notice of the Instruments employed in the Magnetic Survey of Ireland, with some of the Results;—Prof. J. R. Kinahan, Report of Dublin Dredging Committee, appointed 1857–58;—Prof. J. R. Kinahan, Report on Crustacea of Dublin District;—Andrew Henderson, on River Steamers, their Form, Construction, and Fittings, with reference to the necessity for improving the present means of Shallow-Water Navigation on the Rivers of British India;—George C. Hyndman, Report of the Belfast Dredging Committee;—Appendix to Mr. Vignoles' Paper 'On the Adaptation of Suspension Bridges to sustain the passage of Railway Trains;'—Report of the Joint Committee of the Royal Society and the British Association, for procuring a continuance of the Magnetic and Meteorological Observatories;—R. Beckley, Description of a Self-recording Anemometer.

Together with the Transactions of the Sections, Prof. Owen's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-NINTH MEETING, at Aberdeen, September 1859, *Published at* 15s.

CONTENTS:—George C. Foster, Preliminary Report on the Recent Progress and Present State of Organic Chemistry;—Professor Buckman, Report on the Growth of Plants in the Garden of the Royal Agricultural College, Cirencester;—Dr. A. Voelcker, Report on Field Experiments and Laboratory Researches on the Constituents of Manures essential to Cultivated Crops;—A. Thomson, of Banchory, Report on the Aberdeen Industrial Feeding Schools;—On the Upper Silurians of Lesmahagow, Lanarkshire;—Alphonse Gages, Report on the Results obtained by the Mechanico-Chemical Examination of Rocks and Minerals;—William Fairbairn, Experiments to determine the Efficiency of Continuous and Self-acting Brakes for Railway Trains;—Professor J. R. Kinahan, Report of Dublin Bay Dredging Committee for 1858–59;—Rev. Baden Powell, Report on Observations of Luminous Meteors for 1858–59;—Professor Owen, Report on a Series of Skulls of various Tribes of Mankind inhabiting Nepal, collected, and presented to the British Museum, by Bryan H. Hodgson, Esq., late Resident in Nepal, &c. &c.;—Messrs. Maskelyne, Hadow, Hardwich, and Llewelyn, Report on the Present State of our Knowledge regarding the Photographic Image;—G. C. Hyndman, Report of the Belfast Dredging Committee for 1859;—James Oldham, Continuation of Report of the Progress of Steam Navigation at Hull;—Charles Atherton, Mercantile Steam Transport Economy as affected by the Consumption of Coals;—Warren De La Rue, Report on the present state of Celestial Photography in England;—Professor Owen, on the Orders of Fossil and Recent Reptilia, and their Distribution in Time;—Balfour Stewart, on some Results of the Magnetic Survey of Scotland in the years 1857 and 1858, undertaken, at the request of the British Association, by the late John Welsh, Esq., F.R.S.;—W. Fairbairn, The

Patent Laws: Report of Committee on the Patent Laws;—J. Park Harrison, Lunar Influence on the Temperature of the Air:—Balfour Stewart, an Account of the Construction of the Self-recording Magnetographs at present in operation at the Kew Observatory of the British Association;—Professor H. J. Stephen Smith, Report on the Theory of Numbers, Part I.;—Report of the Committee on Steamship Performance;—Report of the Proceedings of the Balloon Committee of the British Association appointed at the Meeting at Leeds;—Prof. William K. Sullivan, Preliminary Report on the Solubility of Salts at Temperatures above 100° Cent., and on the Mutual Action of Salts in Solution.

Together with the Transactions of the Sections, Prince Albert's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTIETH MEETING, at Oxford, June and July 1860, *Published at* 15*s*.

CONTENTS:—James Glaisher, Report on Observations of Luminous Meteors, 1859-60;—J. R. Kinahan, Report of Dublin Bay Dredging Committee;—Rev. J. Anderson, Report on the Excavations in Dura Den;—Prof. Buckman, Report on the Experimental Plots in the Botanical Garden of the Royal Agricultural College, Cirencester;—Rev. R. Walker, Report of the Committee on Balloon Ascents;—Prof. W. Thomson, Report of Committee appointed to prepare a Self-recording Atmospheric Electrometer for Kew, and Portable Apparatus for observing Atmospheric Electricity;—William Fairbairn, Experiments to determine the Effect of Vibratory Action and long-continued Changes of Load upon Wrought-iron Girders;—R. P. Greg, Catalogue of Meteorites and Fireballs, from A.D. 2 to A.D. 1860;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part II.;—Vice-Admiral Moorsom, on the Performance of Steam-vessels, the Functions of the Screw, and the Relations of its Diameter and Pitch to the Form of the Vessel;—Rev. W. V. Harcourt, Report on the Effects of long-continued Heat, illustrative of Geological Phenomena;—Second Report of the Committee on Steamship Performance;—Interim Report on the Gauging of Water by Triangular Notches;—List of the British Marine Invertebrate Fauna.

Together with the Transactions of the Sections, Lord Wrottesley's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-FIRST MEETING, at Manchester, September 1861, *Published at* £1.

CONTENTS:—James Glaisher, Report on Observations of Luminous Meteors;—Dr. E. Smith, Report on the Action of Prison Diet and Discipline on the Bodily Functions of Prisoners, Part I.;—Charles Atherton, on Freight as affected by Differences in the Dynamic Properties of Steamships;—Warren De La Rue, Report on the Progress of Celestial Photography since the Aberdeen Meeting;—B. Stewart, on the Theory of Exchanges, and its recent extension;—Drs. E. Schunck, R. Angus Smith, and H. E. Roscoe, on the Recent Progress and Present Condition of Manufacturing Chemistry in the South Lancashire District;—Dr. J. Hunt, on Ethno-Climatology; or, the Acclimatization of Man;—Prof. J. Thomson, on Experiments on the Gauging of Water by Triangular Notches;—Dr. A. Voelcker, Report on Field Experiments and Laboratory Researches on the Constituents of Manures essential to cultivated Crops;—Prof. H. Hennessy, Provisional Report on the Present State of our Knowledge respecting the Transmission of Sound-signals during Fogs at Sea;—Dr. P. L. Sclater and F. von Hochstetter, Report on the Present State of our Knowledge of the Birds of the Genus *Apteryx* living in New Zealand;—J. G. Jeffreys, Report of the Results of Deep-sea Dredging in Zetland, with a Notice of several Species of Mollusca new to Science or to the British Isles;—Prof. J. Phillips, Contributions to a Report on the Physical Aspect of the Moon;—W. R. Birt, Contribution to a Report on the Physical Aspect of the Moon;—Dr. Collingwood and Mr. Byerley, Preliminary Report of the Dredging Committee of the Mersey and Dee;—Third Report of the Committee on Steamship Performance;—J. G. Jeffreys, Preliminary Report on the Best Mode of preventing the Ravages of *Teredo* and other Animals in our Ships and Harbours;—R. Mallet, Report on the Experiments made at Holyhead to ascertain the Transit-Velocity of Waves, analogous to Earthquake Waves, through the local Rock Formations;

—T. Dobson, on the Explosions in British Coal-Mines during the year 1859;—J. Oldham, Continuation of Report on Steam Navigation at Hull;—Prof. G. Dickie, Brief Summary of a Report on the Flora of the North of Ireland;—Prof. Owen, on the Psychical and Physical Characters of the Mincopies, or Natives of the Andaman Islands, and on the Relations thereby indicated to other Races of Mankind;—Colonel Sykes, Report of the Balloon Committee;—Major-General Sabine, Report on the Repetition of the Magnetic Survey of England;—Interim Report of the Committee for Dredging on the North and East Coasts of Scotland;—W. Fairbairn, on the Resistance of Iron Plates to Statical Pressure and the Force of Impact by Projectiles at High Velocities;—W. Fairbairn, Continuation of Report to determine the effect of Vibratory Action and long-continued Changes of Load upon Wrought-Iron Girders;—Report of the Committee on the Law of Patents;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part III.

Together with the Transactions of the Sections, Mr. Fairbairn's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-SECOND MEETING at Cambridge, October 1862, *Published at* £1.

CONTENTS:—James Glaisher, Report on Observations of Luminous Meteors, 1861–62;—G. B. Airy, on the Strains in the Interior of Beams;—Archibald Smith and F. J. Evans, Report on the three Reports of the Liverpool Compass Committee;—Report on Tidal Observations on the Humber;—T. Aston, on Rifled Guns and Projectiles adapted for Attacking Armour-plate Defences;—Extracts, relating to the Observatory at Kew, from a Report presented to the Portuguese Government, by Dr. J. A. de Souza;—H. T. Mennell, Report on the Dredging of the Northumberland Coast and Dogger Bank;—Dr. Cuthbert Collingwood, Report upon the best means of advancing Science through the agency of the Mercantile Marine;—Messrs. Williamson, Wheatstone, Thomson, Miller, Matthiessen, and Jenkin, Provisional Report on Standards of Electrical Resistance;—Preliminary Report of the Committee for investigating the Chemical and Mineralogical Composition of the Granites of Donegal;—Prof. H. Hennessy, on the Vertical Movements of the Atmosphere considered in connection with Storms and Changes of Weather;—Report of Committee on the application of Gauss's General Theory of Terrestrial Magnetism to the Magnetic Variations;—Fleeming Jenkin, on Thermo-electric Currents in Circuits of one Metal;—W. Fairbairn, on the Mechanical Properties of Iron Projectiles at High Velocities;—A. Cayley, Report on the Progress of the Solution of certain Special Problems of Dynamics;—Prof. G. G. Stokes, Report on Double Refraction;—Fourth Report of the Committee on Steamship Performance;—G. J. Symons, on the Fall of Rain in the British Isles in 1860 and 1861;—J. Ball, on Thermometric Observations in the Alps;—J. G. Jeffreys, Report of the Committee for Dredging on the North and East Coasts of Scotland;—Report of the Committee on Technical and Scientific Evidence in Courts of Law;—James Glaisher, Account of Eight Balloon Ascents in 1862;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part IV.

Together with the Transactions of the Sections, the Rev. Prof. R. Willis's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-THIRD MEETING, at Newcastle-upon-Tyne, August and September 1863, *Published at* £1 5*s*.

CONTENTS:—Report of the Committee on the Application of Gun-cotton to Warlike Purposes;—A. Matthiessen, Report on the Chemical Nature of Alloys;—Report of the Committee on the Chemical and Mineralogical Constitution of the Granites of Donegal, and on the Rocks associated with them;—J. G. Jeffreys, Report of the Committee appointed for exploring the Coasts of Shetland by means of the Dredge;—G. D. Gibb, Report on the Physiological Effects of the Bromide of Ammonium;—C. K. Aken, on the Transmutation of Spectral Rays, Part I.;—Dr. Robinson, Report of the Committee on Fog Signals;—Report of the Committee on Standards of Electrical Resistance;—E. Smith, Abstract of Report by the Indian Government on the Foods used by the Free and Jail Populations in India;—A. Gages, Synthetical Researches on the Formation of Minerals, &c.;—R. Mallet, Preliminary Report on the Experimental Determination of the Temperatures of Volcanic Foci, and of the Temperature, State of Saturation, and Velocity of the issuing Gases and Vapours;—Report of the Committee on Observations of Luminous Meteors;—Fifth Report of the Committee on Steamship Performance;—G. J. Allman, Report on the Present State of our Knowledge of the Reproductive System in the Hydroida;—J. Glaisher, Account of Five Balloon Ascents made in 1863;—P. P. Carpenter, Supplementary Report on the Present State of our Knowledge with regard to the Mollusca of the West Coast of North America;—Prof. Airy, Report on Steam Boiler Explosions;—C. W. Siemens, Observations on the Electrical Resistance and Electrification of some Insulating Materials under Pressures up to 300 Atmospheres;—C. M. Palmer, on the Construction of Iron Ships and the Progress of Iron Shipbuilding on the Tyne, Wear, and Tees;—Messrs. Richardson, Stevenson, and Clapham, on the Chemical Manufactures of the Northern Districts;—Messrs. Sopwith and Richardson, on the Local Manufacture of Lead, Copper, Zinc, Antimony, &c.;—Messrs. Daglish and Forster, on the Magnesian Limestone of Durham;—I. L. Bell, on the Manufacture of Iron in connexion with the Northumberland and Durham Coal-field;—T. Spencer, on the Manufacture of Steel in the Northern District;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part V.

Together with the Transactions of the Sections, Sir William Armstrong's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-FOURTH MEETING, at Bath, September 1864, *Published at* 18*s*.

CONTENTS:—Report of the Committee for Observations of Luminous Meteors;—Report of the Committee on the best means of providing for a Uniformity of Weights and Measures;—T. S. Cobbold, Report of Experiments respecting the Development and Migration of the Entozoa;—B. W. Richardson, Report on the Physiological Action of Nitrite of Amyl;—J. Oldham, Report of the Committee on Tidal Observations;—G. S. Brady, Report on Deep-sea Dredging on the Coasts of Northumberland and Durham in 1864;—J. Glaisher, Account of Nine Balloon Ascents made in 1863 and 1864;—J. G. Jeffreys, Further Report on Shetland Dredgings;—Report of the Committee on the Distribution of the Organic Remains of the North Staffordshire Coal-field;—Report of the Committee on Standards of Electrical Resistance;—G. J. Symons, on the Fall of Rain in the British Isles in 1862 and 1863;—W. Fairbairn, Preliminary Investigation of the Mechanical Properties of the proposed Atlantic Cable.

Together with the Transactions of the Sections, Sir Charles Lyell's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-FIFTH MEETING, at Birmingham, September 1865, *Published at* £1 5*s*.

CONTENTS:—J. G. Jeffreys, Report on Dredging among the Channel Isles;—F. Buckland, Report on the Cultivation of Oysters by Natural and Artificial Methods;—Report of the Committee for exploring Kent's Cavern;—Report of the Committee on Zoological Nomenclature;—Report on the Distribution of the Organic Remains of the North Staffordshire Coal-field;—Report on the Marine Fauna and Flora of the South Coast of Devon and Cornwall;—Interim Report on the Resistance of Water to Floating and Immersed Bodies;—Report on Observations of Luminous Meteors;—Report on Dredging on the Coast of Aberdeenshire;—J. Glaisher, Account of Three Balloon Ascents;—Interim Report on the Transmission of Sound under Water;—G. J. Symons, on the Rainfall of the British Isles;—W. Fairbairn, on the Strength of Materials considered in relation to the Construction of Iron Ships;—Report of the Gun-Cotton Committee;—A. F. Osler, on the Horary and Diurnal Variations in the Direction and Motion of the Air at Wrottesley, Liverpool, and Birmingham;—B. W. Richardson, Second Report on the Physiological Action of certain of the Amyl Compounds;—Report on further Researches in the Lingula-flags of South Wales;—Report of the Lunar Committee for Mapping the Surface of the Moon;—Report on Standards of Electrical Resistance;—Report of the Committee appointed to communicate with the Russian Government respecting Magnetical Observations at Tiflis;—Appendix to Report on the Distribution of the Vertebrate Remains from the North Staffordshire Coal-field;—H. Woodward, First Report on the Structure and Classification of the Fossil Crustacea;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part VI.;—Report on the best means of providing for a Uniformity of Weights and Measures, with reference to the interests of Science:—A. G. Findlay, on the Bed of the Ocean;—Prof. A. W. Williamson, on the Composition of Gases evolved by the Bath Spring called King's Bath.

Together with the Transactions of the Sections, Prof. Phillips's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-SIXTH MEETING, at Nottingham, August 1866, *Published at* £1 4*s*.

CONTENTS:—Second Report on Kent's Cavern, Devonshire;—A. Matthiessen, Preliminary Report on the Chemical Nature of Cast Iron;—Report on Observations of Luminous Meteors;—W. S. Mitchell, Report on the Alum Bay Leaf-bed;—Report on the Resistance of Water to Floating and Immersed Bodies;—Dr. Norris, Report on Muscular Irritability;—Dr. Richardson, Report on the Physiological Action of certain compounds of Amyl and Ethyl;—H. Woodward, Second Report on the Structure and Classification of the Fossil Crustacea;—Second Report on the 'Menevian Group,' and the other Formations at St. David's, Pembrokeshire;—J. G. Jeffreys, Report on Dredging among the Hebrides;—Rev. A. M. Norman, Report on the Coasts of the Hebrides, Part II.;—J. Alder, Notices of some Invertebrata, in connexion with Mr. Jeffreys's Report;—G. S. Brady, Report on the *Ostracoda* dredged amongst the Hebrides;—Report on Dredging in the Moray Firth;—Report on the Transmission of Sound-Signals under Water;—Report of the Lunar Committee;—Report of the Rainfall Committee;—Report on the best means of providing for a Uniformity of Weights and Measures, with reference to the Interests of Science;—J. Glaisher, Account of Three Balloon Ascents;—Report on the Extinct Birds of the Mascarene Islands;—Report on the Penetration of Ironclad Ships by Steel Shot;—J. A. Wanklyn, Report on Isomerism among the Alcohols;—Report on Scientific Evidence in Courts of Law;—A. L. Adams, Second Report on Maltese Fossiliferous Caves, &c.

Together with the Transactions of the Sections, Mr. Grove's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-SEVENTH MEETING, at Dundee, September 1867, *Published at* £1 6*s*.

CONTENTS:—Report of the Committee for Mapping the Surface of the Moon;—Third Report on Kent's Cavern, Devonshire;—On the present State of the Manufacture of Iron in Great Britain;—Third Report on the Structure and Classification of the Fossil Crustacea;—Report on the Physiological Action of the Methyl Compounds;—Preliminary Report on the Exploration of the Plant-Beds of North Greenland;—Report of the Steamship Performance Committee;—On the Meteorology of Port Louis, in the Island of Mauritius;—On the Construction and Works of the Highland Railway;—Experimental Researches on the Mechanical Properties of Steel;—Report on the Marine Fauna and Flora of the South Coast of Devon and Cornwall;—Supplement to a Report on the Extinct Didine Birds of the Mascarene Islands;—Report on Observations of Luminous Meteors;—Fourth Report on Dredging among the Shetland Isles;—Preliminary Report on the Crustacea, &c., procured by the Shetland Dredging Committee in 1867;—Report on the Foraminifera obtained in the Shetland Seas;—Second Report of the Rainfall Committee;—Report on the best means of providing for a Uniformity of Weights and Measures, with reference to the interests of Science;—Report on Standards of Electrical Resistance.

Together with the Transactions of the Sections, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-EIGHTH MEETING, at Norwich, August 1868, *Published at* £1 5*s*.

CONTENTS:—Report of the Lunar Committee —Fourth Report on Kent's Cavern, Devonshire;—On Puddling Iron;—Fourth Report on the Structure and Classification of the Fossil Crustacea;—Report on British Fossil Corals;—Report on Spectroscopic Investigations of Animal Substances;—Report of Steamship Performance Committee;—Spectrum Analysis of the Heavenly Bodies;—On Stellar Spectrometry;—Report on the Physiological Action of the Methyl and allied Compounds;—Report on the Action of Mercury on the Biliary Secretion;—Last Report on Dredging among the Shetland Isles;—Reports on the Crustacea, &c., and on the Annelida and Foraminifera from the Shetland Dredgings;—Report on the Chemical Nature of Cast Iron, Part I.;—Interim Report on the Safety of Merchant Ships and their Passengers;—Report on Observations of Luminous Meteors;—Preliminary Report on Mineral Veins containing Organic Remains;—Report on the Desirability of Explorations between India and China;—Report of Rainfall Committee;—Report on Synthetical Researches on Organic Acids;—Report on Uniformity of Weights and Measures;—Report of the Committee on Tidal Observations;—Report of the Committee on Underground Temperature;—Changes of the Moon's Surface;—Report on Polyatomic Cyanides.

Together with the Transactions of the Sections, Dr. Hooker's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-NINTH MEETING, at Exeter, August 1869, *Published at* £1 2*s*.

CONTENTS:—Report on the Plant-beds of North Greenland;—Report on the existing knowledge on the Stability, Propulsion, and Seagoing qualities of Ships;—Report on Steam-boiler Explosions;—Preliminary Report on the Determination of the Gases existing in Solution in Well-waters;—The Pressure of Taxation on Real Property;—On the Chemical Reactions of Light discovered by Prof. Tyndall;—On Fossils obtained at Kiltorkan Quarry, co. Kilkenny;—Report of the Lunar Committee;—Report on the Chemical Nature of Cast Iron;—Report on the Marine Fauna and Flora of the South Coast of Devon and Cornwall;—Report on the Practicability of establishing a 'Close Time' for the Protection of Indigenous Animals;—Experimental Researches on the Mechanical Properties of Steel;—Second Report on British Fossil Corals;—Report of the Committee appointed to get cut and prepared Sections of Mountain-Limestone Corals for Photographing;—Report on the Rate of Increase of Underground Temperature;—Fifth Report on Kent's Cavern, Devonshire;—Report on the Connexion between Chemical Constitution and Physiological Action;—On Emission, Absorption, and Reflection of Obscure Heat;—Report on Observations of Luminous Meteors;—Report on Uniformity of Weights and Measures;—Report on the Treatment and Utilization of Sewage;—Supplement to Second Report of the Steamship-Performance Committee;—Report on Recent Progress in Elliptic and Hyperelliptic Functions;—Report on Mineral Veins in Carboniferous Limestone and their Organic Contents;—Notes on the Foraminifera of Mineral Veins and the Adjacent Strata;—Report of the Rainfall Committee;—Interim Report on the Laws of the Flow and Action of Water containing Solid Matter in Suspension;—Interim Report on Agricultural Machinery;—Report on the Physiological Action of Methyl and Allied Series;—On the Influence of Form considered in Relation to the Strength of Railway-axles and other portions of Machinery subjected to Rapid Alterations of Strain;—On the Penetration of Armour-plates with Long Shells of Large Capacity fired obliquely;—Report on Standards of Electrical Resistance.

Together with the Transactions of the Sections, Prof. Stokes's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTIETH MEETING, at Liverpool, September 1870, *Published at* 18*s*.

CONTENTS:—Report on Steam-boiler Explosions;—Report of the Committee on the Hæmatite Iron-ores of Great Britain and Ireland;—Report on the Sedimentary

Deposits of the River Onny;—Report on the Chemical Nature of Cast Iron;—Report on the practicability of establishing a 'Close Time' for the protection of Indigenous Animals;—Report on Standards of Electrical Resistance;—Sixth Report on Kent's Cavern;—Third Report on Underground Temperature;—Second Report of the Committee appointed to get cut and prepared Sections of Mountain-Limestone Corals;—Second Report on the Stability, Propulsion, and Seagoing Qualities of Ships;—Report on Earthquakes in Scotland;—Report on the Treatment and Utilization of Sewage;—Report on Observations of Luminous Meteors, 1869-70;—Report on Recent Progress in Elliptic and Hyperelliptic Functions;—Report on Tidal Observations;—On a new Steam-power Meter;—Report on the Action of the Methyl and Allied Series;—Report of the Rainfall Committee;—Report on the Heat generated in the Blood in the Process of Arterialization;—Report on the best means of providing for Uniformity of Weights and Measures.

Together with the Transactions of the Sections, Prof. Huxley's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-FIRST MEETING, at Edinburgh, August 1871, *Published at* 16*s*.

Contents:—Seventh Report on Kent's Cavern;—Fourth Report on Underground Temperature;—Report on Observations of Luminous Meteors, 1870–71;—Fifth Report on the Structure and Classification of the Fossil Crustacea;—Report of the Committee appointed for the purpose of urging on Her Majesty's Government the expediency of arranging and tabulating the results of the approaching Census in the three several parts of the United Kingdom in such a manner as to admit of ready and effective comparison;—Report of the Committee appointed for the purpose of Superintending the Publication of Abstracts of Chemical Papers;—Report of the Committee for discussing Observations of Lunar Objects suspected of change;—Second Provisional Report on the Thermal Conductivity of Metals;—Report on the Rainfall of the British Isles;—Third Report on the British Fossil Corals;—Report on the Heat generated in the Blood during the Process of Arterialization;—Report of the Committee appointed to consider the subject of Physiological Experimentation;—Report on the Physiological Action of Organic Chemical Compounds;—Report of the Committee appointed to get cut and prepared Sections of Mountain-Limestone Corals;—Second Report on Steam-Boiler Explosions;—Report on the Treatment and Utilization of Sewage;—Report on promoting the Foundation of Zoological Stations in different parts of the World;—Preliminary Report on the Thermal Equivalents of the Oxides of Chlorine;—Report on the practicability of establishing a 'Close Time' for the protection of Indigenous Animals;—Report on Earthquakes in Scotland;—Report on the best means of providing for a Uniformity of Weights and Measures;—Report on Tidal Observations.

Together with the Transactions of the Sections, Sir William Thomson's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-SECOND MEETING, at Brighton, August 1872, *Published at* £1 4*s*.

Contents:—Report on the Gaussian Constants for the Year 1829;—Second Supplementary Report on the Extinct Birds of the Mascarene Islands;—Report of the Committee for Superintending the Monthly Reports of the Progress of Chemistry;—Report of the Committee on the best means of providing for a Uniformity of Weights and Measures;—Eighth Report on Kent's Cavern;—Report on promoting the Foundation of Zoological Stations in different parts of the World;—Fourth Report on the Fauna of South Devon;—Preliminary Report of the Committee appointed to Construct and Print Catalogues of Spectral Rays arranged upon a Scale of Wave-numbers;—Third Report on Steam-Boiler Explosions;—Report on Observations of Luminous Meteors, 1871–72;—Experiments on the Surface-friction experienced by a Plane moving through Water;—Report of the Committee on the Antagonism between the Action of Active Substances;—Fifth Report on Underground Temperature;—Preliminary Report of the Committee on Siemens's Electrical-Resistance Pyrometer;—Fourth Report on the Treatment and Utilization of Sewage;—Interim

Report of the Committee on Instruments for Measuring the Speed of Ships and Currents;—Report on the Rainfall of the British Isles;—Report of the Committee on a Geographical Exploration of the Country of Moab;—Sur l'élimination des Fonctions Arbitraires;—Report on the Discovery of Fossils in certain remote parts of the North-western Highlands;—Report of the Committee on Earthquakes in Scotland;—Fourth Report on Carboniferous-Limestone Corals;—Report of the Committee to consider the mode in which new Inventions and Claims for Reward in respect of adopted Inventions are examined and dealt with by the different Departments of Government;—Report of the Committee for discussing Observations of Lunar Objects suspected of change;—Report on the Mollusca of Europe;—Report of the Committee for investigating the Chemical Constitution and Optical Properties of Essential Oils;—Report on the practicability of establishing a 'Close Time' for the preservation of Indigenous Animals;—Sixth Report on the Structure and Classification of Fossil Crustacea;—Report of the Committee appointed to organize an Expedition for observing the Solar Eclipse of Dec. 12, 1871;—Preliminary Report of a Committee on Terato-embryological Inquiries;—Report on Recent Progress in Elliptic and Hyperelliptic Functions;—Report on Tidal Observations;—On the Brighton Waterworks;—On Amsler's Planimeter.

Together with the Transactions of the Sections, Dr. Carpenter's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-THIRD MEETING, at Bradford, September 1873, *Published at £1 5s.*

CONTENTS:—Report of the Committee on Mathematical Tables;—Observations on the Application of Machinery to the Cutting of Coal in Mines;—Concluding Report on the Maltese Fossil Elephants;—Report of the Committee for ascertaining the Existence in different parts of the United Kingdom of any Erratic Blocks or Boulders;—Fourth Report on Earthquakes in Scotland;—Ninth Report on Kent's Cavern;—On the Flint and Chert Implements found in Kent's Cavern;—Report of the Committee for Investigating the Chemical Constitution and Optical Properties of Essential Oils;—Report of Inquiry into the Method of making Gold-assays; —Fifth Report on the Selection and Nomenclature of Dynamical and Electrical Units;—Report of the Committee on the Labyrinthodonts of the Coal-measures;—Report of the Committee appointed to construct and print Catalogues of Spectral Rays;—Report of the Committee appointed to explore the Settle Caves;—Sixth Report on Underground Temperature;—Report on the Rainfall of the British Isles;—Seventh Report on Researches in Fossil Crustacea;—Report on Recent Progress in Elliptic and Hyperelliptic Functions;—Report on the desirability of establishing a 'Close Time' for the preservation of Indigenous Animals;—Report on Luminous Meteors; —On the Visibility of the Dark Side of Venus;—Report of the Committee for the Foundation of Zoological Stations in different parts of the World;—Second Report of the Committee for collecting Fossils from North-western Scotland;—Fifth Report on the Treatment and Utilization of Sewage;—Report of the Committee on Monthly Reports of the Progress of Chemistry;—On the Bradford Waterworks;—Report on the possibility of Improving the Methods of Instruction in Elementary Geometry; —Interim Report of the Committee on Instruments for Measuring the Speed of Ships, &c.;—Report of the Committee for Determinating High Temperatures by means of the Refrangibility of Light evolved by Fluid or Solid Substances;—On a periodicity of Cyclones and Rainfall in connexion with Sun-spot Periodicity;—Fifth Report on the Structure of Carboniferous-Limestone Corals;—Report of the Committee on preparing and publishing brief forms of Instructions for Travellers, Ethnologists, &c.;—Preliminary Note from the Committee on the Influence of Forests on the Rainfall;—Report of the Sub-Wealden Exploration Committee;—Report of the Committee on Machinery for obtaining a Record of the Roughness of the Sea and Measurement of Waves near shore;—Report on Science Lectures and Organization;—Second Report on Science Lectures and Organization.

Together with the Transactions of the Sections, Prof. A. W. Williamson's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-FOURTH MEETING, at Belfast, August 1874, *Published at* £1 5*s.*

CONTENTS:—Tenth Report on Kent's Cavern;—Report for investigating the Chemical Constitution and Optical Properties of Essential Oils;—Second Report of the Sub-Wealden Exploration Committee;—On the Recent Progress and Present State of Systematic Botany;—Report of the Committee for investigating the Nature of Intestinal Secretion;—Report of the Committee on the Teaching of Physics in Schools;—Preliminary Report for investigating Isomeric Cresols and their Derivatives;—Third Report of the Committee for collecting Fossils from localities in North-western Scotland;—Report on the Rainfall of the British Isles;—On the Belfast Harbour;—Report of Inquiry into the Method of making Gold-assays;—Report of a Committee on Experiments to determine the Thermal Conductivities of certain Rocks;—Second Report on the Exploration of the Settle Caves;—On the Industrial uses of the Upper Bann River;—Report of the Committee on the Structure and Classification of the Labyrinthodonts;—Second Report of the Committee for recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England and Wales, &c.;—Sixth Report on the Treatment and Utilization of Sewage;—Report on the Anthropological Notes and Queries for the use of Travellers;—On Cyclone and Rainfall Periodicities;—Fifth Report on Earthquakes in Scotland;—Report of the Committee appointed to prepare and print Tables of Wave-numbers;—Report of the Committee for testing the new Pyrometer of Mr. Siemens;—Report to the Lords Commissioners of the Admiralty on Experiments for the Determination of the Frictional Resistance of Water on a Surface &c.;—Second Report for the Selection and Nomenclature of Dynamical and Electrical Units;—On Instruments for measuring the Speed of Ships;—Report of the Committee on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report of the Committee to inquire into the economic effects of Combinations of Labourers and Capitalists;—Preliminary Report on Dredging on the Coasts of Durham and North Yorkshire;—Report on Luminous Meteors;—Report on the best means of providing for a Uniformity of Weights and Measures.

Together with the Transactions of the Sections, Prof. John Tyndall's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-FIFTH MEETING, at Bristol, August 1875, *Published at* £1 5*s.*

CONTENTS:—Eleventh Report on Kent's Cavern;—Seventh Report on Underground Temperature;—Report on the Zoological Station at Naples;—Report of a Committee appointed to inquire into the Methods employed in the Estimation of Potash and Phosphoric Acid in Commercial Products;—Report on the present state of our Knowledge of the Crustacea;—Second Report on the Thermal Conductivities of certain Rocks;—Preliminary Report of the Committee for extending the Observations on the Specific Volumes of Liquids;—Sixth Report on Earthquakes in Scotland;—Seventh Report on the Treatment and Utilization of Sewage;—Report of the Committee for furthering the Palestine Explorations;—Third Report of the Committee for recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England and Wales, &c.;—Report of the Rainfall Committee;—Report of the Committee for investigating Isomeric Cresols and their Derivatives;—Report of the Committee for investigating the Circulation of the Underground Waters in the New Red Sandstone and Permian Formations of England;—On the Steering of Screw-Steamers;—Second Report of the Committee on Combinations of Capital and Labour;—Report on the Method of making Gold-assays;—Eighth Report on Underground Temperature;—Tides in the River Mersey;—Sixth Report of the Committee on the Structure of Carboniferous Corals;—Report of the Committee appointed to explore the Settle Caves;—On the River Avon (Bristol), its Drainage-Area, &c.;—Report of the Committee on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report of the Committee appointed to superintend the Publication of the Monthly Reports of the Progress of Chemistry;—Report on Dredging off the Coasts of Durham and North Yorkshire in 1874;—Report on Luminous Meteors;—On the Analytical Forms called Trees;—Report of the Committee on Mathematical Tables;—Report of the Committee on Mathematical Notation and Printing;—Second Report of the Committee for investigating Intestinal Secretion;—Third Report of the Sub-Wealden Exploration Committee.

Together with the Transactions of the Sections, Sir John Hawkshaw's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-SIXTH MEETING, at Glasgow, September 1876, *Published at* £1 5*s*.

CONTENTS:—Twelfth Report on Kent's Cavern;—Report on Improving the Methods of Instruction in Elementary Geometry;—Results of a Comparison of the British-Association Units of Electrical Resistance;—Third Report on the Thermal Conductivities of certain Rocks;—Report of the Committee on the practicability of adopting a Common Measure of Value in the Assessment of Direct Taxation;—Report of the Committee for testing experimentally Ohm's Law;—Report of the Committee on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report of the Committee on the Effect of Propellers on the Steering of Vessels;—On the Investigation of the Steering Qualities of Ships;—Seventh Report on Earthquakes in Scotland;—Report on the present state of our Knowledge of the Crustacea;—Second Report of the Committee for investigating the Circulation of the Underground Waters in the New Red Sandstone and Permian Formations of England;—Fourth Report of the Committee on the Erratic Blocks of England and Wales, &c.;—Fourth Report of the Committee on the Exploration of the Settle Caves (Victoria Cave);—Report on Observations of Luminous Meteors, 1875–76;—Report on the Rainfall of the British Isles, 1875–76;—Ninth Report on Underground Temperature;—Nitrous Oxide in the Gaseous and Liquid States;—Eighth Report on the Treatment and Utilization of Sewage;—Improved Investigations on the Flow of Water through Orifices, with Objections to the modes of treatment commonly adopted;—Report of the Anthropometric Committee;—On Cyclone and Rainfall Periodicities in connexion with the Sun-spot Periodicity;—Report of the Committee for determining the Mechanical Equivalent of Heat;—Report of the Committee on Tidal Observations;—Third Report of the Committee on the Conditions of Intestinal Secretion and Movement;—Report of the Committee for collecting and suggesting subjects for Chemical Research.

Together with the Transactions of the Sections, Dr. T. Andrews's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-SEVENTH MEETING, at Plymouth, August 1877, *Published at* £1 4*s*.

CONTENTS:—Thirteenth Report on Kent's Cavern;—Second and Third Reports on the Methods employed in the estimation of Potash and Phosphoric Acid in Commercial Products;—Report on the present state of our Knowledge of the Crustacea (Part III.);—Third Report on the Circulation of the Underground Waters in the New Red Sandstone and Permian Formations of England;—Fifth Report on the Erratic Blocks of England, Wales, and Ireland;—Fourth Report on the Thermal Conductivities of certain Rocks;—Report on Observations of Luminous Meteors, 1876–77;—Tenth Report on Underground Temperature;—Report on the Effect of Propellers on the Steering of Vessels;—Report on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report on some Double Compounds of Nickel and Cobalt;—Fifth Report on the Exploration of the Settle Caves (Victoria Cave);—Report on the Datum Level of the Ordnance Survey of Great Britain;—Report on the Zoological Station at Naples;—Report of the Anthropometric Committee;—Report on the Conditions under which Liquid Carbonic Acid exists in Rocks and Minerals.

Together with the Transactions of the Sections, Prof. Allen Thomson's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-EIGHTH MEETING, at Dublin, August 1878, *Published at £1 4s.*

CONTENTS:—Catalogue of the Oscillation-Frequencies of Solar Rays;—Report on Mr. Babbage's Analytical Machine;—Third Report of the Committee for determining the Mechanical Equivalent of Heat;—Report of the Committee for arranging for the taking of certain Observations in India, and Observations on Atmospheric Electricity at Madeira;—Report on the commencement of Secular Experiments upon the Elasticity of Wires;—Report on the Chemistry of some of the lesser-known Alkaloids, especially Veratria and Bebeerine;—Report on the best means for the Development of Light from Coal-Gas;—Fourteenth Report on Kent's Cavern;—Report on the Fossils in the North-west Highlands of Scotland;—Fifth Report on the Thermal Conductivities of certain Rocks;—Report on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report on the occupation of a Table at the Zoological Station at Naples;—Report of the Anthropometric Committee;—Report on Patent Legislation;—Report on the Use of Steel for Structural Purposes;—Report on the Geographical Distribution of the Chiroptera;—Recent Improvements in the Port of Dublin;—Report on Mathematical Tables;—Eleventh Report on Underground Temperature;—Report on the Exploration of the Fermanagh Caves;—Sixth Report on the Erratic Blocks of England, Wales, and Ireland;—Report on the present state of our Knowledge of the Crustacea (Part IV.);—Report on two Caves in the neighbourhood of Tenby;—Report on the Stationary Tides in the English Channel and in the North Sea, &c.;—Second Report on the Datum-level of the Ordnance Survey of Great Britain;—Report on instruments for measuring the Speed of Ships;—Report of Investigations into a Common Measure of Value in Direct Taxation;—Report on Sunspots and Rainfall;—Report on Observations of Luminous Meteors;—Sixth Report on the Exploration of the Settle Caves (Victoria Cave);—Report on the Kentish Boring Exploration;—Fourth Report on the Circulation of Underground Waters in the Jurassic, New Red Sandstone, and Permian Formations, with an Appendix on the Filtration of Water through Triassic Sandstone;—Report on the Effect of Propellers on the Steering of Vessels.

Together with the Transactions of the Sections, Mr. Spottiswoode's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-NINTH MEETING, at Sheffield, August 1879, *Published at £1 4s.*

CONTENTS:—Report on the commencement of Secular Experiments upon the Elasticity of Wires;—Fourth Report of the Committee for determining the Mechanical Equivalent of Heat;—Report of the Committee for endeavouring to procure reports on the Progress of the Chief Branches of Mathematics and Physics;—Twelfth Report on Underground Temperature;—Report on Mathematical Tables;—Sixth Report on the Thermal Conductivities of certain Rocks;—Report on Observations of Atmospheric Electricity at Madeira;—Report on the Calculation of Tables of the Fundamental Invariants of Algebraic Forms;—Report on the Calculation of Sun-Heat Coefficients;—Second Report on the Stationary Tides in the English Channel and in the North Sea, &c.;—Report on Observations of Luminous Meteors;—Report on the question of Improvements in Astronomical Clocks;—Report of the Committee for improving an Instrument for detecting the presence of Fire-damp in Mines;—Report on the Chemistry of some of the lesser-known Alkaloids, especially Veratria and Bebeerine;—Seventh Report on the Erratic Blocks of England, Wales, and Ireland;—Fifteenth Report on Kent's Cavern;—Report on certain Caves in Borneo;—Fifth Report on the Circulation of Underground Waters in the Jurassic, Red Sandstone, and Permian Formations of England;—Report on the Tertiary (Miocene) Flora, &c., of the Basalt of the North of Ireland;—Report on the possibility of Establishing a 'Close Time' for the Protection of Indigenous Animals;—Report on the Marine Zoology of Devon and Cornwall;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on Excavations at Portstewart and elsewhere in the North of Ireland;—Report of the Anthropometric Committee;—Report on the Investigation of the Natural History of Socotra;—Report on Instruments for measuring the Speed of Ships;—Third Report on the Datum-level of the Ordnance Survey of Great Britain;—Second Report on Patent Legislation;—On Self-acting Intermittent Siphons and the conditions which determine the commencement of their Action;—On some further Evidence as to the Range of the Palæozoic Rocks beneath the South-east of England;—Hydrography, Past and Present.

Together with the Transactions of the Sections, Prof. Allman's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FIFTIETH MEETING, at Swansea, August and September 1880, *Published at £1 4s.*

CONTENTS:—Report on the Measurement of the Lunar Disturbance of Gravity;—Thirteenth Report on Underground Temperature;—Report of the Committee for devising and constructing an improved form of High Insulation Key for Electrometer Work;—Report on Mathematical Tables;—Report on the Calculation of Tables of the Fundamental Invariants of Algebraic Forms;—Report on Observations of Luminous Meteors;—Report on the question of Improvements in Astronomical Clocks;—Report on the commencement of Secular Experiments on the Elasticity of Wires;—Sixteenth and concluding Report on Kent's Cavern;—Report on the mode of reproduction of certain species of Ichthyosaurus from the Lias of England and Würtemburg;—Report on the Carboniferous Polyzoa;—Report on the 'Geological Record';—Sixth Report on the Circulation of the Underground Waters in the Permian, New Red Sandstone, and Jurassic Formations of England, and the Quantity and Character of the Water supplied to towns and districts from these formations;—Second Report on the Tertiary (Miocene) Flora, &c., of the Basalt of the North of Ireland;—Eighth Report on the Erratic Blocks of England, Wales, and Ireland;—Report on an Investigation for the purpose of fixing a Standard of White Light;—Report of the Anthropometric Committee;—Report on the Influence of Bodily Exercise on the Elimination of Nitrogen;—Second Report on the Marine Zoology of South Devon;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on accessions to our knowledge of the Chiroptera during the past two years (1878–80);—Preliminary Report on the accurate measurement of the specific inductive capacity of a good Sprengel Vacuum, and the specific resistance of gases at different pressures;—Comparison of Curves of the Declination Magnetographs at Kew, Stonyhurst, Coimbra, Lisbon, Vienna, and St. Petersburg;—First Report on the Caves of the South of Ireland;—Report on the Investigation of the Natural History of Socotra;—Report on the German and other systems of teaching the Deaf to speak;—Report of the Committee for considering whether it is important that H.M. Inspectors of Elementary Schools should be appointed with reference to their ability for examining in the scientific specific subjects of the Code in addition to other matters;—On the Anthracite Coal and Coalfield of South Wales;—Report on the present state of our knowledge of Crustacea (Part V.);—Report on the best means for the Development of Light from Coal-gas of different qualities (Part II.);—Report on Palæontological and Zoological Researches in Mexico;—Report on the possibility of establishing a 'Close Time' for Indigenous Animals;—Report on the present state of our knowledge of Spectrum Analysis;—Report on Patent Legislation;—Preliminary Report on the present Appropriation of Wages, &c.;—Report on the present state of knowledge of the application of Quadratures and Interpolation to Actual Data;—The French Deep-sea Exploration in the Bay of Biscay;—Third Report on the Stationary Tides in the English Channel and in the North Sea, &c.;—List of Works on the Geology, Mineralogy, and Palæontology of Wales (to the end of 1873);—On the recent Revival in Trade.

Together with the Transactions of the Sections, Dr. A. C. Ramsay's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FIFTY-FIRST MEETING, at York, August and September 1881, *Published at £1 4s.*

CONTENTS:—Report on the Calculation of Tables of the Fundamental Invariants of Algebraic Forms;—Report on Recent Progress in Hydrodynamics (Part I.);—Report on Meteoric Dust;—Second Report on the Calculation of Sun-heat Coefficients;—Fourteenth Report on Underground Temperature;—Report on the Measurement of the Lunar Disturbance of Gravity;—Second Report on an Investigation for the purpose of fixing a Standard of White Light;—Final Report on the Thermal Conductivities of certain Rocks;—Report on the manner in which Rudimentary Science should be taught, and how Examinations should be held therein, in Elementary Schools;—Third Report on the Tertiary Flora of the North of Ireland;—Report on the Method of Determining the Specific Refraction of Solids from their Solutions;—Fourth Report on the Stationary Tides in the English Channel and in the North Sea, &c.;—Second Report on Fossil Polyzoa;—Report on the Maintenance of the Scottish Zoological Station;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on the Migration of Birds;—Report on the Natural History of Socotra;—Report on the Natural History of Timor-laut;—Report on the Marine Fauna of the Southern Coast of Devon and Cornwall;—Report on the Earthquake Phenomena of Japan;—Ninth Report on the Erratic Blocks of England, Wales, and Ireland;—Second Report on the Caves of the South of Ireland;—Report on Patent Legislation;—Report of the Anthropometric Committee;—Report on the Appropriation of Wages, &c.;—Report on Observations of Luminous Meteors;—Report on Mathematical Tables;—Seventh Report on the Circulation of Underground Waters in the Jurassic, New Red Sandstone, and Permian Formations of England, and the Quality and Quantity of the Water supplied to Towns and Districts from these Formations;—Report on the present state of our Knowledge of Spectrum Analysis;—Interim Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements;—On some new Theorems on Curves of Double Curvature;—Observations of Atmospheric Electricity at the Kew Observatory during 1880;—On the Arrestation of Infusorial Life by Solar Light;—On the Effects of Oceanic Currents upon Climates;—On Magnetic Disturbances and Earth Currents;—On some Applications of Electric Energy to Horticultural and Agricultural purposes;—On the Pressure of Wind upon a Fixed Plane Surface;—On the Island of Socotra;—On some of the Developments of Mechanical Engineering during the last Half-Century.

Together with the Transactions of the Sections, Sir John Lubbock's Address, and Recommendations of the Association and its Committees.

REPORT OF THE FIFTY-SECOND MEETING, at Southampton, August 1882, *Published at £1 4s.*

CONTENTS:—Report on the Calculation of Tables of Fundamental Invariants of Binary Quantics;—Report (provisional) of the Committee for co-operating with the Meteorological Society of the Mauritius in their proposed publication of Daily Synoptic Charts of the Indian Ocean from the year 1861;—Report of the Committee appointed for fixing a Standard of White Light;—Report on Recent Progress in Hydrodynamics (Part II.);—Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements;—Fifteenth Report on Underground Temperature, with Summary of the Results contained in the Fifteen Reports of the Underground Temperature Committee;—Report on Meteoric Dust;—Second Report on the Measurement of the Lunar Disturbance of Gravity;—Report on the present state of our Knowledge of Spectrum Analysis;—Report on the Investigation by means of Photography of the Ultra-Violet Spark Spectra emitted by Metallic Elements, and their combinations under varying conditions;—Report of the Committee for preparing a new Series of Tables of Wave-lengths of the Spectra of the Elements;—Report on the Methods employed in the Calibration of Mercurial Thermometers;—Second Report on the Earthquake Phenomena of Japan;—Eighth Report on the Circulation of the Underground Waters in the Permeable Formations of England, and the Quality and Quantity of the Water supplied to various Towns and Districts from these Formations;—Report on the Conditions under which ordinary Sedimentary Materials may be converted into Metamorphic Rocks;—Report on Explorations in Caves of Carboniferous Limestone in the South of Ireland;—Report on the Preparation of an International Geological Map of Europe;—Tenth Report on the Erratic Blocks of England, Wales, and Ireland;—Report on Fossil Polyzoa (Jurassic Species—British Area only);—Preliminary Report on the Flora of the 'Halifax Hard Bed,' Lower Coal Measures;—Report on the Influence of Bodily Exercise on the Elimination of Nitrogen;—Report of the Committee appointed for obtaining Photographs of the Typical Races in the British Isles;—Preliminary Report on the Ancient Earthwork in Epping Forest known as the Loughton Camp;

—Second Report on the Natural History of Timor-laut;—Report of the Committee for carrying out the recommendations of the Anthropometric Committee of 1880, especially as regards the anthropometry of children and of females, and the more complete discussion of the collected facts;—Report on the Natural History of Socotra and the adjacent Highlands of Arabia and Somali Land;—Report on the Maintenance of the Scottish Zoological Station;—Report on the Migration of Birds;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on the Survey of Eastern Palestine;—Final Report on the Appropriation of Wages, &c.;—Report on the working of the revised New Code, and of other legislation affecting the teaching of Science in Elementary Schools;—Report on Patent Legislation;—Report of the Committee for determining a Gauge for the manufacture of various small Screws;—Report on the best means of ascertaining the Effective Wind Pressure to which buildings and structures are exposed;—On the Boiling Points and Vapour Tension of Mercury, of Sulphur, and of some Compounds of Carbon, determined by means of the Hydrogen Thermometer;—On the Method of Harmonic Analysis used in deducing the Numerical Values of the Tides of long period, and on a Misprint in the Tidal Report for 1872;—List of Works on the Geology and Palæontology of Oxfordshire, of Berkshire, and of Buckinghamshire;—Notes on the oldest Records of the Sea-Route to China from Western Asia;—The Deserts of Africa and Asia;—State of Crime in England, Scotland, and Ireland in 1880;—On the Treatment of Steel for the Construction of Ordnance, and other purposes;—The Channel Tunnel;—The Forth Bridge.

Together with the Transactions of the Sections, Dr. C. W. Siemens's Address, and Recommendations of the Association and its Committees.

REPORT OF THE FIFTY-THIRD MEETING, at Southport, September 1883, *Published at £1 4s.*

CONTENTS:—Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements;—Sixteenth Report on Underground Temperature;—Report on the best Experimental Methods that can be used in observing Total Solar Eclipses;—Report on the Harmonic Analysis of Tidal Observations;—Report of the Committee for co-operating with the Meteorological Society of the Mauritius in their proposed publication of Daily Synoptic Charts of the Indian Ocean from the year 1861;—Report on Mathematical Tables;—Report of the Committee for co-operating with the Scottish Meteorological Society in making Meteorological Observations on Ben Nevis;—Report on Meteoric Dust;—Report of the Committee appointed for fixing a Standard of White Light;—Report on Chemical Nomenclature;—Report on the investigation by means of Photography of the Ultra-Violet Spark Spectra emitted by Metallic Elements, and their combinations under varying conditions;—Report on Isomeric Naphthalene Derivatives;—Report on Explorations in Caves in the Carboniferous Limestone in the South of Ireland;—Report on the Exploration of Raygill Fissure, Yorkshire;—Eleventh Report on the Erratic Blocks of England, Wales, and Ireland;—Ninth Report on the Circulation of the Underground Waters in the Permeable Formations of England, and the Quality and Quantity of the Water supplied to various Towns and Districts from these Formations;—Report on the Fossil Plants of Halifax;—Fourth Report on Fossil Polyzoa;—Fourth Report on the Tertiary Flora of the North of Ireland;—Report on the Earthquake Phenomena of Japan;—Report on the Fossil Phyllopoda of the Palæozoic Rocks;—Third Report on the Natural History of Timor Laut;—Report on the Natural History of Socotra and the adjacent Highlands of Arabia and Somali Land;—Report on the Exploration of Kilima-njaro and the adjoining mountains of Eastern Equatorial Africa;—Report on the Migration of Birds;—Report on the Maintenance of the Scottish Zoological Station;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on the Influence of Bodily Exercise on the Elimination of Nitrogen;—Report on the Ancient Earthwork in Epping Forest, known as the 'Loughton' or 'Cowper's' Camp;—Final Report of the Anthropometric Committee;—Report of the Committee for defining the Facial Characteristics of the Races and Principal Crosses in the British Isles, and obtaining Illustrative Photographs;—Report on the Survey of Eastern Palestine;—Report on the workings of the proposed revised New Code, and of other legislation affecting the teaching of Science in Elementary Schools;—Report on Patent Legislation;—Report of the

Committee for determining a Gauge for the manufacture of various small Screws;—Report of the 'Local Scientific Societies' Committee;—On some results of photographing the Solar Corona without an Eclipse;—On Lamé's Differential Equation;—Recent Changes in the Distribution of Wealth in relation to the Incomes of the Labouring Classes;—On the Mersey Tunnel;—On Manganese Bronze;—Nest Gearing.

Together with the Transactions of the Sections, Professor Cayley's Address, and Recommendations of the Association and its Committees.

REPORT OF THE FIFTY-FOURTH MEETING, at Montreal, August and September, 1884, *Published at* 1*l.* 4*s.*

CONTENTS:—Report of the Committee for considering and advising on the best means for facilitating the adoption of the Metric System of Weights and Measures in Great Britain;—Report of the Committee for considering the best methods of recording the direct intensity of Solar Radiation;—Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements;—Report of the Committee for co-operating with the Meteorological Society of the Mauritius, in their proposed publication of Daily Synoptic Charts of the Indian Ocean from the year 1861;—Second Report on the Harmonic Analysis of Tidal Observations;—Report of the Committee for co-operating with Mr. E. J. Lowe in his project of establishing a Meteorological Observatory near Chepstow on a permanent and scientific basis;—Report of the Committee for co-operating with the Directors of the Ben Nevis Observatory in making Meteorological Observations on Ben Nevis;—Report of the Committee for reducing and tabulating the Tidal Observations in the English Channel, made with the Dover Tide-gauge, and for connecting them with Observations made on the French Coast;—Fourth Report on Meteoric Dust;—Second Report on Chemical Nomenclature;—Report on Isomeric Naphthalene Derivatives;—Second Report on the Fossil Phyllopoda of the Palæozoic Rocks;—Tenth Report on the Circulation of Underground Waters in the Permeable Formations of England and Wales, and the Quantity and Character of the Water supplied to various Towns and Districts from these Formations;—Fifth and last Report on Fossil Polyzoa;—Twelfth Report on the Erratic Blocks of England, Wales, and Ireland;—Report upon the National Geological Surveys of Europe;—Report on the Rate of Erosion of the Sea-coasts of England and Wales, and the Influence of the Artificial Abstraction of Shingle or other material in that action;—Report on the Exploration of the Raygill Fissure in Lothersdale, Yorkshire;—Fourth Report on the Earthquake Phenomena of Japan;—Report on the occupation of a Table at the Zoological Station at Naples;—Fourth Report on the Natural History of Timor Laut;—Report on the Influence of Bodily Exercise on the Elimination of Nitrogen;—Report on the Migration of Birds;—Report on the Preparation of a Bibliography of certain groups of Invertebrata;—Report on the Exploration of Kilima-njaro, and the adjoining mountains of Eastern Equatorial Africa;—Report on the Survey of Eastern Palestine;—Report of the Committee for defraying the expenses of completing the Preparation of the final Report of the Anthropometric Committee;—Report on the teaching of Science in Elementary Schools;—Report of the Committee for determining a Gauge for the manufacture of the various small Screws used in Telegraphic and Electrical Apparatus, in Clockwork, and for other analogous purposes;—Report on Patent Legislation;—Report of the Committee for defining the Facial Characteristics of the Races and Principal Crosses in the British Isles, and obtaining Illustrative Photographs with a view to their publication;—Report on the present state of our knowledge of Spectrum Analysis;—Report of the Committee for preparing a new series of Wave-length Tables of the Spectra of the Elements;—On the Connection between Sun-spots and Terrestrial Phenomena;—On the Seat of the Electromotive Forces in the Voltaic Cell;—On the Archæan Rocks of Great Britain;—On the Concordance of the Mollusca inhabiting both sides of the North Atlantic and the intermediate Seas;—On the Characteristics of the North American Flora; On the Theory of the Steam Engine;—Improvements in Coast Signals, with Supplementary Remarks on the New Eddystone Lighthouse;—On American Permanent Way.

Together with the Transactions of the Sections, Lord Rayleigh's Address, and Recommendations of the Association and its Committees.

REPORT OF THE FIFTY-FIFTH MEETING, at Aberdeen, September 1885, *Published at £1 4s.*

CONTENTS.—Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements;—Report of the Committee for promoting Tidal Observations in Canada;—Fifth Report on Meteoric Dust;—Third Report on the Harmonic Analysis of Tidal Observations;—Report of the Committee for co-operating with the Meteorological Society of the Mauritius in their proposed publication of Daily Synoptic Charts of the Indian Ocean from the year 1861;—Report of the Committee for reducing and tabulating the Tidal Observations in the English Channel, made with the Dover Tide-gauge, and for connecting them with Observations made on the French Coast;—Report on Standards of White Light;—Report of the Committee for co-operating with Mr. E. J. Lowe in his project of establishing a Meteorological Observatory near Chepstow on a permanent and scientific basis;—Report on the best means of Comparing and Reducing Magnetic Observations;—Report of the Committee for co-operating with the Scottish Meteorological Society in making Meteorological Observations on Ben Nevis;—Seventeenth Report on Underground Temperature;—Report on Electrical Theories;—Second Report of the Committee for considering the best methods of recording the direct intensity of Solar Radiation;—Report on Optical Theories;—Report of the Committee for investigating certain Physical Constants of Solution, especially the Expansion of Saline Solutions;—Third Report on Chemical Nomenclature;—Report of the Committee for the Investigation by means of Photography of the Ultra-Violet Spark Spectra emitted by Metallic Elements and their Combinations under varying conditions;—Report of the Committee for investigating the subject of Vapour Pressures and Refractive Indices of Salt Solutions;—Report of the Committee for preparing a new series of Wave-length Tables of the Spectra of the Elements and Compounds;—Thirteenth Report on the Erratic Blocks of England, Wales, and Ireland;—Third Report on the Fossil Phyllopoda of the Palæozoic Rocks;—Fifth Report on the Earthquake Phenomena of Japan;—Eleventh Report on the Circulation of Underground Waters in the Permeable Formations of England and Wales, and the Quantity and Character of the Water supplied to various Towns and Districts from these Formations;—Report on the Volcanic Phenomena of Vesuvius;—Report on the Fossil Plants of the Tertiary and Secondary Beds of the United Kingdom;—Report on the Rate of Erosion of the Sea-coasts of England and Wales, and the Influence of the Artificial Abstraction of Shingle or other material in that action;—Report on the occupation of a Table at the Zoological Station at Naples;—Report of the Committee for promoting the Establishment of a Marine Biological Station at Granton, Scotland;—Report on the Aid given by the Dominion Government and the Government of the United States to the Encouragement of Fisheries, and to the Investigation of the various forms of Marine Life on the coasts and rivers of North America;—Report of the Committee for promoting the Establishment of Marine Biological Stations on the coast of the United Kingdom;—Report on recent Polyzoa;—Third Report on the Exploration of Kilima-njaro and the adjoining mountains of Equatorial Africa;—Report on the Migration of Birds;—Report of the Committee for furthering the Exploration of New Guinea by making a grant to Mr. Forbes for the purposes of his Expedition;—Report of the Committee for furthering the Scientific Examination of the country in the vicinity of Mount Roraima in Guiana by making a grant to Mr. Everard F. im Thurn for the purposes of his Expedition;—Report of the Committee for promoting the Survey of Palestine;—Report on the Teaching of Science in Elementary Schools;—Report on Patent Legislation;—Report of the Committee for investigating and publishing reports on the physical characters, languages, and industrial and social condition of the North-Western Tribes of the Dominion of Canada;—Report of the Corresponding Societies Committee;—On Electrolysis;—A tabular statement of the dates at which, and the localities where Pumice or Volcanic Dust was seen in the Indian Ocean in 1883-4;—List of Works on the Geology, Mineralogy, and Palæontology of Staffordshire, Worcestershire, and Warwickshire;—On Slaty Cleavage and allied Rock-Structures, with special reference to the Mechanical Theories of their Origin;—On the Strength of Telegraph Poles;—On the Use of Index Numbers in the Investigation of Trade Statistics;—The Forth Bridge Works;—Electric Lighting at the Forth Bridge Works;—The New Tay Viaduct.

Together with the Transactions of the Sections, Sir Lyon Playfair's Address, and recommendations of the Association and its Committees.

BRITISH ASSOCIATION

FOR

THE ADVANCEMENT OF SCIENCE.

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[*Office of the Association:*—22 *Albemarle Street, London, W.*]

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1886.

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§ indicates Annual Subscribers entitled to the Annual Report.
‡ indicates Subscribers not entitled to the Annual Report.
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Names of Members of the GENERAL COMMITTEE are printed in SMALL CAPITALS.
Names of Members whose addresses are incomplete or not known are in *italics*.

Notice of changes of residence should be sent to the Secretary, 22 Albemarle Street, London, W.

Year of Election.

Abbatt, Richard, F.R.A.S. Marlborough House, Burgess Hill, Sussex.

1881. *Abbott, R. T. G. Quarry Cottage, Norton, Malton.

1863. *ABEL, Sir FREDERICK AUGUSTUS, C.B., D.C.L., F.R.S., F.C.S., Director of the Chemical Establishment of the War Department. Royal Arsenal, Woolwich.

1856. ‡Abercrombie, John, M.D. 39 Welbeck-street, London, W.

1886. §Abercromby, The Hon. Ralph, F.R.Met.Soc. 21 Chapel-street, Belgrave-square, London, S.W.

1885. *ABERDEEN, The Right Hon. the Earl of, LL.D. 37 Grosvenor-square, London, W.

1885. ‡Aberdeen, The Countess of. 37 Grosvenor-square, London, W.

1885. ‡Abernethy, David W. Ferryhill Cottage, Aberdeen.

1863. *ABERNETHY, JAMES, M.Inst.C.E., F.R.S.E. 4 Delahay-street, Westminster, S.W.

1885. ‡Abernethy, James W. 2 Rubislaw-place, Aberdeen.

1873. *ABNEY, Captain W. DE W., R.E., F.R.S., F.R.A.S., F.C.S. Willeslie House, Wetherby-road, South Kensington, London, S.W.

1886. §Abraham, Harry. 147 High-street, Southampton.

1877. §Ace, Rev. Daniel, D.D., F.R.A.S. Laughton, near Gainsborough, Lincolnshire.

Year of Election.

1884. ‡Achison, George. Collegiate Institute, Toronto, Canada.

1873. ‡Ackroyd, Samuel. Greaves-street, Little Horton, Bradford, Yorkshire.

1882. *Acland, Alfred Dyke. Oxford.

1869. ‡Acland, Charles T. D., M.P. Sprydoncote, Exeter.

1877. *Acland, Captain Francis E. Dyke, R.A. School of Gunnery, Shoeburyness.

1873. *Acland, Rev. H. D., M.A. Nymet St. George, South Molton, Devon.

1873. *ACLAND, Sir HENRY W. D., K.C.B., M.A., M.D., LL.D., F.R.S., F.R.G.S., Radcliffe Librarian and Regius Professor of Medicine in the University of Oxford. Broad-street, Oxford.

1877. *Acland, Theodore Dyke, M.A. 7 Brook-street, London, W.

1860. ‡ACLAND, Sir THOMAS DYKE, Bart., M.A., D.C.L., M.P. Sprydoncote, Exeter; and Athenæum Club, London, S.W.

1884. ‡Adams, Frank Donovan. Geological Survey, Ottawa, Canada.

1876. ‡Adams, James. 9 Royal-crescent West, Glasgow.

*ADAMS, JOHN COUCH, M.A., LL.D., F.R.S., F.R.A.S., Director of the Observatory and Lowndean Professor of Astronomy and Geometry in the University of Cambridge. The Observatory, Cambridge.

1871. §Adams, John R. 3 Queen's-gate-terrace, London, S.W.

1879. *ADAMS, Rev. THOMAS, M.A. Bishop's College, Lennoxville, Canada.

1877. ‡ADAMS, WILLIAM. 3 Sussex-terrace, Plymouth.

1869. *ADAMS, WILLIAM GRYLLS, M.A., F.R.S., F.G.S., F.C.P.S., Professor of Natural Philosophy and Astronomy in King's College, London. 43 Notting Hill-square, London, W.

1873. ‡*Adams-Acton, John. Margutta House, 103 Marylebone-road, London, N.W.*

1879. ‡Adamson, Robert, M.A., LL.D., Professor of Logic and Political Economy in Owens College, Manchester. 60 Parsonage-road, Withington, Manchester.

1865. *Adkins, Henry. Northfield, near Birmingham.

1883. §Adshead, Samuel. School of Science, Macclesfield.

1884. ‡Agnew, Cornelius R. 266 Maddison-avenue, New York, U.S.A.

1884. ‡Aikins, Dr. W. T. Jarvis-street, Toronto, Canada.

1864. *Ainsworth, David. The Flosh, Cleator, Carnforth.

1871. *Ainsworth, John Stirling. Harecroft, Cumberland.

Ainsworth, Peter. Smithills Hall, Bolton.

1871. ‡Ainsworth, William M. The Flosh, Cleator, Carnforth.

AIRY, Sir GEORGE BIDDELL, K.C.B., M.A., LL.D., D.C.L., F.R.S., F.R.A.S. The White House, Croom's Hill, Greenwich, S.E.

1871. §Aitken, John, F.R.S.E. Darroch, Falkirk, N.B.

Akroyd, Edward. Bankfield, Halifax.

1884. *Alabaster, H. 22 Paternoster-row, London, E.C.

1886. §Albright, G. S. The Elms, Edgbaston, Birmingham.

1862. ‡ALCOCK, Sir RUTHERFORD, K.C.B., D.C.L., F.R.G.S. The Athenæum Club, Pall Mall, London, S.W.

1861. *Alcock, Thomas, M.D. Oakfield, Sale, Manchester.

*Aldam, William. Frickley Hall, near Doncaster.

1883. ‡Alexander, George. Kildare-street Club, Dublin.

1873. ‡Alexander, Reginald, M.D. 13 Hallfield-road, Bradford, Yorkshire.

1858. ‡ALEXANDER, WILLIAM, M.D. Halifax.

1883. §Alger, Miss Ethel. Widey Court, near Plymouth.

1883. §Alger, W. H. Widey Court, near Plymouth.

1883. §Alger, Mrs. W. H. Widey Court, near Plymouth.

1867. ‡Alison, George L. C. Dundee.

1859. ‡Allan, Alexander. Scottish Central Railway, Perth.

Year of Election.

1885. ‡Allan, David. West Cults, near Aberdeen.
1871. ‡Allan, G., M.Inst.C.E. 10 Austin Friars, London, E.C.
1871. §ALLEN, ALFRED H., F.C.S. 1 Surrey-street, Sheffield.
1879. *Allen, Rev. A. J. C. The College, Chester.
1884. §Allen, Rev. George. Shaw Vicarage, Oldham.
1878. ‡Allen, John Romilly. 5 Albert-terrace, Regent's Park, London, N.W.
1861. ‡Allen, Richard. Didsbury, near Manchester.
1863. ‡Allhusen, C. Elswick Hall, Newcastle-on-Tyne.
*ALLMAN, GEORGE J., M.D., LL.D., F.R.S. L. & E., M.R.I.A., F.L.S., Emeritus Professor of Natural History in the University of Edinburgh. Ardmore, Parkstone, Dorset.
1886. §Allport, Samuel. 50 Whitall-street, Birmingham.
1873. ‡Ambler, John. North Park-road, Bradford, Yorkshire.
1883. §Amery, John Sparke. Druid House, Ashburton, Devon.
1883. §Amery, Peter Fabyan Sparke. Druid House, Ashburton, Devon.
1884. ‡Ami, Henry. Geological Survey, Ottawa, Canada.
1876. ‡Anderson, Alexander. 1 St. James's-place, Hillhead, Glasgow.
1878. ‡Anderson, Beresford. Saint Ville, Killiney.
1885. §Anderson, Charles Clinton. 4 Knaresborough-place, Cromwell-road, London, S.W.
1850. ‡Anderson, Charles William. Cleadon, South Shields.
1883. ‡Anderson, Miss Constance. 17 Stonegate, York.
1885. *Anderson, Hugh Kerr. Frognal Park, Hampstead, London, N.W.
1850. ‡*Anderson, John.* 31 *St. Bernard's-crescent, Edinburgh.*
1874. ‡Anderson, John, J.P., F.G.S. Holywood, Belfast.
1859. ‡ANDERSON, PATRICK. 15 King-street, Dundee.
1880. *ANDERSON, TEMPEST, M.D., B.Sc. 17 Stonegate, York.
1886. *Anderson, William, M.Inst.C.E. Lesney House, Erith, Kent.
1880. §Andrew, Mrs. 126 Jamaica-street, Stepney, London, E.
1883. ‡Andrew, Thomas, F.G.S. 18 Southernhay, Exeter.
1880. *Andrews, Thornton, M.Inst.C.E. Cefn Eithen, Swansea.
1886. §Andrews, William. Gosford Green, Coventry.
1883. §Anelay, Miss M. Mabel. Girton College, Cambridge.
1877. §ANGELL, JOHN, F.C.S. The Grammar School, Manchester.
1886. §Annan, John. Wolverhampton.
1886. §Ansell, Joseph. 38 Waterloo-street, Birmingham.
1878. ‡Anson, Frederick H. 9 Delahay-street, Westminster, S.W.
Anthony, John, M.D. 6 Greenfield-crescent, Edgbaston, Birmingham.
1868. ‡*Appleby, C. J. Emerson-street, Bankside, Southwark, London, S.E.*
1886. §Arblaster, Edmund. 13 Hagley-road, Edgbaston, Birmingham.
1884. ‡Archbold, George. Oswego, New York, U.S.A.
1870. ‡Archer, Francis, jun. 3 Brunswick-street, Liverpool.
1874. ‡Archer, William, F.R.S., M.R.I.A. 11 South Frederick-street, Dublin.
1884. *Archibald, E. Douglas. Grosvenor House, Tunbridge Wells.
1851. ‡ARGYLL, His Grace the Duke of, K.G., K.T., D.C.L., F.R.S. L. & E., F.G.S. Argyll Lodge, Kensington, London, W.; and Inverary, Argyleshire.
1884. §Arlidge, John Thomas, M.D., B.A. The High Grove, Stoke-upon-Trent.
1883. §Armistead, Richard. Wharncliffe House, Beaufort-road, Brooklands, near Manchester.
1883. *Armistead, William. Wharncliffe House, Beaufort-road, Brooklands, near Manchester.
1861. ‡Armitage, William. 95 Portland-street, Manchester.

Year of Election.

1867. *Armitstead, George. Errol Park, Errol, N.B.
1879. *Armstrong, Sir Alexander, K.C.B., M.D., LL.D., F.R.S., F.R.G.S. The Albany, London, W.
1886. §Armstrong, G. F. St. Oswald's, Grasmere R.S.O.
1873. §ARMSTRONG, HENRY E., Ph.D., F.R.S., Sec.C.S., Professor of Chemistry in the City and Guilds of London Institute Central Institution, Exhibition-road, London, S.W. 55 Granville Park, Lewisham, S.E.
1876. ‡Armstrong, James. Bay Ridge, Long Island, New York, U.S.A.
1884. ‡Armstrong, Robert B. Junior Carlton Club, Pall Mall, London, S.W.
Armstrong, Thomas. Higher Broughton, Manchester.
1857. *ARMSTRONG, Sir WILLIAM GEORGE, C.B., LL.D., D.C.L., F.R.S. Jesmond Dene, Newcastle-upon-Tyne.
1870. ‡Arnott, Thomas Reid. Bramshill, Harlesden Green, London, N.W.
1853. *Arthur, Rev. William, M.A. Clapham Common, London, S.W.
1886. §Ascough, Jesse. Patent Borax Company, Newmarket-street, Birmingham.
1870. *Ash, Dr. T. Linnington. Holsworthy, North Devon.
1874. ‡Ashe, Isaac, M.B. Dundrum, Co. Dublin.
1884. *Asher, Asher, M.D. 18 Endsleigh-street, Tavistock-square, London, W.C.
1873. ‡Ashton, John. Gorse Bank House, Windsor-road, Oldham.
Ashton, Thomas. Ford Bank, Didsbury, Manchester.
1866. ‡Ashwell, Henry. Mount-street, New Basford, Nottingham.
*Ashworth, Edmund. Egerton Hall, Bolton-le-Moors.
Ashworth, Henry. Turton, near Bolton.
1875. *Aspland, W. Gaskell. Care of Manager, Union Bank, Chancery-lane, London, W.C.
1861. §Asquith, J. R. Infirmary-street, Leeds.
1861. ‡Aston, Theodore. 11 New-square, Lincoln's Inn, London, W.C.
1872. *ATCHISON, ARTHUR T., M.A. (SECRETARY.) 22 Albemarle-street, London, W.
1858. ‡*Atherton, Charles. Sandover, Isle of Wight.*
1861. ‡Atkin, Eli. Newton Heath, Manchester.
1865. *ATKINSON, EDMUND, Ph.D., F.C.S. Portesbery Hill, Camberley, Surrey.
1884. ‡Atkinson, Edward. Brookline, Massachusetts, Boston, U.S.A.
1863. *Atkinson, G. Clayton. 21 Windsor-terrace, Newcastle-on-Tyne.
1861. ‡Atkinson, Rev. J. A. Longsight Rectory, near Manchester.
1858. *Atkinson, John Hastings. 12 East Parade, Leeds.
1881. ‡Atkinson, J. T. The Quay, Selby, Yorkshire.
1883. *Atkinson, Miss Maria. The Laurels, Sale, Cheshire.
1881. ‡Atkinson, Robert William. Town Hall-buildings, Newcastle-on-Tyne.
1863. *ATTFIELD, Professor J., M.A., Ph.D., F.R.S., F.C.S. 17 Bloomsbury-square, London, W.C.
1884. ‡Auchincloss, W. S. 209 Church-street, Philadelphia, U.S.A.
1886. §Aulton, A. D., M.D. Walsall.
1860. *Austin-Gourlay, Rev. William E. C., M.A. The Rectory, Stanton St. John, near Oxford.
1865. *Avery, Thomas. Church-road, Edgbaston, Birmingham.
1881. ‡AXON, W. E. A. Fern Bank, Higher Broughton, Manchester.
1877. *AYRTON, W. E., F.R.S., Professor of Applied Physics in the City and Guilds of London Institute Central Institution, Exhibition-road, London, S.W.

Year of Election.

***Babington, Charles Cardale**, M.A., F.R.S., F.L.S., F.G.S., Professor of Botany in the University of Cambridge. 5 Brookside, Cambridge.
1884. ‡Baby, The Hon. G. Montreal, Canada.
Backhouse, Edmund. Darlington.
1863. ‡Backhouse, T. W. West Hendon House, Sunderland.
1883. *Backhouse, W. A. St. John's Wolsingham, near Darlington.
1881. ‡Baden-Powell, George S., C.M.G., M.A., M.P., F.R.A.S., F.S.S. 8 St. George's-place, Hyde Park, London, S.W.
1877. ‡Badock, W. F. Badminton House, Clifton Park, Bristol.
1883. ‡Bagrual, P. H. St. Stephen's Club, Westminster, S.W.
1883. ‡Baildon, Dr. 65 Manchester-road, Southport.
1883. §*Bailey, Charles, F.L.S. Ashfield, College-road, Whalley Range, Manchester.*
1870. §Bailey, Dr. Francis J. 51 Grove-street, Liverpool.
1878. ‡Bailey, John. 3 Blackhall-place, Dublin.
1865. ‡Bailey, Samuel, F.G.S. The Peck, Walsall.
1855. ‡Bailey, William. Horseley Fields Chemical Works, Wolverhampton.
1866. ‡Baillon, Andrew. St. Mary's Gate, Nottingham.
1866. ‡Baillon, L. St. Mary's Gate, Nottingham.
1878. ‡Baily, Walter. 176 Haverstock-hill, London, N.W.
1857. ‡**Baily, William Hellier**, F.L.S., F.G.S., Acting Palæontologist to the Geological Survey of Ireland. 14 Hume-street, Dublin.
1885. §**Bain, Alexander**, M.A., LL.D., Rector of the University of Aberdeen. Ferryhill Lodge, Aberdeen.
1873. ‡Bain, Sir James. 3 Park-terrace, Glasgow.
1885. §Bain, William N. 7 Aytoun-road, Pollockshiels, Glasgow.
*Bainbridge, Robert Walton. Middleton House, Middleton-in-Teesdale, by Darlington.
***Baines, Sir Edward**, J.P. Belgrave-mansions, Grosvenor-gardens, London, S.W.; and St. Ann's Hill, Burley, Leeds.
1858. ‡*Baines Frederick. Burley, near Leeds.*
1858. ‡Baines, T. Blackburn. 'Mercury' Office, Leeds.
1882. ***Baker, Benjamin**, M.Inst.C.E. 2 Queen Square-place, Westminster, S.W.
1866. ‡Baker, Francis B. Sherwood-street, Nottingham.
1886. §Baker, Harry. 262 Plymouth-grove, Manchester.
1861. *Baker, John. The Gables, Buxton.
1881. ‡Baker, Robert, M.D. The Retreat, York.
1865. ‡Baker, Robert L. Barham House, Leamington.
1863. ‡Baker, William. 6 Taptonville, Sheffield.
1875. *Baker, W. Mills. The Holmes, Stoke Bishop, Bristol.
1875. ‡**Baker, W. Proctor.** Brislington, Bristol.
1881. ‡Baldwin, Rev. G. W. de Courcy, M.A. Lord Mayor's Walk, York.
1884. ‡Balete, Professor E. Polytechnic School, Montreal, Canada.
1871. ‡Balfour, G. W. Whittinghame, Prestonkirk, Scotland.
1875. ‡**Balfour, Isaac Bayley**, D.Sc., M.D., F.R.S.L. & E., Professor of Botany in the University of Oxford. Botanic Gardens, Oxford.
1878. *Ball, Charles Bent, M.D. 16 Lower Fitzwilliam-street, Dublin.
1835. ***Ball, John**, M.A., F.R.S., F.L.S., M.R.I.A. 10 Southwell-gardens, South Kensington, London, S.W.
1866. ***Ball, Sir Robert Stawell**, M.A., LL.D., F.R.S., F.R.A.S., Andrews Professor of Astronomy in the University of Dublin, and Astronomer Royal for Ireland. The Observatory, Dunsink, Co. Dublin.

Year of Election.
1878. ‡BALL, VALENTINE, M.A., F.R.S., F.G.S., Director of the Museum of Science and Art, Dublin.
1883. *Ball, W. W. Rouse, M.A. Trinity College, Cambridge.
1886. §Ballantyne, J. W., M.B. 50 Queen-street, Edinburgh.
1883. ‡*Balloch, Miss. Glasgow.*
1884. ‡Ballon, Dr. Naham. Sandwich, Illinois, U.S.A.
1869. ‡Bamber, Henry K., F.C.S. 5 Westminster-chambers, Victoria-street, Westminster, S.W.
1882. ‡Bance, Major Edward. Limewood, The Avenue, Southampton.
1852. ‡Bangor, Viscount. Castleward, Co. Down, Ireland.
1879. ‡*Banham, H. French. Mount View, Glossop-road, Sheffield.*
1870. ‡BANISTER, Rev. WILLIAM, B.A. St. James's Mount, Liverpool.
1884. ‡Bannatyne, Hon. A. G. Winnipeg, Canada.
1884. ‡Barbeau, E. J. Montreal, Canada.
1866. ‡Barber, John. Long-row, Nottingham.
1884. ‡Barber, Rev. S. F. West Raynham Rectory, Swaffham, Norfolk.
1861. *Barbour, George. Bolesworth Castle, Tattenhall, Chester.
1859. ‡Barbour, George F. 11 George-square, Edinburgh.
1855. ‡Barclay, Andrew. Kilmarnock, Scotland.
Barclay, Charles, F.S.A. Bury Hill, Dorking.
1871. ‡Barclay, George. 17 Coates-crescent, Edinburgh.
1852. *Barclay, J. Gurney. 54 Lombard-street, London, E.C.
1860. *Barclay, Robert. High Leigh, Hoddesden, Herts.
1876. *Barclay, Robert. 21 Park-terrace, Glasgow.
1886. §Barclay, Thomas. 17 Bull-street, Birmingham.
1868. *Barclay, W. L. 54 Lombard-street, London, E.C.
1881. ‡Barfoot, William, J.P. Whelford-place, Leicester.
1882. ‡Barford, J. G. Above Bar, Southampton.
1863. *Barford, James Gale, F.C.S. Wellington College, Wokingham, Berkshire.
1886. §Barham, F. F. Bank of England, Birmingham.
1860. *Barker, Rev. Arthur Alcock, B.D. East Bridgford Rectory, Nottingham.
1879. ‡Barker, Elliott. 2 High-street, Sheffield.
1882. *Barker, Miss J. M. Hexham House, Hexham.
1879. *Barker, Rev. Philip C., M.A., LL.B. North Petherton, Bridgwater.
1865. ‡Barker, Stephen. 30 Frederick-street, Edgbaston, Birmingham.
1870. ‡BARKLY, Sir HENRY, G.C.M.G., K.C.B., F.R.S., F.R.G.S. 1 Bina-gardens, South Kensington, London, S.W.
1886. §Barling, Gilbert. 85 Edmund-street, Edgbaston, Birmingham.
1873. ‡Barlow, Crawford, B.A. 2 Old Palace-yard, Westminster, S.W.
1883. ‡Barlow, J. J. 37 Park-street, Southport.
1878. ‡Barlow, John, M.D., Professor of Physiology in Anderson's College, Glasgow.
1883. ‡Barlow, John R. Greenthorne, near Bolton.
Barlow, Lieut.-Col. Maurice (14th Regt. of Foot). 5 Great George-street, Dublin.
1885. ‡Barlow, William. Hillfield, Muswell Hill, London, N.
1873. ‡BARLOW, WILLIAM HENRY, F.R.S., M.Inst.C.E. 2 Old Palace-yard, Westminster, S.W.
1861. *Barnard, Major R. Cary, F.L.S. Bartlow, Leckhampton, Cheltenham.
1881. ‡Barnard, William, LL.B. Harlow, Essex.
1868. §Barnes, Richard H. Heatherlands, Parkstone, Dorset.
Barnes, Thomas Addison. Brampton Collieries, near Chesterfield.
1884. §Barnett, I. D. Port Hope, Ontario, Canada.

Year of Election.

1886. §Barnsley, Charles H. 32 Duchess-road, Edgbaston, Birmingham.
1881. ‡Barr, Archibald, B.Sc., Professor of Civil and Mechanical Engineering in the Yorkshire College, Leeds.
1859. ‡Barr, Lieut.-General. Apsleytoun, East Grinstead, Sussex.
1883. ‡Barrett, John Chalk. Errismore, Birkdale, Southport.
1883. ‡Barrett, Mrs. J. C. Errismore, Birkdale, Southport.
1860. ‡Barrett, T. B. High-street, Welshpool, Montgomery.
1872. *BARRETT, W. F., F.R.S.E., M.R.I.A., Professor of Physics in the Royal College of Science, Dublin.
1883. ‡Barrett, William Scott. Winton Lodge, Crosby, near Liverpool.
1874. *BARRINGTON, R. M. Fassaroe, Bray, Co. Wicklow.
1874. *Barrington-Ward, Mark J., M.A., F.L.S., F.R.G.S., H.M. Inspector of Schools. Thorneloe Lodge, Worcester.
1885. *Barron, Frederick Cadogan, M.Inst.C.E. The Priory, Bromley, Kent.
1881. §BARRON, G. B., M.D. Summerseat, Southport.
1866. ‡Barron, William. Elvaston Nurseries, Borrowash, Derby.
1886. §Barrow, George William. Baldraud, Lancaster.
1886. §Barrow, Richard Bradbury. Lawn House, 13 Ompton-road, Edgbaston, Birmingham.
1886. §Barrows, Joseph. The Poplars, Yardley, near Birmingham.
1886. §Barrows, Joseph, jun. Ferndale, Harborne-road, Edgbaston, Birmingham.
1862. *BARRY, CHARLES. 15 Pembridge-square, London, W.
1883. ‡Barry, Charles E. 15 Pembridge-square, London, W.
1875. ‡Barry, John Wolfe. 23 Delahay-street, Westminster, S.W.
1881. ‡Barry, J. W. Duncombe-place, York.
1884. *Barstow, Miss Frances. Garrow Hill, near York.
1858. *Bartholomew, Charles. Castle Hill House, Ealing, Middlesex, W.
1858. *Bartholomew, William Hamond. Ridgeway House, Cumberland-road, Headingley, Leeds.
1884. ‡Bartlett, James Herbert. 148 Mansfield-street, Montreal, Canada.
1873. ‡Bartley, George C. T., M.P. St. Margaret's House, Victoria-street, London, S.W.
1868. *Barton, Edward (27th Inniskillens). Clonelly, Ireland.
1884. ‡Barton, H. M. Foster-place, Dublin.
1852. ‡Barton, James. Farndreg, Dundalk.
1864. ‡Bartrum, John S. 41 Gay-street, Bath.
*Bashforth, Rev. Francis, B.D. Minting Vicarage, near Horncastle.
1876. ‡Bassano, Alexander. 12 Montagu-place, London, W.
1876. ‡Bassano, Clement. Jesus College, Cambridge.
1866. *BASSETT, HENRY. 26 Belitha-villas, Barnsbury, London, N.
1884. ‡Bassnett, Mrs. Thomas. Box 335, Jacksonville, Florida, U.S.A.
1869. ‡Bastard, S. S. Summerland-place, Exeter.
1871. ‡BASTIAN, H. CHARLTON, M.D., M.A., F.R.S., F.L.S., Professor of Pathological Anatomy at University College, London. 20 Queen Anne-street, London, W.
1848. ‡BATE, C. SPENCE, F.R.S., F.L.S. 8 Mulgrave-place, Plymouth.
1883. ‡Bateman, A. E. Board of Trade, London, S.W.
1873. *Bateman, Daniel. Wissahickon, Philadelphia, U.S.A.
1868. ‡Bateman, Frederick, M.D. Upper St. Giles's-street, Norwich.
BATEMAN, JAMES, M.A., F.R.S., F.R.G.S., F.L.S. Home House, Worthing.
1842. *BATEMAN, JOHN FREDERIC LA TROBE, F.R.S., F.G.S., F.R.G.S., M.Inst.C.E. 16 Great George-street, London, S.W.
1864. ‡BATES, HENRY WALTER, F.R.S., F.L.S., Assist.-Sec. R.G.S. 1 Savile-row, London, W.

Year of Election.

1852. ‡Bateson, Sir Robert, Bart. Belvoir Park, Belfast.
1884. ‡Bateson, William, B.A. St. John's College, Cambridge.
1851. ‡BATH AND WELLS, The Right Rev. Lord ARTHUR HERVEY, Lord Bishop of. The Palace, Wells, Somerset.
1881. *Bather, Francis Arthur. Red House, Roehampton, Surrey, S.W.
1836. ‡Batten, Edmund Chisholm. 25 Thurloe-square, London, S.W.
1869. ‡*Batten, John Winterbotham. 35 Palace Gardens-terrace, Kensington, London, W.*
1863. §BAUERMAN, H., F.G.S. 41 Acre-lane, Brixton, London, S.W.
1861. ‡Baxendell, Joseph, F.R.S., F.R.A.S. 14 Liverpool-road, Birkdale, Southport.
1867. ‡Baxter, Edward. Hazel Hall, Dundee.
1867. ‡Baxter, The Right Hon. William Edward, M.P. Ashcliffe, Dundee.
1868. ‡Bayes, William, M.D. 58 Brook-street, London, W.
1866. ‡Bayley, Thomas. Lenton, Nottingham.
Bayly, John. Seven Trees, Plymouth.
1875. *Bayly, Robert. Torr-grove, near Plymouth.
1876. *BAYNES, ROBERT E., M.A. Christ Church, Oxford.
1883. *Bazley, Gardner. Hatherop Castle, Fairford, Gloucestershire.
Bazley, Sir Thomas Sebastian, Bart., M.A. Hatherop Castle, Fairford, Gloucestershire.
1886. §Beale, C. Lime Tree House, Rowley Regis, Dudley.
1886. §Beale, Charles G. Maple Bank, Edgbaston, Birmingham.
1860. *BEALE, LIONEL S., M.D., F.R.S., Professor of the Principles and Practice of Medicine in King's College, London. 61 Grosvenor-street, London, W.
1882. §Beamish, Major A. W., R.E. 28 Grosvenor-road, London, S.W.
1884. ‡Beamish, G. H. M. Prison, Liverpool.
1872. ‡Beanes, Edward, F.C.S. Moatlands, Paddock Wood, Brenchley, Kent.
1870. ‡Beard, Rev. Charles. 13 South-hill-road, Toxteth Park, Liverpool.
1883. ‡Beard, Mrs. 13 South-hill-road, Toxteth Park, Liverpool.
1842. *Beatson, William. Ash Mount, Rotherham.
1855. *Beaufort, W. Morris, F.R.A.S., F.R.G.S., F.R.M.S., F.S.S. 18 Piccadilly, London, W.
1886. §Beaugrand, M. H. Montreal.
1861. *Beaumont, Rev. Thomas George. Chelmondiston Rectory, Ipswich.
1885. §Beaumont, W. W. 163 Strand, London, W.C.
1871. *Beazley, Lieut.-Colonel George G. 74 Redcliffe-square, London, S.W.
1859. *Beck, Joseph, F.R.A.S. 68 Cornhill, London, E.C.
1864. §Becker, Miss Lydia E. 155 Shrewsbury-street, Whalley Range, Manchester.
1860. ‡BECKLES, SAMUEL H., F.R.S., F.G.S. 9 Grand-parade, St. Leonard's-on-Sea.
1885. §BEDDARD, FRANK E., M.A., F.Z.S., Prosector to the Zoological Society of London. Society's Gardens, Regent's Park, London, N.W.
1866. ‡Beddard, James. Derby-road, Nottingham.
1870. §BEDDOE, JOHN, M.D., F.R.S. Clifton, Bristol.
1858. ‡Bedford, James. Woodhouse Cliff, near Leeds.
1878. ‡BEDSON, P. PHILLIPS, D.Sc., F.C.S., Professor of Chemistry in the College of Physical Science, Newcastle-on-Tyne.
1884. ‡Beers, W. G., M.D. 34 Beaver Hall-terrace, Montreal, Canada.
1873. ‡Behrens, Jacob. Springfield House North-parade, Bradford, Yorkshire.
1874. ‡Belcher, Richard Boswell. Blockley, Worcestershire.

Year of Election.

1873. ‡Bell, Asahel P. 32 St. Anne's-street, Manchester.
1871. §Bell, Charles B. 6 Spring-bank, Hull.
1884. ‡Bell, Charles Napier. Winnipeg, Canada.
Bell, Frederick John. Woodlands, near Maldon, Essex.
1860. ‡Bell, Rev. George Charles, M.A. Marlborough College, Wilts.
1880. §Bell, Henry Oswin. 13 Northumberland-terrace, Tynemouth.
1879. ‡*Bell, Henry S. Kenwood Bank, Sharrow, Sheffield.*
1862. *BELL, Sir ISAAC LOWTHIAN, Bart., F.R.S., F.C.S., M.Inst.C.E. Rounton Grange, Northallerton.
1875. ‡Bell, James, Ph.D., F.R.S., F.C.S. The Laboratory, Somerset House, London, W.C.
1871. *BELL, J. CARTER, F.C.S. Bankfield, The Cliff, Higher Broughton, Manchester.
1883. *Bell, John Henry. Dalton Lees, Huddersfield.
1853. ‡Bell, John Pearson, M.D. Waverley House, Hull.
1864. ‡Bell, R. Queen's College, Kingston, Canada.
1876. ‡Bell, R. Bruce, M.Inst.C.E. 203 St. Vincent-street, Glasgow.
1863. *Bell, Thomas. Oakwood, Epping.
1867. ‡Bell, Thomas. Belmont, Dundee.
1882. ‡*Bell, W. Alexander, B.A. 3 Madeira-terrace, Kemp Town, Brighton.*
1842. Bellhouse, Edward Taylor. Eagle Foundry, Manchester.
Bellingham, Sir Alan. Castle Bellingham, Ireland.
1882. §Bellingham, William. 15 Killieser-avenue, Telford Park, Streatham Hill, London, S.W.
1884. ‡Bemrose, Joseph. 15 Plateau-street, Montreal, Canada.
1864. *Bendyshe, T. 3 Sea View-terrace, Margate.
1886. §Benger, Frederick Baden. 7 Exchange-street, Manchester.
1885. ‡BENHAM, WILLIAM BLAXLAND, B.Sc. 34 Belsize-road, London, N.W.
1870. ‡BENNETT, ALFRED W., M.A., B.Sc., F.L.S. 6 Park Village East, Regent's Park, London, N.W.
1836. §Bennett, Henry. Bedminster, Bristol.
1881. §Bennett, John R. 16 West Park, Clifton, Bristol.
1883. *Bennett, Laurence Henry. Trinity College, Oxford.
1881. ‡Bennett, Rev. S. H., M.A. St. Mary's Vicarage, Bishophill Junior, York.
1870. *Bennett, William. Heysham Tower, Lancaster.
1870. *Bennett, William. Oak Hill Park, Old Swan, near Liverpool.
1852. *Bennoch, Francis, F.S.A. 5 Tavistock-square, London, W.C.
1848. ‡Benson, Starling, F.G.S. Gloucester-place, Swansea.
1870. ‡Benson, W. Alresford, Hants.
1863. ‡Benson, William. Fourstones Court, Newcastle-on-Tyne.
1885. *Bent, J. Theodore. 13 Great Cumberland-place, London, W.
1884. ‡Bentham, William. 724 Sherbrooke-street, Montreal, Canada.
1842. *Bentley John. 2 Portland-place, London, W.*
1863. §BENTLEY, ROBERT, F.L.S., Professor of Botany in King's College, London. 38 Penywern-road, Earl's Court, London, S.W.
1886. §Benton, William Elijah. Littleworth House, Hednaford, Staffordshire.
1876. ‡Bergius, Walter C. 9 Loudon-terrace, Hillhead, Glasgow.
1868. ‡BERKELEY, Rev. M. J., M.A., F.R.S., F.L.S. Sibbertoft, Market Harborough.
1863. ‡Berkley, C. Marley Hill, Gateshead, Durham.
1886. §Bernard, W. L. 1 New-court, Lincoln's Inn, London, W.C.
1870. ‡Berwick, George, M.D. 36 Fawcett-street, Sunderland.
1862. ‡Besant, William Henry, M.A., D.Sc., F.R.S. St. John's College, Cambridge.

Year of Election.

1865. *BESSEMER, Sir HENRY, F.R.S. Denmark Hill, London, S.E.
1882. *Bessemer, Henry, jun. 5 Palace-gate, Kensington, London, W.
1858. ‡Best, William. Leydon-terrace, Leeds.
Bethune, Admiral, C.B., F.R.G.S. Balfour, Fifeshire.
1883. ‡Betley, Ralph, F.G.S. Mining School, Wigan.
1876. *Bettany, G. T., M.A., B.Sc., F.L.S., F.R.M.S. 2 Eckington-villas, Ashbourne-grove, East Dulwich, S.E.
1883. ‡Bettany, Mrs. 2 Eckington-villas, Ashbourne-grove, East Dulwich, S.E.
1880. *Bevan, Rev. James Oliver, M.A., F.G.S. The Vicarage, Vowchurch, Hereford.
1859. ‡Beveridge, Robert, M.B. 36 King-street, Aberdeen.
1885. ‡Beveridge, R. Beath Villa, Ferryhill, Aberdeen.
1884. *Beverley, Michael, M.D. 52 St. Giles'-street, Norwich.
1874. *Bevington, James B. Merle Wood, Sevenoaks.
1863. ‡Bewick, Thomas John, F.G.S. Suffolk House, Laurence Pountney Hill, London, E.C.
1844. *Bickerdike, Rev. John, M.A. Shireshead Vicarage, Garstang.
1886. §Bickersteth, The Very Rev. E., D.D., Dean of Lichfield. The Deanery, Lichfield.
1870. ‡Bickerton, A.W., F.C.S. Christchurch, Canterbury, New Zealand.
1885. *BIDWELL, SHELFORD, M.A., LL.B., F.R.S. Riverstone Lodge, Southfields, Wandsworth, Surrey, S.W.
1863. ‡Bigger, Benjamin. Gateshead, Durham.
1882. §Biggs, C. H. W., F.C.S. 1 Bloomfield, Bromley, Kent.
1864. ‡Biggs, Robert. 16 Green Park, Bath.
Bilton, Rev. William, M.A., F.G.S. United University Club, Suffolk-street, London, S.W.
1886. §Bindloss, G. F. Leighton-road, London, N.W.
1884. *Bingham, John E. Electric Works, Sheffield.
1881. ‡Binnie, Alexander R., F.G.S. Town Hall, Bradford, Yorkshire.
1873. ‡Binns, J. Arthur. Manningham, Bradford, Yorkshire.
1879. ‡Binns, E. Knowles, F.R.G.S. 216 Heavygate-road, Sheffield.
Birchall, Edwin, F.L.S. Douglas, Isle of Man.
1880. ‡Bird, Henry, F.C.S. South Down, near Devonport.
1866. *Birkin, Richard. Aspley Hall, near Nottingham.
1871. *BISCHOF, GUSTAV. 4 Hart-street, Bloomsbury, London, W.C.
1868. ‡Bishop, John. Thorpe Hamlet, Norwich.
1883. §Bishop, John le Marchant. 100 Mosley-street, Manchester.
1866. ‡Bishop, Thomas. Bramcote, Nottingham.
1885. ‡Bissett, J. P. Wyndem, Banchory, N.B.
1886. *Bixby, Captain W. H. War Department, Washington, U.S.A.
1877. ‡BLACHFORD, The Right Hon. Lord, K.C.M.G. Cornwood, Ivybridge.
1884. ‡Black, Francis, F.R.G.S. Edinburgh.
1881. §Black, William Galt, F.R.C.S.E. Caledonian United Service Club, Edinburgh.
1869. ‡Blackall, Thomas. 13 Southernhay, Exeter.
1834. Blackburn, Bewicke. Calverley Park, Tunbridge Wells.
1876. ‡Blackburn, Hugh, M.A. Roshven, Fort William, N.B.
1884. ‡Blackburn, Robert. New Edinburgh, Ontario, Canada.
Blackburne, Rev. John, M.A. Yarmouth, Isle of Wight.
Blackburne, Rev. John, jun., M.A. Rectory, Horton, near Chippenham.
1877. ‡Blackie, J. Alexander. 17 Stanhope-street, Glasgow.
1859. ‡Blackie, John Stewart, M.A., Professor of Greek in the University of Edinburgh.
1876. ‡Blackie, Robert. 7 Great Western-terrace, Glasgow.

Year of Election.

1855. *BLACKIE, W. G., Ph.D., F.R.G.S. 17 Stanhope-street, Glasgow.
884. ‡Blacklock, Frederick W. 25 St. Famille-street, Montreal, Canada.
1883. ‡Blacklock, Mrs. Sea View, Lord-street, Southport.
1884. ‡Blaikie, James, M.A. 14 Viewforth-place, Edinburgh.
1878. §Blair, Matthew. Oakshaw, Paisley.
1883. §Blair, Mrs. Oakshaw, Paisley.
1863. ‡Blake, C. Carter, D.Sc. 27 Hastings-street, Burton-crescent, London, W.C.
1886. §Blake, Dr. James. San Francisco, California.
1849. *BLAKE, HENRY WOLLASTON, M.A., F.R.S., F.R.G.S. 8 Devonshire-place, Portland-place, London, W.
1883. *BLAKE, Rev. J. F., M.A., F.G.S., Professor of Natural Science in University College, Nottingham.
1846. *Blake, William. Bridge House, South Petherton, Somerset.
1878. ‡Blakeney, Rev. Canon, M.A., D.D. The Vicarage, Sheffield.
1886. §Blakie, John. The Bridge House, Newcastle, Staffordshire.
1861. §Blakiston, Matthew, F.R.G.S. Free Hills, Burledon, Hants.
1881. §Blamires, Thomas H. Close Hill, Lockwood, near Huddersfield.
1884. *Blandy, William Charles, B.A. 1 Friar-street, Reading.
1869. ‡BLANFORD, W. T., LL.D., F.R.S., Sec. G.S., F.R.G.S. 72 Bedford-gardens, Campden Hill, London, W.
1884. *Blish, William G. Niles, Michigan, U.S.A.
1869. *BLOMEFIELD, Rev. LEONARD, M.A., F.L.S., F.G.S. 19 Belmont, Bath.
1880. §Bloxam, G. W., M.A., F.L.S. 11 Chalcot-crescent, Regent's Park, London, N.W.
1883. ‡Blumberg, Dr. 65 Hoghton-street, Southport.
1870. ‡Blundell, Thomas Weld. Ince Blundell Hall, Great Crosby, Lancashire.
1859. ‡Blunt, Sir Charles, Bart. Heathfield Park, Sussex.
1859. ‡Blunt, Captain Richard. Bretlands, Chertsey, Surrey.
1885. §BLYTH, JAMES, M.A., F.R.S.E., Professor of Natural Philosophy in Anderson's College, Glasgow.
Blyth, B. Hall. 135 George-street, Edinburgh.
1883. ‡Blyth, Miss Phœbe. 3 South Mansion House-road, Edinburgh.
1867. ‡Blyth-Martin, W. Y. Blyth House, Newport, Fife.
1870. ‡Boardman, Edward. Queen-street, Norwich.
1883. ‡*Bodman, Miss Caroline M. 45 Devonshire-street, Portland-place, London, W.*
1884. ‡Body, Rev. C. W. E., M.A. Trinity College, Toronto, Canada.
1871. ‡Bohn, Mrs. North End House, Twickenham.
1881. ‡Bojanowski, Dr. Victor de. 27 Finsbury-circus, London, E.C.
1876. ‡Bolton, J. C. Carbrook, Stirling.
1866. ‡*Bond, Banks. Low Pavement, Nottingham.*
Bond, Henry John Hayes, M.D. Cambridge.
1883. §Bonney, Frederic, F.R.G.S. Colton House, Rugeley, Staffordshire.
1883. §Bonney, Miss S. 23 Denning-road, Hampstead, London, N.W.
1871. *BONNEY, Rev. THOMAS GEORGE, D.Sc., LL.D., F.R.S., F.S.A., F.G.S., Professor of Geology in University College, London. 23 Denning-road, Hampstead, London, N.W.
1866. ‡Booker, W. H. Cromwell-terrace, Nottingham.
1861. ‡Booth, James. Elmfield, Rochdale.
1883. §Booth, James. Hazelhurst House, Turton.
1883. ‡Booth, Richard. 4 Stone-buildings, Lincoln's Inn, London, W.C.
1876. ‡*Booth, Rev. William H. Yardley, Birmingham.*

Year of Election.

1883. ‡Boothroyd, Benjamin. Rawlinson-road, Southport.
1880. ‡Boothroyd, Samuel. Warley House, Southport.
1876. *Borland, William. 260 West George-street, Glasgow.
1882. ‡Borns, Henry, Ph.D., F.C.S. 51 Merton-road, Wimbledon, Surrey.
1876. *Bosanquet, R. H. M., M.A., F.C.S., F.R.A.S. St. John's College, Oxford.
*Bossey, Francis, M.D. Mayfield, Oxford-road, Redhill, Surrey.
1881. §Bothamley, Charles H. Yorkshire College, Leeds.
1867. §Botly, William, F.S.A. Salisbury House, Hamlet-road, Upper Norwood, London, S.E.
1872. ‡Bottle, Alexander. Dover.
1868. ‡Bottle, J. T. 28 Nelson-road, Great Yarmouth.
1871. *BOTTOMLEY, JAMES THOMSON, M.A., F.R.S.E., F.C.S. 13 University-gardens, Glasgow.
1884. *Bottomley, Mrs. 13 University-gardens, Glasgow.
Bottomley, William. 11 Delamere-street, London, W.
1876. ‡Bottomley, William, jun. 6 Rokeley-terrace, Hillhead, Glasgow.
1870. ‡Boult, Swinton. 1 Dale-street, Liverpool.
1883. §Bourdas, Isaiah. 59 Belgrave-road, London, S.W.
1883. ‡BOURNE, A. G., D.Sc., F.L.S., Professor of Zoology in the Presidency College, Madras.
1866. §BOURNE, STEPHEN, F.S.S. Abberley, Wallington, Surrey.
1884. §BOVEY, HENRY T., M.A., Professor of Civil Engineering and Applied Mechanics in McGill University, Montreal. Ontario-avenue, Montreal, Canada.
1872. ‡*Bovill, William Edward. 29 James-street, Buckingham-gate, London, S.W.*
1870. ‡Bower, Anthony. Bowersdale, Seaforth, Liverpool.
1881. *Bower, F. O., F.L.S., Professor of Botany in the University of Glasgow.
1867. ‡Bower, Dr. John. Perth.
1856. *Bowlby, Miss F. E. 23 Lansdowne-parade, Cheltenham
1886. §Bowlby, Rev. Canon. 101 Newhall-street, Birmingham.
1884. §Bowley, Edwin. Burnt Ash Hill, Lee, Kent.
1880. ‡Bowly, Christopher. Cirencester.
1863. ‡Bowman, R. Benson. Newcastle-on-Tyne.
BOWMAN, Sir WILLIAM, Bart., M.D., LL.D., F.R.S., F.R.C.S. 5 Clifford-street, London, W.
1869. ‡Bowring, Charles T. Elmsleigh, Prince's-park, Liverpool.
1863. ‡Boyd, Edward Fenwick. Moor House, near Durham.
1884. *Boyd, M. A., M.D. 30 Merrion-square, Dublin.
1871. ‡Boyd, Thomas J. 41 Moray-place, Edinburgh.
1865. ‡BOYLE, The Very Rev. G. D., M.A., Dean of Salisbury. The Deanery, Salisbury.
1884. *Boyle, R. Vicars, C.S.I. Care of Messrs. Grindlay & Co., 55 Parliament-street, London, S.W.
1872. *BRABROOK, E. W., F.S.A. 28 Abingdon-street, Westminster, S.W.
1869. *Braby, Frederick, F.G.S., F.C.S. Bushey Lodge, Teddington, Middlesex.
1884. *Brace, W. H., M.D. 7 Queen's Gate-terrace, London, S.W.
1880. ‡Bradford, H. Stretton House, Walters-road, Swansea.
1857. *Brady, Cheyne, M.R.I.A. Trinity Vicarage, West Bromwich.
1863. ‡BRADY, GEORGE S., M.D., F.R.S., F.L.S., Professor of Natural History in the College of Physical Science, Newcastle-on-Tyne. 22 Fawcett-street, Sunderland.
1862. ‡BRADY, HENRY BOWMAN, F.R.S., F.L.S., F.G.S. Care of H. N. Martin, Esq., 29 Mosley-street, Newcastle-on-Tyne.

Year of
Election.

1880. *Brady, Rev. Nicholas, M.A. Wennington, Essex.
1864. §BRAHAM, PHILIP, F.C.S. Bath.
1870. ‡Braidwood, Dr. Delemere-terrace, Birkenhead.
1879. ‡Bramley, Herbert. Claremont-crescent, Sheffield.
1865. §BRAMWELL, Sir FREDERICK J., LL.D., F.R.S., M.Inst.C.E. 5 Great George-street, London, S.W.
1872. ‡Bramwell, William J. 17 Prince Albert-street, Brighton.
1867. ‡Brand, William. Milnefield, Dundee.
1861. *Brandreth, Rev. Henry. Dickleburgh Rectory, Scole, Norfolk.
1885. *Bratby, W. Pott-street, Ancoats, Manchester.
1852. ‡BRAZIER, JAMES S., F.C.S., Professor of Chemistry in Marischal College and University of Aberdeen.
1869. *BREADALBANE, The Right Hon. the Earl of. Taymouth Castle, N.B.; and Carlton Club, Pall Mall, London, S.W.
1868. ‡Bremridge, Elias. 17 Bloomsbury-square, London, W.C.
1877. ‡Brent, Francis. 19 Clarendon-place, Plymouth.
1882. *Bretherton, C. E. 1 Garden-court, Temple, London, E.C.
1881. *Brett, Alfred Thomas, M.D. Watford House, Watford.
1866. ‡Brettell, Thomas (Mine Agent). Dudley.
1875. ‡Briant, T. Hampton Wick, Kingston-on-Thames.
1886. §Bridge, T. W., M.A., Professor of Zoology in the Mason Science College, Birmingham.
1884. ‡Bridges, C. J. Winnipeg, Canada.
1870. *Bridson, Joseph R. Sawrey, Windermere.
1870. ‡Brierley, Joseph. New Market-street, Blackburn.
1886. §Brierley, Leonard. Somerset-road, Edgbaston, Birmingham.
1879. ‡Brierley, Morgan. Denshaw House, Saddleworth.
1870. *BRIGG, JOHN. Broomfield, Keighley, Yorkshire.
1866. *Briggs, Arthur. Cragg Royd, Rawdon, near Leeds.
1863. *BRIGHT, Sir CHARLES TILSTON, M.Inst.C.E., F.G.S., F.R.G.S., F.R.A.S. 20 Bolton-gardens, London, S.W.
1870. ‡Bright, H. A., M.A., F.R.G.S. Ashfield, Knotty Ash.
BRIGHT, The Right Hon. JOHN, M.P. Rochdale, Lancashire.
1868. ‡Brine, Captain Lindesay, F.R.G.S. United Service Club, Pall Mall, London, S.W.
1884. ‡Brisette, M. H. 424 St. Paul-street, Montreal, Canada.
1879. ‡Brittain, Frederick. Taptonville-crescent, Sheffield.
1879. *BRITTAIN, W. H. Storth Oaks, Ranmoor, Sheffield.
1878. ‡Britten, James, F.L.S. Department of Botany, British Museum, London, W.C.
1884. *Brittle, John R., M.Inst.C.E., F.R.S.E. Farad Villa, Vanbrugh Hill, Blackheath, London, S.E.
1859. *BRODHURST, BERNARD EDWARD, F.R.C.S., F.L.S. 20 Grosvenor-street, Grosvenor-square, London, W.
1883. *Brodie, David, M.D. Beverly House, St. Thomas' Hill, Canterbury.
1865. ‡BRODIE, Rev. PETER BELLINGER, M.A., F.G.S. Rowington Vicarage, near Warwick.
1884. ‡Brodie, William, M.D. 64 Lafayette-avenue, Detroit, Michigan, U.S.A.
1878. *Brook, George, F.L.S. The University, Edinburgh.
1880. ‡Brook, G. B. Brynsyfi, Swansea.
1881. §Brook, Robert G. Rowen-street, St. Helen's, Lancashire.
1855. ‡Brooke, Edward. Marsden House, Stockport, Cheshire.
1864. *Brooke, Rev. Canon J. Ingham. Thornhill Rectory, Dewsbury.
1855. ‡Brooke, Peter William. Marsden House, Stockport, Cheshire.
1878. ‡Brooke, Sir Victor, Bart., F.L.S. Colebrook, Brookeborough, Co. Fermanagh.

Year of
Election.

1863. ‡Brooks, John Crosse. Wallsend, Newcastle-on-Tyne.
1846. *Brooks, Thomas. Cranshaw Hall, Rawtenstall, Manchester.
1847. ‡Broome, C. Edward, F.L.S. Elmhurst, Batheaston, near Bath.
1883. §Brotherton, E. A. Bolton Bridge-road, Ilkley, Leeds.
1886. §Brough, Joseph. University College, Aberystwith.
1885. *Browett, Alfred. 14 Dean-street, Birmingham.
1863. *Brown, Alexander Crum, M.D., F.R.S. L. & E., F.C.S., Professor of Chemistry in the University of Edinburgh. 8 Belgrave-crescent, Edinburgh.
1867. ‡Brown, Charles Gage, M.D. 88 Sloane-street, London, S.W.
1855. ‡Brown, Colin. 192 Hope-street, Glasgow.
1871. ‡Brown, David. 93 Abbey-hill, Edinburgh.
1863. *Brown, Rev. Dixon. Unthank Hall, Haltwhistle, Carlisle.
1883. ‡Brown, Mrs. Ellen F. Campbell. 27 Abercromby-square, Liverpool.
1881. ‡Brown, Frederick D. 26 St. Giles's-street, Oxford.
1883. ‡Brown, George Dransfield. Henley Villa, Ealing, Middlesex, W.
1884. ‡Brown, Gerald Culmer. Lachute, Quebec, Canada.
1883. ‡Brown, Mrs. H. Bienz. 26 Ferryhill-place, Aberdeen.
1884. §Brown, Harry. University College, London, W.C.
1883. ‡Brown, Mrs. Helen. 52 Grange Loan, Edinburgh.
1870. §Brown, Horace T. 47 High-street, Burton-on-Trent.
Brown, Hugh. Broadstone, Ayrshire.
1883. ‡Brown, Miss Isabella Spring. 52 Grange Loan, Edinburgh.
1870. *Brown, Professor J. Campbell, D.Sc., F.C.S. University College, Liverpool.
1876. §Brown, John. Edenderry House, Belfast.
1881. *Brown, John, M.D. 66 Bank-parade, Burnley, Lancashire.
1882. *Brown, John. Swiss Cottage, Park-valley, Nottingham.
1859. ‡Brown, Rev. John Crombie, LL.D., F.L.S. Haddington, N.B.
1874. ‡Brown, John S. Edenderry, Shaw's Bridge, Belfast.
1882. *Brown, Mrs. Mary. Burnley, Lancashire.
1885. ‡Brown, Miss. Springfield House, Ilkley, Yorkshire.
1886. §Brown R. Laurel Bank, Barnhill, Perth.
1863. ‡Brown, Ralph. Lambton's Bank, Newcastle-on-Tyne.
1871. ‡Brown, Robert, M.A., Ph.D., F.L.S., F.R.G.S. Fersley, Rydal-road, Streatham, London, S.W.
1868. ‡Brown, Samuel. Grafton House, Swindon, Wilts.
1850. ‡Brown, William, F.R.S.E. 25 Dublin-street, Edinburgh.
1865. ‡Brown, William. 41A New-street, Birmingham.
1884. ‡Brown, William George. Ivy, Albemarle Co., Virginia, U.S.A.
1885. ‡Brown, W. A. The Court House, Aberdeen.
1879. ‡Browne, J. Crichton, M.D., LL.D., F.R.S. L. & E. 7 Cumberland-terrace, Regent's Park, London, N.W.
1866. *Browne, Rev. J. H. Lowdham Vicarage, Nottingham.
1862. *Browne, Robert Clayton, jun., B.A. Browne's Hill, Carlow, Ireland.
1872. ‡Browne, R. Mackley, F.G.S. Redcot, Bradbourne, Sevenoaks, Kent.
1865. *Browne, William, M.D. Heath Wood, Leighton Buzzard.
1865. ‡Browning, John, F.R.A.S. 63 Strand, London, W.C.
1883. ‡Browning, Oscar, M.A. King's College, Cambridge.
1855. ‡Brownlee, James, jun. 30 Burnbank-gardens, Glasgow.
1863. *Brunel, H. M. 23 Delahay-street, Westminster, S.W.
1863. ‡Brunel, J. 23 Delahay-street, Westminster, S.W.
1875. *Brunlees, Sir James, F.R.S.E., F.G.S., M.Inst.C.E. 5 Victoria-street, Westminster, S.W.
1875. ‡Brunlees, John. 5 Victoria-street, Westminster, S.W.
1868. ‡Brunton, T. Lauder, M.D., D.Sc., F.R.S. 50 Welbeck-street, London, W.

Year of Election.
1878. §Brutton, Joseph. Yeovil.
1886. *Bryan, G. H. Trumpington-road, Cambridge.
1877. ‡*Bryant George. 82 Claverton-street, Pimlico, London, S.W.*
1884. ‡Bryce, Rev. Professor George. The College, Manitoba, Canada.
BRYCE, Rev. R. J., LL.D. Fitzroy-avenue, Belfast.
1859. ‡Bryson, William Gillespie. Cullen, Aberdeen.
1871. §BUCHAN, ALEXANDER, M.A., F.R.S.E., Sec. Scottish Meteorological Society. 72 Northumberland-street, Edinburgh.
1867. ‡Buchan, Thomas. Strawberry Bank, Dundee.
1885. *Buchan, William Paton. Fairyknowe, Cambuslang, N.B.
Buchanan, Archibald. Catrine, Ayrshire.
Buchanan, D. C. 12 Barnard-road, Birkenhead, Cheshire.
1881. *Buchanan, John H., M.D. Sowerby, Thirsk.
1871. ‡BUCHANAN, JOHN YOUNG. 10 Moray-place, Edinburgh.
1884. ‡Buchanan, W. Frederick. Winnipeg, Canada.
1883. ‡Buckland, Miss A. W. 54 Doughty-street, London, W.C.
1886. *Buckle, Edmund W. The Rectory, Weston-super-Mare.
1864. §BUCKLE, Rev. GEORGE, M.A. The Rectory, Weston-super-Mare.
1865. *Buckley, Henry. 27 Wheeley's-road, Edgbaston, Birmingham.
1886. §Buckley, Samuel. 76 Clyde-road, Albert-park, Didsbury.
1884. *Buckmaster, Charles Alexander, M.A., F.C.S. Science and Art Department, South Kensington, London, S.W.
1880. §Buckney, Thomas, F.R.A.S. Delhi House, Coventry Park, Streatham, S.W.
1869. ‡Bucknill, J. C., M.D., F.R.S. E 2 Albany, London, W.
1851. *BUCKTON, GEORGE BOWDLER, F.R.S., F.L.S., F.C.S. Weycombe, Haslemere, Surrey.
1875. §Budgett, Samuel. Cotham House, Bristol.
1883. ‡Buick, Rev. George R., M.A. Cullybackey, Co. Antrim, Ireland.
1871. ‡Bulloch, Matthew. 4 Bothwell-street, Glasgow.
1881. ‡Bulmer, T. P. Mount-villas, York.
1883. ‡Bulpit, Rev. F. W. Crossens Rectory, Southport.
1865. ‡Bunce, John Mackray. 'Journal' Office, New-street, Birmingham.
1863. §Bunning, T. Wood. Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.
1886. §Burbury, S. H. 1 New-square, Lincoln's Inn, London, W.C.
1842. *Burd, John. 5 Gower-street, London, W.C.
1875. ‡Burder, John, M.D. 7 South-parade, Bristol.
1869. ‡Burdett-Coutts, Baroness. 1 Stratton-street, Piccadilly, London, W.
1881. ‡Burdett-Coutts, W. L. A. B., M.P. 1 Stratton-street, Piccadilly, London, W.
1884. *Burland, Jeffrey H. 287 University-street, Montreal, Canada.
1883. *Burne, Colonel Sir Owen Tudor, K.C.S.I., C.I.E., F.R.G.S. 57 Sutherland-gardens, Maida Vale, London, W.
1876. ‡Burnet, John. 14 Victoria-crescent, Dowanhill, Glasgow.
1885. *Burnett, W. Kendall, M.A. 123½ Union-street, Aberdeen.
1877. ‡Burns, David, C.E. Alston, Carlisle.
1884. §Burns, Professor James Austin. Southern Medical College, Atlanta, Georgia, U.S.A.
1883. ‡Burr, Percy J. 20 Little Britain, London, E.C.
1881. §Burroughs, S. M. 7 Snow-hill, London, E.C.
1883. *Burrows, Abraham. Greenhall, Atherton, near Manchester.
1860. ‡Burrows, Montague, M.A., Professor of Modern History, Oxford.
1877. ‡Burt, J. Kendall. Kendal.
1874. ‡*Burt, Rev. J. T. Broadmoor, Berks.*
1866. *BURTON, FREDERICK M., F.G.S. Highfield, Gainsborough.
1864. ‡Bush, W. 7 Circus, Bath.

Year of Election.

Bushell, Christopher. Royal Assurance-buildings, Liverpool.
1878. ‡BUTCHER, J. G., M.A. 22 Collingham-place, London, S.W.
1884. *Butcher, William Deane, M.R.C.S.Eng. Clydesdale, Windsor.
1884. ‡Butler, Matthew I. Napanee, Ontario, Canada.
1884. *Butterworth, W. Greenhill, Church-lane, Harpurhey, Manchester.
1872. ‡Buxton, Charles Louis. Cromer, Norfolk.
1870. ‡Buxton, David, Ph.D. 298 Regent-street, London, W.
1883. ‡Buxton, Miss F. M. Newnham College, Cambridge.
1868. ‡Buxton, S. Gurney. Catton Hall, Norwich.
1881. ‡Buxton, Sydney. 7 Grosvenor-crescent, London, S.W.
1883. ‡Buxton, Rev. Thomas, M.A. 19 Westcliffe-road, Birkdale, Southport.
1872. ‡Buxton, Sir Thomas Fowell, Bart., F.R.G.S. Warlies, Waltham Abbey, Essex.
1854. ‡BYERLEY, ISAAC, F.L.S. Seacombe, Cheshire.
1885. ‡Byres, David. 63 North Bradford, Aberdeen.
1852. ‡Byrne, Very Rev. James. Ergenagh Rectory, Omagh.
1883. §Byrom, John R. Mere Bank, Fairfield, near Manchester.
1875. ‡Byrom, W. Ascroft, F.G.S. 31 King-street, Wigan.

1863. ‡Cail, Richard. Beaconsfield, Gateshead.
1858. *Caine, Rev. William, M.A. Christ Church Rectory, Denton, near Manchester.
1863. ‡Caird, Edward. Finnart, Dumbartonshire.
1876. ‡Caird, Edward B. 8 Scotland-street, Glasgow.
1861. *Caird, James Key. 8 Magdalene-road, Dundee.
1855. *Caird, James Tennant. Belleaire, Greenock.
1875. ‡*Caldicott, Rev. J. W., D.D. The Grammar School, Bristol.*
1886. *Caldwell, William Hay. Cambridge.
1868. ‡Caley, A. J. Norwich.
1857. ‡Callan, Rev. N. J., Professor of Natural Philosophy in Maynooth College.
1854. ‡Calver, Captain E. K., R.N., F.R.S. 23 Park-place East, Sunderland, Durham.
1884. ‡Cameron, Æneas. Yarmouth, Nova Scotia, Canada.
1876. ‡Cameron, Charles, M.D., LL.D., M.P. 1 Huntly-gardens, Glasgow.
1857. ‡CAMERON, Sir CHARLES A., M.D. 15 Pembroke-road, Dublin.
1884. ‡Cameron, James C., M.D. 41 Belmont-park, Montreal, Canada.
1870. ‡Cameron, John, M.D. 17 Rodney-street, Liverpool.
1881. ‡Cameron, Major-General, C.B. 3 Driffield-terrace, York.
1884. ‡Campbell, Archibald H. Toronto, Canada.
1874. *CAMPBELL, Sir GEORGE, K.C.S.I., M.P., D.C.L., F.R.G.S., F.S.S. Southwell House, Southwell-gardens, South Kensington, London, S.W.; and Edenwood, Cupar, Fife.
1883. ‡Campbell, H. J. 81 Kirkstall-road, Talfourd Park, Streatham Hill, S.W.
Campbell, Sir Hugh P. H., Bart. 10 Hill-street, Berkeley-square, London, W.; and Marchmont House, near Dunse, Berwickshire.
1876. ‡Campbell, James A., LL.D., M.P. Stracathro House, Brechin.
Campbell, John Archibald, M.D., F.R.S.E. Albyn-place, Edinburgh.
1859. ‡Campbell, William. Dunmore, Argyllshire.
CAMPBELL-JOHNSTON, ALEXANDER ROBERT, F.R.S. 84 St. George's-square, London, S.W.
1876. ‡Campion, Frank, F.G.S., F.R.G.S. The Mount, Duffield-road, Derby.
1862. *CAMPION, Rev. WILLIAM M., D.D. Queen's College, Cambridge.
1882. ‡Candy, F. H. 71 High-street, Southampton.
1880. ‡Capper, Robert. Westbrook, Swansea.
1883. §Capper, Mrs. R. Westbrook, Swansea.
1873. *CARBUTT, EDWARD HAMER. 19 Hyde Park-gardens, London, W.

Year of
Election.

*Carew, William Henry Pole. Antony, Torpoint, Devonport.
1883. ‡Carey-Hobson, Mrs. 54 Doughty-street, London, W.C.
1877. ‡Carkeet, John, C.E. 3 St. Andrew's-place, Plymouth.
1876. ‡*Carlile, Thomas. 5 St. James's-terrace, Glasgow.*
CARLISLE, The Right Rev. HARVEY GOODWIN, D.D., D.C.L., Lord Bishop of. Carlisle.
1861. ‡*Carlton, James. Mosley-street, Manchester.*
1867. ‡Carmichael, David (Engineer). Dundee.
1867. ‡Carmichael, George. 11 Dudhope-terrace, Dundee.
1876. ‡Carmichael, Neil, M.D. 22 South Cumberland-street, Glasgow.
1884. ‡Carnegie, John. Peterborough, Ontario, Canada.
1885. *CARNELLEY, THOMAS, D.Sc., Professor of Chemistry in University College, Dundee.
1884. ‡Carpenter, Louis G. Agricultural College, Lansing, Michigan, U.S.A.
1871. *CARPENTER, P. HERBERT, D.Sc., F.R.S. Eton College, Windsor.
1854. ‡Carpenter, Rev. R. Lant, B.A. Bridport.
1872. §CARPENTER, WILLIAM LANT, B.A., B.Sc., F.C.S. 36 Craven-park, Harlesden, London, N.W
1884. *Carpmael, Charles. Toronto, Canada.
1867. ‡CARRUTHERS, WILLIAM, Pres.L.S., F.R.S., F.G.S. British Museum, London, S.W.
1883. §Carson, John. 51 Royal Avenue, Belfast.
1861. *Carson, Rev. Joseph, D.D., M.R.I.A. 18 Fitzwilliam-place, Dublin.
1868. ‡Carteighe, Michael, F.C.S. 172 New Bond-street, London, W.
1886. *Carter, E. Harold. 33 Waterloo-street, Birmingham.
1866. ‡Carter, H. H. The Park, Nottingham.
1855. ‡Carter, Richard, F.G.S. Cockerham Hall, Barnsley, Yorkshire.
1870. ‡Carter, Dr. William. 62 Elizabeth-street, Liverpool.
1883. ‡Carter, W. C. Manchester and Salford Bank, Southport.
1883. ‡Carter, Mrs. Manchester and Salford Bank, Southport.
1878. *Cartwright, E. Henry. Magherafelt Manor, Co. Derry.
1870. §Cartwright, Joshua, M.Inst.C.E., Borough Surveyor. Bury, Lancashire.
1862. ‡Carulla, Facundo. Care of Messrs. Daglish and Co., 8 Harrington-street, Liverpool.
1884. *Carver, Rev. Canon Alfred J., D.D., F.R.G.S. Lynnhurst, Streatham Common, London, S.W.
1884. ‡Carver, Mrs. Lynnhurst, Streatham Common, London, S.W.
1883. §Carver, James. Garfield House, Elm-avenue, Nottingham.
1868. ‡Cary, Joseph Henry. Newmarket-road, Norwich.
1866. ‡Casella, L. P., F.R.A.S. The Lawns, Highgate, London, N.
1878. ‡Casey, John, LL.D., F.R.S., M.R.I.A., Professor of Higher Mathematics in the Catholic University of Ireland. 86 South Circular-road, Dublin.
1871. ‡Cash, Joseph. Bird-grove, Coventry.
1873. *Cash, William, F.G.S. 38 Elmfield-terrace, Saville Park, Halifax.
Castle, Charles. Clifton, Bristol.
1874. ‡Caton, Richard, M.D., Lecturer on Physiology at the Liverpool Medical School. 18A Abercromby-square, Liverpool.
1859. ‡Catto, Robert. 44 King-street, Aberdeen.
1884. *Cave, Herbert. Christ Church, Oxford.
1849. ‡Cawley, Charles Edward. The Heath, Kirsall, Manchester.
1886. §Cay, Albert. Ashleigh, Westbourne-road, Birmingham.
1860. §CAYLEY, ARTHUR, M.A., D.C.L., LL.D., F.R.S., V.P.R.A.S., Sadlerian Professor of Pure Mathematics in the University of Cambridge. Garden House, Cambridge.

Year of Election.

Cayley, Digby. Brompton, near Scarborough.
Cayley, Edward Stillingfleet. Wydale, Malton, Yorkshire.
1871. *Cecil, Lord Sackville. Hayes Common, Beckenham, Kent.
1879. §Chadburn, Alfred. Brincliffe Rise, Sheffield.
1870. ‡Chadburn, C. H. Lord-street, Liverpool.
1860. ‡CHADWICK, DAVID. The Poplars, Herne Hill, London, S.E.
1842. CHADWICK, EDWIN, C.B. Park Cottage, East Sheen, Middlesex, S.W.
1883. ‡Chadwick, James Percy. 51 Alexandra-road, Southport.
1859. ‡Chadwick, Robert. Highbank, Manchester.
1883. ‡Chalk, William. 24 Gloucester-road, Birkdale, Southport.
1859. ‡Chalmers, John Inglis. Aldbar, Aberdeen.
1883. ‡Chamberlain, George, J.P. Helensholme, Birkdale Park, Southport.
1884. ‡Chamberlain, Montague. St. John's, New Brunswick, Canada.
1883. ‡*Chambers, Benjamin. Hawkshead-street South, Southport.*
1883. ‡CHAMBERS, CHARLES, F.R.S. Colába Observatory, Bombay.
1883. ‡Chambers, Mrs. Colába Observatory, Bombay.
1883. ‡*Chambers, Charles, jun. The College, Cooper's Hill, Staines.*
1842. Chambers, George. High Green, Sheffield.
1868. ‡Chambers, W. O. Lowestoft, Suffolk.
1877. *CHAMPERNOWNE, ARTHUR, M.A., F.G.S. Dartington Hall, Totnes, Devon.
*Champney, Henry Nelson. 4 New-street, York.
1881. *Champney, John E. Woodlands, Halifax.
1865. ‡Chance, A. M. Edgbaston, Birmingham.
1865. *Chance, James T. 51 Prince's-gate, London, S.W.
1886. *Chance, John Horner. 40 Augustus-road, Edgbaston, Birmingham.
1865. ‡Chance, Robert Lucas. Chad Hill, Edgbaston, Birmingham.
1861. *Chapman, Edward, M.A., F.L.S., F.C.S. Frewen Hall, Oxford.
1884. ‡Chapman, Professor. University College, Toronto, Canada.
1877. §Chapman, T. Algernon, M.D. Burghill, Hereford.
1871. ‡Chappell, William, F.S.A. Strafford Lodge, Oatlands Park, Weybridge Station.
1874. ‡Charles, John James, M.A., M.D. 11 Fisherwick-place, Belfast.
1836. CHARLESWORTH, EDWARD, F.G.S. 277 Strand, London, W.C.
1874. ‡Charley, William. Seymour Hill, Dunmurry, Ireland.
1866. ‡CHARNOCK, RICHARD STEPHEN, Ph.D., F.S.A., F.R.G.S. Junior Garrick Club, Adelphi-terrace, London, W.C.
1886. §Chate, Robert W. Southfield, Edgbaston, Birmingham.
1883. ‡Chater, Rev. John. Part-street, Southport.
1884. *Chatterton, George. 46 Queen Anne's-gate, London, S.W.
1886. §Chattock, A. P. University College, Bristol.
1867. *Chatwood, Samuel, F.R.G.S. Irwell House, Drinkwater Park, Prestwich.
1884. ‡CHAUVEAU, The Hon. Dr. Montreal, Canada.
1883. ‡Chawner, W., M.A. Emanuel College, Cambridge.
1864. ‡CHEADLE, W. B., M.A., M.D., F.R.G.S. 2 Hyde Park-place, Cumberland-gate, London, S.W.
1874. *Chermside, Lieut.-Colonel H. C., R.E., C.B. Care of Messrs. Cox & Co., Craig's-court, Charing Cross, London, S.W.
1884. ‡Cherriman, Professor J. B. Ottawa, Canada.
1879. *Chesterman, W. Broomsgrove-road, Sheffield.
1879. ‡*Cheyne, Commander J. P., R.N. 1 Westgate-terrace, West Brompton, London, S.W.*
CHICHESTER, The Right Rev. RICHARD DURNFORD, D.D., Lord Bishop of. Chichester
1865. *Child, Gilbert W., M.A., M.D., F.L.S. Cowley House, Oxford.
1883. §Chinery, Edward F. Monmouth House, Lymington.

Year of Election.

1884. ‡Chipman, W. W. L. 6 Place d'Armes, Ontario, Canada.
1842. *Chiswell, Thomas. 17 Lincoln-grove, Plymouth-grove, Manchester.
1863. ‡Cholmeley, Rev. C. H. Dinton Rectory, Salisbury.
1882. ‡Chorley, George. Midhurst, Sussex.
1861. ‡Christie, Professor R. C., M.A. 7 St. James's-square, Manchester.
1884. *Christie, William. 13 Queen's Park, Toronto, Canada.
1875. *Christopher, George, F.C.S. 8 Rectory-grove, Clapham, London, S.W.
1876. *CHRYSTAL, GEORGE, M.A., F.R.S.E., Professor of Mathematics in the University of Edinburgh. 5 Belgrave-crescent, Edinburgh.
1870. §CHURCH, A. H., M.A., F.C.S., Professor of Chemistry to the Royal Academy of Arts, London. Shelsley, Ennerdale-road, Kew, Surrey.
1860. ‡Church, William Selby, M.A. St. Bartholomew's Hospital, London, E.C.
1881. ‡CHURCHILL, Lord ALFRED SPENCER. 16 Rutland-gate, London, S.W.
1857. ‡Churchill, F., M.D. Ardtrea Rectory, Stewartstown, Co. Tyrone.
1868. ‡Clabburn, W. H. Thorpe, Norwich.
1863. ‡Clapham, Henry. 5 Summerhill-grove, Newcastle-on-Tyne.
1869. *Clapp, Frederick. Roseneath, St. James's-road, Exeter.
1857. ‡Clarendon, Frederick Villiers. 1 Belvidere-place, Mountjoy-square, Dublin.
1859. ‡Clark, David. Coupar Angus, Fifeshire.
1876. ‡Clark, David R., M.A. 31 Waterloo-street, Glasgow.
1877. *Clark, F. J. Street, Somerset.
1876. ‡Clark, George W. 31 Waterloo-street, Glasgow.
Clark, G. T. 44 Berkeley-square, London, W.
1876. ‡Clark, Dr. John. 138 Bath-street, Glasgow.
1881. ‡Clark, J. Edmund, B.A., B.Sc., F.G.S. 20 Bootham, York.
1861. ‡Clark, Latimer. 5 Westminster-chambers, Victoria-street, London, S.W.
1855. ‡Clark, Rev. William, M.A. Barrhead, near Glasgow.
1883. ‡Clarke, Rev. Canon, D.D. 59 Hoghton-street, Southport.
1865. ‡Clarke, Rev. Charles. Charlotte-road, Edgbaston, Birmingham.
1875. ‡Clarke, Charles S. 4 Worcester-terrace, Clifton, Bristol.
1886. §Clarke, David. Langley-road, Small Heath, Birmingham.
Clarke, George. Mosley-street, Manchester.
1886. §Clarke, Rev. H. J. Great Barr Vicarage, Birmingham.
1872. *CLARKE, HYDE. 32 St. George's-square, Pimlico, London, S.W.
1875. ‡CLARKE, JOHN HENRY. 4 Worcester-terrace, Clifton, Bristol.
1861. *Clarke, John Hope. 45 Nelson-street, Chorlton-on-Medlock, Manchester.
1877. ‡Clarke, Professor John W. University of Chicago, Illinois, U.S.A.
1851. ‡CLARKE, JOSHUA, F.L.S. Fairycroft, Saffron Walden.
Clarke, Thomas, M.A. Knedlington Manor, Howden, Yorkshire.
1883. ‡Clarke, W. P., J.P. 15 Hesketh-street, Southport.
1884. ‡Claxton, T. James. 461 St. Urbain-street, Montreal, Canada.
1861. ‡Clay, Charles, M.D. 101 Piccadilly, Manchester.
*Clay, Joseph Travis, F.G.S. Rastrick, near Brighouse, Yorkshire.
1866. ‡Clayden, P. W. 13 Tavistock-square, London, W.C.
1850. ‡CLEGHORN, HUGH, M.D., F.L.S. Stravithie, St. Andrews, Scotland.
1859. ‡Cleghorn, John. Wick.
1875. ‡Clegram, T. W. B. Saul Lodge, near Stonehouse, Gloucestershire.
1861. §CLELAND, JOHN, M.D., D.Sc., F.R.S., Professor of Anatomy in the University of Glasgow. 2 College, Glasgow.

Year of Election.

1873. ‡Cliff, John, F.G.S. Nesbit Hall, Fulneck, Leeds.
1886. §Clifford, Arthur. Beechcroft, Edgbaston, Birmingham.
1883. ‡Clift, Frederic, LL.D. Norwood, Surrey.
1861. *CLIFTON, R. BELLAMY, M.A., F.R.S., F.R.A.S., Professor of Experimental Philosophy in the University of Oxford. Portland Lodge, Park Town, Oxford.
Clonbrock, Lord Robert. Clonbrock, Galway.
1878. §Close, Rev. Maxwell H., F.G.S. 40 Lower Baggot-street, Dublin.
1873. ‡Clough, John. Bracken Bank, Keighley, Yorkshire.
1861. *Clouston, Peter. 1 Park-terrace, Glasgow.
1883. *CLOWES, FRANK, D.Sc., F.C.S., Professor of Chemistry in University College, Nottingham. University College, Nottingham.
1863. *Clutterbuck, Thomas. Warkworth, Acklington.
1881. *Clutton, William James. The Mount, York.
1885. §Clyne James. Rubislaw Den South, Aberdeen.
1868. ‡Coaks, J. B. Thorpe, Norwich.
1855. *Coats, Sir Peter. Woodside, Paisley.
Cobb, Edward. Falkland House, St. Ann's, Lewes.
1884. §Cobb, John. Lenzie, near Glasgow.
1864. *Cochrane, James Henry. Elm Lodge, Prestbury, Cheltenham.
1884. *Cockburn-Hood, J. J. Walton Hall, Kelso, N.B.
1883. ‡Cockshott, J. J. 74 Belmont-street, Southport.
1861. *Coe, Rev. Charles C., F.R.G.S. Fairfield, Heaton, Bolton.
1881. §COFFIN, WALTER HARRIS, F.C.S. 94 Cornwall-gardens, South Kensington, London, S.W.
1865. ‡Coghill, H. Newcastle-under-Lyme.
1884. *Cohen, B. L. 30 Hyde Park-gardens, London, W.
1876. ‡*Colbourn, E. Rushton. 5 Marchmont-terrace, Hillhead, Glasgow.*
1853. ‡Colchester, William, F.G.S. Springfield House, Ipswich.
1868. ‡Colchester, W. P. Bassingbourn, Royston.
1879. ‡Cole, Skelton. 387 Glossop-road, Sheffield.
1876. ‡Colebrooke, Sir T. E., Bart., F.R.G.S. 14 South-street, Park-lane, London, W.; and Abington House, Abington, N.B.
1860. ‡COLEMAN, J. J., F.C.S. Ardarrode, Bearsden, near Glasgow.
1878. ‡Coles, John, Curator of the Map Collection R.G.S. 1 Savile-row, London, W.
1854. *Colfox, William, B.A. Westmead, Bridport, Dorsetshire.
1857. ‡Colles, William, M.D. 21 Stephen's-green, Dublin.
1869. ‡Collier, W. F. Woodtown, Horrabridge, South Devon.
1854. ‡COLLINGWOOD, CUTHBERT, M.A., M.B., F.L.S. 2 Gipsy Hill-villas, Upper Norwood, Surrey, S.E.
1861. *Collingwood, J. Frederick, F.G.S. New Athenæum Club, 3 Pall Mall East, London, S.W.
1865. *Collins, James Tertius. Churchfield, Edgbaston, Birmingham.
1876. ‡COLLINS, J. H., F.G.S. 64 Bickerton-road, London, N.
1876. ‡Collins, Sir William. 3 Park-terrace East, Glasgow.
1884. §Collins, William J., M.D., B.Sc. Albert-terrace, Regent's Park, London, N.W.
1883. ‡*Collis W. Elliott. 3 Lincoln's-Inn-fields, London, W.C.*
1868. *COLMAN, J. J., M.P. Carrow House, Norwich; and 108 Cannon-street, London, E.C.
1882. §Colmer, Joseph G. Office of the High Commissioner for Canada, 9 Victoria-chambers, London, S.W.
1884. ‡Colomb, Capt. J. C. R., M.P., F.R.G.S. Dromquinna, Kenmare, Kerry, Ireland; and Junior United Service Club, London, S.W.
1870. ‡Coltart, Robert. The Hollies, Aigburth-road, Liverpool.
1884. §Common, A. A., F.R.S., F.R.A.S. 63 Eaton-rise, Ealing, Middlesex, W.

Year of Election.

1846. *Compton, Lord William. 145 Piccadilly, London, W.
1884. §Conklin, Dr. William A. Central Park, New York, U.S.A.
1852. ‡Connal, Sir Michael. 16 Lynedock-terrace, Glasgow.
1871. *Connor, Charles C. Notting Hill House, Belfast.
1881. ‡CONROY, Sir JOHN, Bart. Arborfield, Reading, Berks.
1876. ‡Cook, James. 162 North-street, Glasgow.
1882. ‡COOKE, Major-General A. C., R.E., C.B., F.R.G.S., Director-General of the Ordnance Survey. Southampton.
1876. *COOKE, CONRAD W. 2 Victoria-mansions, Victoria-street, London, S.W.
1881. ‡Cooke, F. Bishophill, York.
1868. ‡Cooke, Rev. George H. Wanstead Vicarage, near Norwich.
Cooke, J. B. Cavendish-road, Birkenhead.
1868. ‡COOKE, M. C., M.A. 2 Grosvenor-villas, Upper Holloway, London, N.
1884. ‡Cooke, R. P. Brockville, Ontario, Canada.
1878. ‡Cooke, Samuel, M.A., F.G.S. Poona, Bombay.
1881. ‡Cooke, Thomas. Bishophill, York.
1859. *Cooke, His Honour Judge, M.A., F.S.A. 42 Wimpole-street, London, W.; and Rainthorpe Hall, Long Stratton.
1883. §Cooke-Taylor, R. Whateley. Frenchwood House, Preston.
1883. ‡Cooke-Taylor, Mrs. Frenchwood House, Preston.
1865. ‡Cooksey, Joseph. West Bromwich, Birmingham.
1869. ‡Cooling, Edwin, F.R.G.S. Mile Ash, Derby.
1883. ‡*Coomer, John. 53 Albert-road, Southport.*
1884. ‡Coon, John S. 604 Main-street, Cambridge Pt., Massachusetts, U.S.A.
1883. ‡Cooper, George B. 67 Great Russell-street, London, W.C.
1850. ‡COOPER, Sir HENRY, M.D. 7 Charlotte-street, Hull.
1838. Cooper, James. 58 Pembridge-villas, Bayswater, London, W.
1884. §Cooper, Mrs. M. A. West Tower, Marple, Cheshire.
1846. ‡Cooper, William White, F.R.C.S. 19 Berkeley-square, London, W.
1868. ‡Cooper, W. J. The Old Palace, Richmond, Surrey.
1884. ‡Cope, E. D. Philadelphia, U.S.A.
1878. ‡Cope, Rev. S. W. Bramley, Leeds.
1871. ‡Copeland, Ralph, Ph.D., F.R.A.S. Dun Echt, Aberdeen.
1868. ‡Copeman, Edward, M.D. Upper King-street, Norwich.
1885. ‡Copland, W., M.A. Tortorston, Peterhead, N.B.
1881. ‡Copperthwaite, H. Holgate Villa, Holgate-lane, York.
1863. ‡Coppin, John. North Shields.
1842. Corbett, Edward. Grange Avenue, Levenshulme, Manchester.
1881. §Cordeaux, John. Great Cotes, Ulceby, Lincolnshire.
1883. *Core, Thomas H. Fallowfield, Manchester.
1870. *CORFIELD, W. H., M.A., M.D., F.C.S., F.G.S., Professor of Hygiène and Public Health in University College. 19 Savile-row, London, W.
1885. ‡Corry, John. Rosenheim, Parkhill-road, Croydon.
1886. §Cossins, Jethro A. Warwick-chambers, Corporation-street, Birmingham.
1883. ‡Costelloe, B. F. C., M.A., B.Sc. 33 Chancery-lane, London, W.C.
Cottam, George. 2 Winsley-street, London, W.
1857. ‡Cottam, Samuel. Brazenose-street, Manchester.
1874. *COTTERILL, J. H., M.A., F.R.S., Professor of Applied Mechanics. Royal Naval College, Greenwich, S.E.
1864. ‡COTTON, General FREDERICK C., R.E., C.S.I. 13 Longridge-road, Earl's Court-road, London, S.W.
1869. ‡COTTON, WILLIAM. Pennsylvania, Exeter.

Year of Election.

1879. ‡Cottrill, Gilbert I. Shepton Mallett, Somerset.
1876. ‡Couper, James. City Glass Works, Glasgow.
1876. ‡Couper, James, jun. City Glass Works, Glasgow.
1874. ‡Courtauld, John M. Bocking Bridge, Braintree, Essex.
1834. ‡Cowan, Charles. 38 West Register-street, Edinburgh.
Cowan, John. Valleyfield, Pennycuick, Edinburgh.
1863. ‡Cowan, John A. Blaydon Burn, Durham.
1876. ‡Cowan, J. B., M.D. Helensburgh, N.B.
1863. ‡Cowan, Joseph, jun. Blaydon, Durham.
1872. *Cowan, Thomas William, F.G.S. Comptons Lea, Horsham.
1886. §Cowen, Mrs. G. R. 9 The Ropewalk, Nottingham.
Cowie, The Very Rev. Benjamin Morgan, M.A., D.D., Dean of Exeter. The Deanery, Exeter.
1871. ‡Cowper, C. E. 6 Great George-street, Westminster, S.W.
1860. ‡Cowper, Edward Alfred, M.Inst.C.E. 6 Great George-street, Westminster, S.W.
1867. *Cox, Edward. Lyndhurst, Dundee.
1867. *Cox, George Addison. Beechwood, Dundee.
1870. *Cox, James. 8 Falkner-square, Liverpool.
1882. ‡Cox, Thomas A., District Engineer of the S., P., and D. Railway. Lahore, Punjab. Care of Messrs. Grindlay & Co., Parliament-street, London, S.W.
1867. *Cox, Thomas Hunter. Duncarse, Dundee.
1867. ‡Cox, William. Foggley, Lochee, by Dundee.
1883. §Crabtree, William, M.Inst.C.E. Manchester-road, Southport.
1884. §CRAIGIE, Major P. G., F.S.S. 6 Lyndhurst-road, Hampstead, London, N.W.
1876. ‡Cramb, John. Larch Villa, Helensburgh, N.B.
1879. §Crampton, Thomas Russell, M.Inst.C.E. 19 Ashley-place, London, S.W.
1858. ‡Cranage, Edward, Ph.D. The Old Hall, Wellington, Shropshire.
1884. ‡Crathern, James. Sherbrooke-street, Montreal, Canada.
1876. ‡Crawford, Chalmond. Ridemon, Crosscar.
1871. *Crawford, William Caldwell, M.A. 1 Lockharton-gardens, Slateford, Edinburgh.
1871. *CRAWFORD AND BALCARRES, The Right Hon. the Earl of, LL.D., F.R.S., F.R.A.S. The Observatory, Dun Echt, Aberdeen.
1883. *Crawshaw, Edward. 25 Tollington-park, London, N.
1870. *Crawshay, Mrs. Robert. Cathedine, Bwlch, Breconshire.
1885. §Creak, Staff Commander E. W., R.N., F.R.S. Richmond Lodge, Blackheath, London, S.E.
1879. ‡Creswick, Nathaniel. Handsworth Grange, near Sheffield.
1876. *Crewdson, Rev. George. St. George's Vicarage, Kendal.
1880. *Crisp, Frank, B.A., LL.B., F.L.S. 5 Lansdowne-road, Notting Hill, London, W.
1878. ‡Croke, John O'Byrne, M.A. The French College, Blackrock, Dublin.
1859. ‡Croll, A. A. 10 Coleman-street, London, E.C.
1857. ‡Crolly, Rev. George. Maynooth College, Ireland.
1885. ‡Crombie, Charles W. 41 Carden-place, Aberdeen.
1885. ‡Crombie, John. Balgownie Lodge, Aberdeen.
1885. ‡Crombie, John, jun. Daveston, Aberdeen.
1885. ‡CROMBIE, J. W., M.A. Balgownie Lodge, Aberdeen.
1885. ‡Crombie, Theodore. 18 Albyn-place, Aberdeen.
1886. §Crompton, Dickinson W. 40 Harborne-road, Edgbaston, Birmingham.

Year of Election.

1870. ‡Crookes, Joseph. Marlborough House, Brook Green, Hammersmith, London, W.
1865. §CROOKES, WILLIAM, F.R.S., F.C.S. 7 Kensington Park-gardens, London, W.
1879. ‡Crookes, Mrs. 7 Kensington Park-gardens, London, W.
1855. ‡Cropper, Rev. John. Wareham, Dorsetshire.
1870. ‡Crosfield, C. J. 16 Alexandra-drive, Prince's Park, Liverpool.
1870. ‡Crosfield, William. Annesley, Aigburth, Liverpool.
1870. *Crosfield, William, jun. 16 Alexandra-drive, Prince's Park, Liverpool.
1861. ‡Cross, Rev. John Edward, M.A. Appleby Vicarage, near Brigg.
1883. ‡Cross, Rev. Prebendary, LL.B. Part-street, Southport.
1868. ‡Crosse, Thomas William. St. Giles's-street, Norwich.
1886. §Crosskey, Cecil. 117 Gough-road, Birmingham.
1867. §CROSSKEY, Rev. H. W., LL.D., F.G.S. 117 Gough-road, Birmingham.
1853. ‡Crosskill, William. Beverley, Yorkshire.
1870. *Crossley, Edward, F.R.A.S. Bemerside, Halifax.
1871. ‡Crossley, Herbert. Broomfield, Halifax.
1866. *Crossley, Louis J., F.M.S. Moorside Observatory, near Halifax.
1883. §Crowder, Robert. Stanwix, Carlisle.
1882. §Crowley, Frederick. Ashdell, Alton, Hampshire.
1861. ‡Crowley, Henry. Trafalgar-road, Birkdale Park, Southport.
1883. ‡Crowther, Elon. Cambridge-road, Huddersfield.
1863. ‡Cruddas, George. Elswick Engine Works, Newcastle-on-Tyne.
1885. ‡Cruickshank, Alexander, LL.D. 20 Rose-street, Aberdeen.
1860. ‡Cruickshank, John. Aberdeen.
1859. ‡Cruickshank, Provost. Macduff, Aberdeen.
1873. ‡Crust, Walter. Hall-street, Spalding.
1883. *Cryer, Major J. H. The Grove, Manchester-road, Southport.
Culley, Robert. Bank of Ireland, Dublin.
1883. *Culverwell, Edward P. 40 Trinity College, Dublin.
1878. ‡Culverwell, Joseph Pope. St. Lawrence Lodge, Sutton, Dublin.
1883. ‡Culverwell, T. J. H. Litfield House, Clifton, Bristol.
1859. ‡Cumming, Sir A. P. Gordon, Bart. Altyre.
1874. ‡Cumming, Professor. 33 Wellington-place, Belfast.
1861. *Cunliffe, Edward Thomas. The Parsonage, Handforth, Manchester.
1861. *Cunliffe, Peter Gibson. Dunedin, Handforth, Manchester.
1882. *Cunningham, Major Allan, R.E., A.I.C.E. Brompton Barracks, Chatham.
1877. *CUNNINGHAM, D. J., M.D., Professor of Anatomy in Trinity College, Dublin.
1852. ‡Cunningham, John. Macedon, near Belfast.
1885. ‡Cunningham, J. T. Scottish Marine Station, Granton, Edinburgh.
1869. ‡CUNNINGHAM, ROBERT O., M.D., F.L.S., Professor of Natural History in Queen's College, Belfast.
1883. *Cunningham, Rev. William, B.D., D.Sc. Trinity College, Cambridge.
1850. ‡Cunningham, Rev. William Bruce. Prestonpans, Scotland.
1881. ‡Curley, T., C.E., F.G.S. Hereford.
1885. §Curphey, William S. 268 Renfrew-street, Glasgow.
1884. §Currier, John McNab. Castleton, Vermont, U.S.A.
1867. *Cursetjee, Manockjee, F.R.G.S., Judge of Bombay. Villa-Byculla, Bombay.
1857. ‡CURTIS, ARTHUR HILL, LL.D. 1 Hume-street, Dublin.
1878. ‡Curtis, William. Caramore, Sutton, Co. Dublin.
1884. ‡Cushing, Frank Hamilton. Washington, U.S.A.
1883. ‡Cushing, Mrs. M. Croydon, Surrey.
1881. §Cushing, Thomas, F.R.A.S. India Store Depôt, Belvedere-road, Lambeth, London, S.W.

Year of Election.
1854. ‡Daglish, Robert, M.Inst.C.E. Orrell Cottage, near Wigan.
1883. ‡Dähne, F. W., Consul of the German Empire. 18 Somerset-place, Swansea.
1863. ‡Dale, J. B. South Shields.
1865. ‡Dale, Rev. R. W. 12 Calthorpe-street, Birmingham.
1867. ‡Dalgleish, W. Dundee.
1870. ‡DALLINGER, Rev. W. H., LL.D., F.R.S., F.L.S. Wesley College, Glossop-road, Sheffield.
Dalmahoy, James, F.R.S.E. 9 Forres-street, Edinburgh.
Dalton, Edward, LL.D., F.S.A. Dunkirk House, Nailsworth.
*Dalton, Rev. J. E., B.D. Seagrave, Loughborough.
1862. ‡DANBY, T. W., M.A., F.G.S. 1 Westbourne-terrace-road, London, W.
1859. ‡Dancer, J. B., F.R.A.S. Old Manor House, Ardwick, Manchester.
1876. ‡Dansken, John. 4 Eldon-terrace, Partickhill, Glasgow.
1849. *Danson, Joseph, F.C.S. Montreal, Canada.
1861. *DARBISHIRE, ROBERT DUKINFIELD, B.A., F.G.S. 26 George-street, Manchester.
1883. ‡Darbishire, S. D., M.D. 60 High-street, Oxford.
1876. ‡Darling, G. Erskine. 247 West George-street, Glasgow.
1884. ‡Darling, Thomas. 99 Drummond-street, Montreal, Canada.
1882. ‡DARWIN, FRANCIS, M.A., F.R.S., F.L.S. Huntingdon-road, Cambridge.
1881. *DARWIN, GEORGE HOWARD, M.A., LL.D., F.R.S., F.R.A.S., Plumian Professor of Astronomy and Experimental Philosophy in the University of Cambridge. Newnham Grange, Cambridge.
1878. *Darwin, Horace. The Orchard, Huntingdon-road, Cambridge.
1882. §Darwin, W. E., F.G.S. Bassett, Southampton.
1848. ‡DaSilva, Johnson. Burntwood, Wandsworth Common, London, S.W.
1878. ‡D'Aulmay, G. 22 Upper Leeson-street, Dublin.
1872. ‡Davenport, John T. 64 Marine Parade, Brighton.
1880. §Davey, Henry, M.Inst.C.E. Rupert Lodge, Grove-road, Headingley, Leeds.
1884. ‡David, A. J., B.A., LL.B. 4 Harcourt-buildings, Temple, London, E.C.
1870. ‡Davidson, Alexander, M.D. 2 Gambier-terrace, Liverpool.
1885. ‡Davidson, Charles B. Roundhay, Fonthill-road, Aberdeen.
1871. ‡*Davidson, James. Newbattle, Dalkeith, N.B.*
1875. ‡Davies, David. 2 Queen's-square, Bristol.
1870. ‡Davies, Edward, F.C.S. Royal Institution, Liverpool.
1842. Davies-Colley, Dr. Thomas. Newton, near Chester.
1873. *Davis, Alfred. Parliament Mansions, London, S.W.
1870. *Davis, A. S. 6 Paragon-buildings, Cheltenham.
1864. ‡DAVIS, CHARLES E., F.S.A. 55 Pulteney-street, Bath.
Davis, Rev. David, B.A. Lancaster.
1881. ‡Davis, George E. The Willows, Fallowfield, Manchester.
1882. §Davis, Henry C. Berry Pomeroy, Springfield-road, Brighton.
1873. *DAVIS, JAMES W., F.G.S., F.S.A. Chevinedge, near Halifax.
1856. *DAVIS, Sir JOHN FRANCIS, Bart., K.C.B., F.R.S., F.R.G.S. Hollywood, near Compton, Bristol.
1883. ‡Davis, Joseph, J.P. Park-road, Southport.
1883. ‡Davis, Robert Frederick, M.A. Earlsfield, Wandsworth Common, London, S.W.
1885. *Davis, Rudolf. Castle Howell School, Lancaster.
1882. ‡*Davis, W. H. Gloucester Lodge, Portswood, Southampton.*
1886. §Davis, W. H. Hazeldean, Pershore-road, Birmingham.
1886. §Davison, Charles. 38 Charlotte-road, Birmingham.
1864. *Davison, Richard. Beverley-road, Great Driffield, Yorkshire.

Year of Election.

1857. ‡DAVY, EDMUND W., M.D. Kimmage Lodge, Roundtown, near Dublin.

1869. ‡Daw, John. Mount Radford, Exeter.

1869. ‡Daw, R. M. Bedford-circus, Exeter.

1860. *Dawes, John T., F.G.S. Blaen-y-Roe, St. Asaph, North Wales.

1864. ‡DAWKINS, W. BOYD, M.A., F.R.S., F.G.S., F.S.A., Professor of Geology and Palæontology in the Victoria University, Owens College, Manchester. Woodhurst, Fallowfield, Manchester.

1886. §Dawson, Bernard. The Laurels, Malvern Link.

1885. *Dawson, Captain H. P., R.A. Junior United Service Club, Pall Mall, London, S.W.

Dawson, John. Barley House, Exeter.

1884. ‡Dawson, Samuel. 258 University-street, Montreal, Canada.

1855. §DAWSON, Sir WILLIAM, C.M.G., M.A., LL.D., F.R.S., F.G.S., Principal of McGill University. (PRESIDENT.) McGill University, Montreal, Canada.

1859. *Dawson, Captain William G. Plumstead Common, Kent.

1879. ‡Day, Francis. Kenilworth House, Cheltenham.

1871. ‡DAY, ST. JOHN VINCENT, M.Inst.C.E., F.R.S.E. 166 Buchanan-street, Glasgow.

1870. *DEACON, G. F., M.Inst.C.E. Rock Ferry, Liverpool.

1861. ‡Deacon, Henry. Appleton House, near Warrington.

1861. ‡Dean, Henry. Colne, Lancashire.

1870. *Deane, Rev. George, B.A., D.Sc., F.G.S. Spring Hill College, Moseley, near Birmingham.

1884. *Debenham, Frank, F.S.S. 26 Upper Hamilton-terrace, London, N.W.

1866. ‡DEBUS, HEINRICH, Ph.D., F.R.S., F.C.S., Lecturer on Chemistry at Guy's Hospital, London, S.E.

1884. §Deck, Arthur, F.C.S. 9 King's-parade, Cambridge.

1882. *DE CHAUMONT, FRANÇOIS, M.D., F.R.S., Professor of Hygiène in the Royal Victoria Hospital, Netley.

1878. ‡Delany, Rev. William. St. Stanislaus College, Tullamore.

1854. *DE LA RUE, WARREN, M.A., D.C.L., Ph.D., F.R.S., F.C.S., F.R.A.S. 73 Portland-place, London, W.

1879. ‡De la Sala, Colonel. Sevilla House, Navarino-road, London, N.W.

1884. *De Laune, C. DeL. F. Sharsted Court, Sittingbourne.

1870. ‡*De Meschin, Thomas, M.A., LL.D. 8 New-square, Lincoln's Inn, London, W.C.*

Denchar, John. Morningside, Edinburgh.

1873. ‡Denham, Thomas. Huddersfield.

1884. ‡Denman, Thomas W. Lamb's-buildings, Temple, London, E.C.

1875. ‡Denny, William. Seven Ship-yard, Dumbarton.

Dent, William Yerbury. Royal Arsenal, Woolwich.

1870. *Denton, J. Bailey. 22 Whitehall-place, London, S.W.

1874. §DE RANCE, CHARLES E., F.G.S. 28 Jermyn-street, London, S.W.

1856. *DERBY, The Right Hon. the Earl of, K.G., M.A., LL.D., F.R.S., F.R.G.S. 23 St. James's-square, London, S.W.; and Knowsley, near Liverpool.

1874. *Derham, Walter, M.A., LL.M., F.G.S. Henleaze Park, Westbury-on-Trym, Bristol.

1878. ‡De Rinzy, James Harward. Khelat Survey, Sukkur, India.

1868. ‡Dessé, Etheldred, M.B., F.R.C.S. 43 Kensington Gardens-square, Bayswater, London, W.

DE TABLEY, GEORGE, Lord, F.Z.S. Tabley House, Knutsford, Cheshire.

1869. ‡DEVON, The Right Hon. the Earl of, D.C.L. Powderham Castle, near Exeter.

Year of Election.

*DEVONSHIRE, His Grace the Duke of, K.G., M.A., LL.D., F.R.S., F.G.S., F.R.G.S., Chancellor of the University of Cambridge. Devonshire House, Piccadilly, London, W.; and Chatsworth, Derbyshire.
1868. ‡DEWAR, JAMES, M.A., F.R.S. L. & E., F.C.S., Fullerian Professor of Chemistry in the Royal Institution, London, and Jacksonian Professor of Natural Experimental Philosophy in the University of Cambridge. 1 Scroope-terrace, Cambridge.
1881. ‡Dewar, Mrs. 1 Scroope-terrace, Cambridge.
1883. ‡Dewar, James, M.D., F.R.C.S.E. Drylaw House, Davidson's Mains, Midlothian, N.B.
1884. *Dewar, William. 6 Montpellier-grove, Cheltenham.
1872. ‡Dewick, Rev. E. S., M.A., F.G.S. 2 Southwick-place, Hyde Park, London, W.
1884. §De Wolf, O. C., M.D. Chicago, U.S.A.
1873. *DEW-SMITH, A. G., M.A. 7A Eaton-square, London, S.W.
1883. ‡Dickinson, A. P. Fair Elms, Blackburn.
1864. *Dickinson, F. H., F.G.S. Kingweston, Somerton, Taunton; and 121 St. George's-square, London, S.W.
1863. ‡Dickinson, G. T. Claremont-place, Newcastle-on-Tyne.
1867. ‡DICKSON, ALEXANDER, M.D., Professor of Botany in the University of Edinburgh. 11 Royal-circus, Edinburgh.
1884. ‡Dickson, Charles R., M.D. Wolfe Island, Ontario, Canada.
1881. ‡Dickson, Edmund. West Cliff, Preston.
1885. ‡Dickson, Patrick. Laurencekirk, Aberdeen.
1883. ‡Dickson, T. A. West Cliff, Preston.
1862. *DILKE, The Right Hon. Sir CHARLES WENTWORTH, Bart., F.R.G.S. 76 Sloane-street, London, S.W.
1877. §Dillon, James, M.Inst.C.E. 36 Dawson-street, Dublin.
1848. ‡DILLWYN, LEWIS LLEWELYN, M.P., F.L.S., F.G.S. Parkwerne, near Swansea.
1872. ‡DINES, GEORGE. Woodside, Hersham, Walton-on-Thames.
1869. ‡Dingle, Edward. 19 King-street, Tavistock.
1876. ‡Ditchfield, Arthur. 12 Taviton-street, Gordon-square, London, W.C.
1868. ‡Dittmar, William, F.R.S. L. & E., F.C.S., Professor of Chemistry in Anderson's College, Glasgow.
1884. §Dix, John William H. Bristol.
1874. *Dixon, A. E. Dunowen, Cliftonville, Belfast.
1883. ‡Dixon, Miss E. 2 Cliff-terrace, Kendal.
1853. ‡Dixon, Edward. Wilton House, Southampton.
1886. §Dixon, George. 42 Augustus-road, Edgbaston, Birmingham.
1879. *DIXON, HAROLD B., M.A., F.R.S., F.C.S., Professor of Chemistry in the Owens College, Manchester.
1885. ‡Dixon, John Henry. Inveran, Poolewe, Ross-shire, N.B.
1885. ‡Doak, Rev. A. 15 Queen's-road, Aberdeen.
1885. §Dobbin, Leonard. The University, Edinburgh.
1860. *Dobbs, Archibald Edward, M.A. 34 Westbourne Park, London, W.
1878. *DOBSON, G. E., M.A., M.B., F.R.S., F.L.S. Colyford Villa, Exeter.
1864. *Dobson, William. Oakwood, Bathwick Hill, Bath.
1875. *Docwra, George, jun. Liberal Club, Colchester.
1870. *Dodd, John. 34 Fern-grove, Lodge-lane, Liverpool.
1876. ‡Dodds, J. M. St. Peter's College, Cambridge.
Dolphin, John. Delves House, Berry Edge, near Gateshead.
1851. ‡Domvile, William C., F.Z.S. Thorn Hill, Bray, Dublin.
1867. ‡Don, John. The Lodge, Broughty Ferry, by Dundee.
1867. ‡Don, William G. St. Margaret's, Broughty Ferry, by Dundee.

Year of Election.

1885. ‡Donaldson, James, M.A., LL.D., F.R.S.E., Regius Professor of Humanity in the University of Aberdeen. Old Aberdeen.
1882. ‡Donaldson, John. Tower House, Chiswick, Middlesex.
1869. ‡Donisthorpe, G. T. St. David's Hill, Exeter.
1877. *Donkin, Bryan, jun. May's Hill, Shortlands, Kent.
1874. ‡Donnell, Professor, M.A. 76 Stephen's-green South, Dublin.
1861. ‡Donnelly, Colonel, R.E., C.B. South Kensington Museum, London, W.
1881. ‡Dorrington, John Edward. Lypiatt Park, Stroud.
1867. ‡Dougall, Andrew Maitland, R.N. Scotscraig, Tayport, Fifeshire.
1871. ‡Dougall, John, M.D. 2 Cecil-place, Paisley-road, Glasgow.
1863. *Doughty, Charles Montagu. Care of H. M. Doughty, Esq., 5 Stone-court, Lincoln's Inn, London, W.C.
1876. *Douglas, Rev. G. C. M. 18 Royal-crescent West, Glasgow.
1877. *Douglass, Sir James N., M.Inst.C.E. Trinity House, London, E.C.
1878. ‡Douglass, William. 104 Baggot-street, Dublin.
1884. ‡Douglass, William Alexander. Freehold Loan and Savings Company, Church-street, Toronto, Canada.
1886. §Dovaston, John. West Felton, Shropshire.
1883. §Dove, Arthur. Crown Cottage, York.
1884. ‡Dove, Miss Frances. St. Leonard's, St. Andrews, N.B.
1884. ‡Dove, P. Edward, F.R.A.S., Sec.R.Hist.Soc. 23 Old-buildings, Lincoln's Inn, London, W.C.
1884. ‡Dowe, John Melnotte. 69 Seventh-avenue, New York, U.S.A.
1870. ‡Dowie, J. Muir. Gollanol, by Kinross, N.B.
1876. ‡Dowie, Mrs. Muir. Gollanol, by Kinross, N.B.
1884. *Dowling, D. J. Bromley, Kent.
1878. ‡Dowling, Thomas. Claireville House, Terenure, Dublin.
1882. §Downes, Rev. W., B.A., F.G.S. Combe Raleigh Rectory, Honiton.
1857. ‡Downing, S., LL.D. 4 The Hill, Monkstown, Co. Dublin.
1878. ‡Dowse, The Right Hon. Baron. 38 Mountjoy-square, Dublin.
1865. *Dowson, E. Theodore, F.R.M.S. Geldeston, near Beccles, Suffolk.
1881. §Dowson, Joseph Emerson, C.E. 3 Great Queen-street, London, S.W.
1883. ‡Draper, William. De Grey House, St. Leonard's, York.
1868. ‡Dresser, Henry E., F.Z.S. 6 Tenterden-street, Hanover-square, London, W.
1873. §Drew, Frederic, F.G.S., F.R.G.S. Eton College, Windsor.
1879. ‡*Drew, Joseph, M.B. Foxgrove-road, Beckenham, Kent.*
1879. ‡Drew, Samuel, M.D., D.Sc., F.R.S.E. 10 Laura-place, Bath.
1870. §Drysdale, J. J., M.D. 36A Rodney-street, Liverpool.
1884. ‡*Du Bois, Henri. 39 Bentick-street, Glasgow.*
1856. *Ducie, The Right. Hon. Henry John Reynolds Moreton, Earl of, F.R.S., F.G.S. 16 Portman-square, London, W.; and Tortworth Court, Wotton-under-Edge.
1883. ‡*Duck, A. E. Southport.*
1870. ‡Duckworth, Henry, F.L.S., F.G.S. Holme House, Columbia-road, Oxton, Birkenhead.
1867. *Duff, The Right Hon. Mountstuart Elphinstone Grant-, F.R.S., F.R.G.S. Care of W. Hunter, Esq., 14 Adelphi-court, Union-street, Aberdeen.
1852. ‡Dufferin and Clandeboye, The Right Hon. the Earl of, K.P., G.C.B., LL.D., F.R.S., F.R.G.S., Governor-General of India. Clandeboye, near Belfast, Ireland.
1877. ‡Duffey, George F., M.D. 30 Fitzwilliam-place, Dublin.
1875. ‡Duffin, W. E. L'Estrange. Waterford.
1884. §Dugdale, James H. 9 Hyde Park-gardens, London, W.
1883. §Duke, Frederic. Conservative Club, Hastings.

Year of Election.

1859. *Duncan, Alexander. 7 Prince's-gate, London, S.W.
1866. **Duncan James. 71 Cromwell-road, South Kensington, London, S.W.*
1871. ‡Duncan, James Matthew, M.D. 30 Charlotte-square, Edinburgh.
Duncan, J. F., M.D. 8 Upper Merrion-street, Dublin.
1867. ‡DUNCAN, PETER MARTIN, M.B., F.R.S., F.G.S., Professor of Geology in King's College, London. 6 Grosvenor-road, Gunnersbury, London, W.
1880. ‡Duncan, William S. 22 Delamere-terrace, Bayswater, London, W.
1881. ‡Duncombe, The Hon. Cecil. Nawton Grange, York.
1881. ‡Dunhill, Charles H. Gray's-court, York.
1853. *Dunlop, William Henry. Annanhill, Kilmarnock, Ayrshire.
1865. ‡Dunn, David. Annet House, Skelmorlie, by Greenock, N.B.
1882. §Dunn, J. T., M.Sc., F.C.S. High School for Boys, Gateshead-on-Tyne.
1883. §Dunn, Mrs. 115 Scotswood-road, Newcastle-on-Tyne.
1876. ‡Dunnachie, James. 2 West Regent-street, Glasgow.
1878. ‡Dunne, D. B., M.A., Ph.D., Professor of Logic in the Catholic University of Ireland. 4 Clanwilliam-place, Dublin.
1884. ‡Dunnington, F. P. University of Virginia, Albemarle Co., Virginia, U.S.A.
1859. ‡Duns, Rev. John, D.D., F.R.S.E. New College, Edinburgh.
1885. *Dunstan, Wyndham, F.C.S., Professor of Chemistry to the Pharmaceutical Society of Great Britain. 17 Bloomsbury-square, London, W.C.
1866. ‡Duprey, Perry. Woodberry Down, Stoke Newington, London, N.
1869. ‡D'Urban, W. S. M., F.L.S. 4 Queen-terrace, Mount Radford, Exeter.
1860. ‡DURHAM, ARTHUR EDWARD, F.R.C.S., F.L.S., Demonstrator of Anatomy, Guy's Hospital. 82 Brook-street, Grosvenor-square, London, W.
1884. ‡Dyck, Professor Walter. The University, Munich.
1885. *Dyer, Henry, M.A. 8 Highburgh-terrace, Dowanhill, Glasgow.
Dykes, Robert. Kilmorie, Torquay, Devon.
1869. *Dymond, Edward E. Oaklands, Aspley Guise, Woburn.

1868. ‡Eade, Peter, M.D. Upper St. Giles's-street, Norwich.
1884. §Eads, Captain James B. 34 Nassau-street, New York, U.S.A.
1861. ‡Eadson, Richard. 13 Hyde-road, Manchester.
1883. ‡Eagar, Rev. Thomas. The Rectory, Ashton-under-Lyne.
1877. ‡Earle, Ven. Archdeacon, M.A. West Alvington, Devon.
1833. *EARNSHAW, Rev. SAMUEL, M.A. 14 Beechhill-road, Sheffield.
1874. ‡Eason, Charles. 30 Kenilworth-square, Rathgar, Dublin.
1883. ‡*Eastham, Silas. 50 Leyland-road, Southport.*
1871. *EASTON, EDWARD, M.Inst.C.E., F.G.S. 11 Delahay-street, Westminster, S.W.
1863. ‡Easton, James. Nest House, near Gateshead, Durham.
1876. ‡Easton, John. Durie House, Abercromby-street, Helensburgh, N.B.
1883. §Eastwood, Miss. Littleover Grange, Derby.
1884. ‡Eckersley, W. T. Standish Hall, Wigan, Lancashire.
1861. ‡Ecroyd, William Farrer. Spring Cottage, near Burnley.
1858. *Eddison, Francis. Syward Lodge, Dorchester.
1870. *Eddison, John Edwin, M.D., M.R.C.S. 29 Park-square, Leeds.
*Eddy, James Ray, F.G.S. The Grange, Carleton, Skipton.
Eden, Thomas. Talbot-road, Oxton.
1884. *Edgell, R. Arnold, B.A., F.C.S. Ashburnham House, Little Dean's-yard, Westminster, S.W.
1859. ‡Edmond, James. Cardens Haugh, Aberdeen.
1870. *Edmonds, F. B. 72 Portsdown-road, London, W.
1883. ‡Edmonds, William. Wiscombe Park, Honiton, Devon.

Year of Election.

1884. *Edmunds, James, M.D. 8 Grafton-street, Piccadilly, London, W.
1883. ‡Edmunds, Lewis, D.Sc., LL.B. 8 Grafton-street, Piccadilly London, W.
1867. *Edward, Allan. Farington Hall, Dundee.
1867. ‡Edward, Charles. Chambers, 8 Bank-street, Dundee.
1855. *EDWARDS, Professor J. BAKER, Ph.D., D.C.L. Montreal, Canada.
1884. ‡Edwards, W. F. Niles, Michigan, U.S.A.
1876. ‡Elder, Mrs. 6 Claremont-terrace, Glasgow.
1885. *Elgar, Francis, LL.D., F.R.S.E., Professor of Naval Architecture and Marine Engineering in the University of Glasgow. 17 University Gardens, Glasgow.
1868. ‡Elger, Thomas Gwyn Empy, F.R.A.S. Manor Cottage, Kempston, Bedford.
1863. ‡Ellenberger, J. L. Worksop.
1885. §Ellingham, Frank. Thorpe St. Andrew, Norwich.
1883. ‡Ellington, Edward Bayzand, M.Inst.C.E. Palace-chambers, Bridge-street, Westminster, S.W.
1880. *Elliot, Colonel Charles, C.B. Hazelbank, Murrayfield, Midlothian, N.B.
1861. *ELLIOT, Sir WALTER, K.C.S.I., LL.D., F.R.S., F.L.S. Wolfelee, Hawick, N.B.
1864. ‡Elliott, E. B. Washington, U.S.A.
1883. *ELLIOTT, EDWIN BAILEY, M.A. Queen's College, Oxford.
1872. ‡Elliott, Rev. E. B. 11 Sussex-square, Kemp Town, Brighton.
Elliott, John Fogg. Elvet Hill, Durham.
1879. §Elliott, Joseph W. Post Office, Bury, Lancashire.
1886. §Elliott, Thomas Henry. Inland Revenue Department, Somerset House, London, W.C.
1864. *ELLIS, ALEXANDER JOHN, B.A., F.R.S., F.S.A. 25 Argyll-road, Kensington, London, W.
1877. ‡Ellis, Arthur Devonshire. School of Mines, Jermyn-street, London, S.W.; and Thurnscoe Hall, Rotherham, Yorkshire.
1875. *Ellis, H. D. 6 Westbourne-terrace, Hyde Park, London, W.
1883. ‡Ellis, John. 17 Church-street, Southport.
1880. *ELLIS, JOHN HENRY. New Close, Cambridge-road, Southport.
1864. *Ellis, Joseph. Hampton Lodge, Brighton.
1864. ‡Ellis, J. Walter. High House, Thornwaite, Ripley, Yorkshire.
*_Ellis, Rev. Robert, A.M. The Institute, St. Saviour's Gate, York._
1884. ‡Ellis, W. Hodgson. Toronto, Canada.
1869. ‡ELLIS, WILLIAM HORTON. Hartwell House, Exeter.
Ellman, Rev. E. B. Berwick Rectory, near Lewes, Sussex.
1862. ‡Elphinstone, H. W., M.A., F.L.S. 2 Stone-buildings, Lincoln's Inn, London, W.C.
1883. ‡Elwes, George Robert. Bossington, Bournemouth.
1870. *ELY, The Right Rev. Lord ALWYNE COMPTON, D.D., Lord Bishop of. The Palace, Ely, Cambridgeshire.
1863. ‡Embleton, Dennis, M.D. Northumberland-street, Newcastle-on-Tyne.
1884. ‡Emery, Albert H. Stamford, Connecticut, U.S.A.
1863. ‡Emery, The Ven. Archdeacon, B.D. Ely, Cambridgeshire.
1886. §Emmons, Hamilton. Mount Vernon Lodge, Leamington.
1858. ‡Empson, Christopher. Bramhope Hall, Leeds.
1866. ‡Enfield, Richard. Low Pavement, Nottingham.
1866. ‡Enfield, William. Low Pavement, Nottingham.
1884. ‡England, Luther M. Knowlton, Quebec, Canada.
1853. ‡English, Edgar Wilkins. Yorkshire Banking Company, Lowgate, Hull.

Year of Election.
1869. ‡English, J. T. Wayfield House, Stratford-on-Avon.
1883. ‡Entwistle, James P. Beachfield, 2 Westclyffe-road, Southport.
1869. *Enys, John Davis. Care of F. G. Enys, Esq., Enys, Penryn, Cornwall.
1844. ‡Erichsen, John Eric, LL.D., F.R.S., F.R.C.S., Professor of Surgery in University College, London. 6 Cavendish-place, London, W.
1864. *Eskrigge, R. A., F.G.S. 18 Hackins-hey, Liverpool.
1885. ‡Esselmont, Peter, M.P. 34 Albyn-place, Aberdeen.
1862. *ESSON, WILLIAM, M.A., F.R.S., F.C.S., F.R.A.S. Merton College and 13 Bradmore-road, Oxford.
1878. ‡Estcourt, Charles, F.C.S. 8 St. James's-square, John Dalton-street, Manchester.
Estcourt, Rev. W. J. B. Long Newton, Tetbury.
1869. ‡ETHERIDGE, ROBERT, F.R.S. L. & E., F.G.S., Assistant Keeper (Geological and Palæontological Department) Natural History Museum (British Museum). 14 Carlyle-square, London, S.W.
1883. §Eunson, Henry J. 20 St. Giles-street, Northampton.
1881. ‡Evans, Alfred. Exeter College, Oxford.
1870. *Evans, Arthur John, F.S.A. Nash Mills, Hemel Hempstead.
1865. *EVANS, Rev. CHARLES, M.A. The Rectory, Solihull, Birmingham.
1884. §Evans, Horace L. Moreton House, Tyndall Park, Bristol.
1869. *Evans, H. Saville W. Wimbledon Park House, Wimbledon, Surrey.
1861. *EVANS, JOHN, D.C.L., LL.D., Treas.R.S., F.S.A., F.L.S., F.G.S. 65 Old Bailey, London, E.C.; and Nash Mills, Hemel Hempstead.
1883. §Evans, J. C. Nevill-street, Southport.
1883. §Evans, Mrs. J. C. Nevill-street, Southport.
1881. ‡Evans, Lewis. Llanfyrnach R.S.O., Pembrokeshire.
1876. ‡Evans, Mortimer, M.Inst.C.E. 97 West Regent-street, Glasgow.
1885. *Evans, Percy Bagnall. The Spring, Kenilworth.
1865. ‡EVANS, SEBASTIAN, M.A., LL.D. Heathfield, Alleyne Park, Lower Norwood, Surrey, S.E.
1875. ‡Evans, Sparke. 3 Apsley-road, Clifton, Bristol.
1866. ‡Evans, Thomas, F.G.S. Belper, Derbyshire.
1865. *Evans, William. The Spring, Kenilworth.
1886. §Eve, A. S. Elmshurst, Bedford.
1871. §Eve, H. Weston, M.A. University College, London, W.C.
1868. *EVERETT, J. D., M.A., D.C.L., F.R.S. L. & E., Professor of Natural Philosophy in Queen's College, Belfast. 5 Prince's-gardens, Belfast.
1880. ‡Everingham, Edward. St. Helen's-road, Swansea.
1863. *Everitt, George Allen, F.R.G.S. Knowle Hall, Warwickshire.
1886. §Everitt, William E. Finstall Park, Bromsgrove.
1883. ‡Eves, Miss Florence. Uxbridge.
1881. ‡EWART, J. COSSAR, M.D., Professor of Natural History in the University of Edinburgh.
1874. ‡Ewart, William, M.P. Glenmachan, Belfast.
1874. ‡Ewart, W. Quartus. Glenmachan, Belfast.
1859. *Ewing, Sir Archibald Orr, Bart., M.P. Ballikinrain Castle, Killearn, Stirlingshire.
1876. *EWING, JAMES ALFRED, B.Sc., F.R.S.E., Professor of Engineering in University College, Dundee.
1883. ‡Ewing, James L. 52 North Bridge, Edinburgh.
1871. *Exley, John T., M.A. 1 Cotham-road, Bristol.
1884. §Eyerman, John. Easton, Pennsylvania, U.S.A.

Year of Election.

1846. *Eyre, George Edward, F.G.S., F.R.G.S. 59 Lowndes-square, London, S.W.; and Warrens, near Lyndhurst, Hants.
1882. ‡Eyre, G. E. Briscoe. Warrens, near Lyndhurst, Hants.
Eyton, Charles. Hendred House, Abingdon.

1884. ‡Fairbairn, Dr. A. M. Airedale College, Bradford, Yorkshire.
1865. *FAIRLEY, THOMAS, F.R.S.E., F.C.S. 8 Newton-grove, Leeds.
1876. ‡Fairlie, James M. Charing Cross Corner, Glasgow.
1870. ‡Fairlie, Robert, C.E. Woodlands, Clapham Common, London, S.W.
1886. §Fairley, William. Beau Desert, Rugeley, Staffordshire.
1864. ‡Falkner, F. H. Lyncombe, Bath.
1886. §Fallon, T. P., Consul General. Australia.
1883. ‡Fallon, Rev. W. S. 1 St. Alban's-terrace, Cheltenham.
1877. §FARADAY, F. J., F.L.S., F.S.S. College Chambers, 17 Brazenose-street, Manchester.
1886. §Farncombe, Joseph, J.P. Lewes.
1879. *Farnworth, Ernest. Clarence Villa, Penn Fields, Wolverhampton.
1883. ‡Farnworth, Walter. 86 Preston New-road, Blackburn.
1883. ‡Farnworth, William. 86 Preston New-road, Blackburn.
1885. ‡Farquhar, Admiral. Carlogie, Aberdeen.
1859. ‡Farquharson, Robert F. O. Haughton, Aberdeen.
1885. ‡Farquharson, Mrs. R. F. O. Haughton, Aberdeen.
1866. *FARRAR, Ven. FREDERICK WILLIAM, M.A., D.D., F.R.S., Archdeacon of Westminster. St. Margaret's Rectory, Westminster, S.W.
1883. ‡Farrell, John Arthur. Moynalty, Kells, North Ireland.
1857. ‡Farrelly, Rev. Thomas. Royal College, Maynooth.
1869. *Faulding, Joseph. Ebor Villa, Godwin-road, Clive-vale, Hastings.
1883. §Faulding, Mrs. Ebor Villa, Godwin-road, Cive-vale, Hastings.
1863. ‡*Fawcus, George. Alma-place, North Shields.*
1873. *Fazakerley, Miss. Banwell Abbey, Weston-super-Mare, Somerset.
1886. §Felkin, Robert W., M.D., F.R.G.S. 20 Alva-street, Edinburgh.
1845. ‡Felkin, William, F.L.S. The Park, Nottingham.
Fell, John B. Spark's Bridge, Ulverstone, Lancashire.
1864. *FELLOWS, FRANK P., K.S.J.J., F.S.A., F.S.S. 8 The Green, Hampstead, London, N.W.
1852. ‡Fenton, S. Greame. 9 College-square; and Keswick, near Belfast.
1883. ‡Fenwick, E. H. 29 Harley-street, London, W.
1876. *Fergus, Andrew, M.D. 191 Bath-street, Glasgow.
1876. ‡Ferguson, Alexander A. 11 Grosvenor-terrace, Glasgow.
1883. ‡Ferguson, Mrs. A. A. 11 Grosvenor-terrace, Glasgow.
1859. ‡Ferguson, John. Cove, Nigg, Inverness.
1871. *Ferguson, John, M.A., Professor of Chemistry in the University of Glasgow.
1867. ‡Ferguson, Robert M., Ph.D., F.R.S.E. 8 Queen-street, Edinburgh.
1857. ‡Ferguson, Sir Samuel, LL.D., Q.C. 20 Great George's-street North, Dublin.
1854. ‡Ferguson, William, F.L.S., F.G.S. Kinmundy, near Mintlaw, Aberdeenshire.
1867. *Fergusson, H. B. 13 Airlie-place, Dundee.
1883. §Fernald, H. P. Alma House, Cheltenham.
1883. *Fernie John. 113 South 40th Street, Philadelphia, U.S.A.
1862. ‡FERRERS, Rev. NORMAN MACLEOD, D.D., F.R.S. Caius College Lodge, Cambridge.
1873. ‡Ferrier, David, M.A., M.D., F.R.S., Professor of Forensic Medicine in King's College. 34 Cavendish-square, London, W.
1882. §Fewings, James, B.A., B.Sc. The Grammar School, Southampton.

Year of Election.

1875. ‡Fiddes, Walter. Clapton Villa, Tyndall's Park, Clifton, Bristol.
1868. ‡Field, Edward. Norwich.
1886. §Field, H. C. 4 Carpenter-road, Edgbaston, Birmingham.
1869. *FIELD, ROGERS, B.A., M.Inst.C.E. 4 Westminster-chambers, Westminster, S.W.
1882. §Filliter, Freeland. St. Martin's House, Wareham, Dorset.
1883. **Finch, Gerard B., M.A. 10 Lyndhurst-road, Hampstead, London, N.W.*
1883. ‡*Finch, Mrs. Gerard. 10 Lyndhurst-road, Hampstead, London, N.W.*
Finch, John. Bridge Work, Chepstow.
Finch, John, jun. Bridge Work, Chepstow.
1885. ‡FINDLATER, JOHN. 60 Union-street, Aberdeen.
1878. *Findlater, William. 22 Fitzwilliam-square, Dublin.
1885. ‡Findlay, George, M.A. 50 Victoria-street, Aberdeen.
1884. ‡Finlay, Samuel. Montreal, Canada.
1883. §Finney, John Douglass. The West Mansions, De Vere-gardens, Kensington, London, W.
1881. ‡Firth, Colonel Sir Charles. Heckmondwike.
Firth, Thomas. Northwick.
1863. *Firth, William. Burley Wood, near Leeds.
1851. *FISCHER, Professor WILLIAM L. F., M.A., LL.D., F.R.S. St. Andrews, N.B.
1858. ‡Fishbourne, Admiral E. G., R.N. 26 Hogarth-road, Earl's Court-road, London, S.W.
1884. *Fisher, L. C. Galveston, Texas, U.S.A.
1869. ‡FISHER, Rev. OSMOND, M.A., F.G.S. Harlton Rectory, near Cambridge.
1873. §Fisher, William. Maes Fron, near Welshpool, Montgomeryshire.
1879. ‡Fisher, William. Norton Grange, near Sheffield.
1875. *Fisher, W. W., M.A., F.C.S. 5 St. Margaret's-road, Oxford.
1858. ‡Fishwick, Henry. Carr-hill, Rochdale.
1885. §Fison, E. Herbert. Stoke House, Ipswich.
1871. *FISON, FREDERICK W., M.A., F.C.S. Eastmoor, Ilkley, Yorkshire.
1871. ‡FITCH, J. G., M.A., LL.D. 5 Lancaster-terrace, Regent's Park, London, N.W.
1883. ‡Fitch, Rev. J. J. Ivyholme, Southport.
1868. ‡Fitch, Robert, F.G.S., F.S.A. Norwich.
1878. ‡Fitzgerald, C. E., M.D. 27 Upper Merrion-street, Dublin.
1878. §FITZGERALD, GEORGE FRANCIS, M.A., F.R.S., Professor of Natural and Experimental Philosophy. Trinity College, Dublin.
1885. *Fitzgerald, Professor Maurice, B.A. 37 Botanic-avenue, Belfast.
1857. ‡Fitzpatrick, Thomas, M.D. 31 Lower Baggot-street, Dublin.
1881. ‡*Fitzsimmons, Henry, M.D. Minster-yard, York.*
1865. ‡Fleetwood, D. J. 45 George-street, St. Paul's, Birmingham.
Fleetwood, Sir Peter Hesketh, Bart. Rossall Hall, Fleetwood, Lancashire.
1850. ‡*Fleming, Professor Alexander, M.D. 121 Hagley-road, Birmingham.*
1881. ‡Fleming, Rev. Canon James, B.D. The Residence, York.
1876. ‡Fleming, James Brown. Beaconsfield, Kelvinside, near Glasgow.
1876. ‡Fleming, Sandford. Ottawa, Canada.
1867. §FLETCHER, ALFRED E. 57 Gordon-square, London, W.C.
1870. ‡Fletcher, B. Edgington. Norwich.
1886. §Fletcher, Frank M. 57 Gordon-square, London, W.C.
1869. ‡FLETCHER, LAVINGTON E., M.Inst.C.E. Alderley Edge, Cheshire.
Fletcher, T. B. E., M.D. 7 Waterloo-street, Birmingham.

Year of Election.

1862. §FLOWER, WILLIAM HENRY, LL.D., F.R.S., F.L.S., F.G.S., F.R.C.S., Director of the Natural History Department, British Museum, South Kensington, London, S.W.
1877. *Floyer, Ernest A., F.R.G.S., F.L.S. Cairo.
1881. ‡Foljambe, Cecil G. S., M.P. 2 Carlton House-terrace, Pall Mall, London, S.W.
1879. ‡Foote, Charles Newth, M.D. 3 Albion-place, Sunderland.
1879. ‡Foote, Harry D'Oyley, M.D. Rotherham, Yorkshire.
1880. ‡Foote, R. Bruce. Care of Messrs. H. S. King & Co., 65 Cornhill, London, E.C.
1873. *FORBES, GEORGE, M.A., F.R.S.E. 34 Great George-street, London, S.W.
1883. §Forbes, Henry O., F.Z.S. Rubislaw Den, Aberdeen.
1885. ‡Forbes, The Right Hon. Lord. Castle Forbes, Aberdeenshire.
1866. ‡Ford, William. Hartsdown Villa, Kensington Park-gardens East, London, W.
1875. *FORDHAM, H. GEORGE, F.G.S. Odsey Grange, Royston, Cambridgeshire.
1883. §Formby, R. Formby, near Liverpool.
1867. ‡Forster, Anthony. Finlay House, St. Leonard's-on-Sea.
1883. ‡Forsyth, A. R. University College, Liverpool.
1884. ‡Fort, George H. Lakefield, Ontario, Canada.
1854. *Fort, Richard. Read Hall, Whalley, Lancashire.
1877. ‡FORTESCUE, The Right Hon. the Earl. Castle Hill, North Devon.
1882. §Forward, Henry. 3 Burr-street, London, E.
1870. ‡Forwood, Sir William B. Hopeton House, Seaforth, Liverpool.
1875. ‡Foster, A. Le Neve. 51 Cadogan-square, London, S.W.
1865. ‡Foster, Balthazar, M.D., Professor of Medicine in Queen's College, Birmingham. 16 Temple-row, Birmingham.
1865. *FOSTER, CLEMENT LE NEVE, B.A., D.Sc., F.G.S. Llandudno.
1883. ‡Foster, Mrs. C. Le Neve. Llandudno.
1857. *FOSTER, GEORGE CAREY, B.A., F.R.S., F.C.S., Professor of Physics in University College, London. 18 Daleham-gardens, Hampstead, London, N.W.
1881. ‡Foster, J. L. Ogleforth, York.
1845. ‡Foster, John N. Sandy Place, Sandy, Bedfordshire.
1877. §Foster, Joseph B. 6 James-street, Plymouth.
1859. *FOSTER, MICHAEL, M.A., M.D., LL.D., Sec. R.S., F.L.S., F.C.S., Professor of Physiology in the University of Cambridge. Trinity College, and Great Shelford, near Cambridge.
1863. ‡Foster, Robert. 30 Rye-hill, Newcastle-upon-Tyne.
1866. ‡Fowler, George, M.Inst.C.E., F.G.S. Basford Hall, near Nottingham.
1868. ‡Fowler, G. G. Gunton Hall, Lowestoft, Suffolk.
1876. *Fowler, John. 4 Kelvin Bank-terrace, Glasgow.
1882. ‡FOWLER, Sir JOHN, M.Inst.C.E., F.G.S. 2 Queen Square-place, Westminster, S.W.
1870. *Fowler, Sir Robert Nicholas, Bart., M.A., M.P., F.R.G.S. 50 Cornhill, London, E.C.
1884. §Fox, Miss A. M. Penjerrick, Falmouth.
1883. *Fox, Charles. 25 St. George's-avenue, Tufnell Park, London, N.
1883. §Fox, Sir Charles Douglas, M.Inst.C.E. 5 Delahay-street, Westminster, S.W.
1860. *Fox, Rev. Edward, M.A. Upper Heyford, Banbury.
1883. ‡Fox, Howard, United States Consul. Falmouth.
1876. *Fox, Joseph Hayland. The Cleve, Wellington, Somerset.
1860. ‡Fox, Joseph John. Lordship-terrace, Stoke Newington, London, N.
1876. ‡Fox, St. G. Lane. 9 Sussex-place, London, S.W.

Year of Election.
1886. §Foxwell, Arthur, M.A., M.B. 17 Temple-row, Birmingham.
1881. *FOXWELL, HERBERT S., M.A., Professor of Political Economy in University College, London. St. John's College, Cambridge.
1866. *Francis, G. B. Vale House, Hertford.
1884. ‡Francis, James B. Lowell, Massachusetts, U.S.A.
FRANCIS, WILLIAM, Ph.D., F.L.S., F.G.S., F.R.A.S. Red Lion-court, Fleet-street, London, E.C.; and Manor House, Richmond, Surrey.
1846. ‡FRANKLAND, EDWARD, M.D., D.C.L., LL.D., Ph.D., F.R.S., F.C.S. The Yews, Reigate Hill, Surrey.
*Frankland, Rev. Marmaduke Charles. Chowbent, near Manchester.
1882. §Fraser, Alexander, M.B. Royal College of Surgeons, Dublin.
1885. ‡FRASER, ANGUS, M.A., M.D., F.C.S. 232 Union-street, Aberdeen.
1859. ‡Fraser, George B. 3 Airlie-place, Dundee.
Fraser, James William. 8A Kensington Palace-gardens, London, W.
1865. *FRASER, JOHN, M.A., M.D. Chapel Ash, Wolverhampton.
1871. ‡FRASER, THOMAS R., M.D., F.R.S. L. & E., Professor of Materia Medica and Clinical Medicine in the University of Edinburgh. 37 Melville-street, Edinburgh.
1859. *Frazer, Daniel. 127 Buchanan-street, Glasgow.
1871. ‡Frazer, Evan L. R. Brunswick-terrace, Spring Bank, Hull.
1884. *Frazer, Persifor, M.A., D.Sc., Professor of Chemistry in the Franklin Institute of Pennsylvania. 917 Clinton-street, Philadelphia, U.S.A.
1884. *Fream, W., B.Sc., F.L.S., F.G.S., Professor of Natural History in the College of Agriculture, Downton, Salisbury.
1860. ‡Freeborn, Richard Fernandez. 38 Broad-street, Oxford.
1847. *Freeland, Humphrey William, F.G.S. West-street, Chichester.
1877. §Freeman, Francis Ford. 8 Leigham-terrace, Plymouth.
1865. ‡Freeman, James. 15 Francis-road, Edgbaston, Birmingham.
1880. ‡Freeman, Thomas. Brynhyfryd, Swansea.
1841. Freeth, Major-General S. 30 Royal-crescent, Notting Hill, London, W.
1884. *Fremantle, Hon. C. W., C.B. Royal Mint, London, E.
Frere, George Edward, F.R.S. Roydon Hall, Diss, Norfolk.
1869. ‡Frere, Rev. William Edward. The Rectory, Bilton, near Bristol.
1886. §Freshfield, Douglas W., Sec.R.G.S. 1 Savile-row, London, W.
1886. §Freund, Miss Ida. Eyre Cottage, Upper Sydenham, S.E.
1857. *Frith, Richard Hastings, M.R.I.A., F.R.G.S.I. 48 Summer-hill, Dublin.
1883. ‡Froane, William. Beech House, Birkdale, Southport.
1882. §Frost, Edward P., J.P. West Wratting Hall, Cambridgeshire.
1883. ‡Frost, Captain H., J.P. West Wratting, Cambridgeshire.
1875. ‡Fry, F. J. 104 Pembroke-road, Clifton, Bristol.
1875. *Fry, Joseph Storrs. 2 Charlotte-street, Bristol.
1884. §Fryer, Joseph, J.P. Smelt House, Howden-le-Wear, Co. Durham.
1872. *Fuller, Rev. A. Pallant, Chichester.
1859. ‡FULLER, FREDERICK, M.A. 9 Palace-road, Surbiton.
1869. ‡FULLER, GEORGE, M.Inst.C.E. 71 Lexham-gardens, Kensington, London, W.
1884. §Fuller, William. Oswestry.
1864. *Furneaux, Rev. Alan. St. German's Parsonage, Cornwall.

1881. ‡Gabb, Rev. James, M.A. Bulmer Rectory, Welburn, Yorkshire.
*Gadesden, Augustus William, F.S.A. Ewell Castle, Surrey.
1857. ‡GAGES, ALPHONSE, M.R.I.A. Museum of Irish Industry, Dublin.

Year of Election.

1863. **Gainsford, W. D.* *Aswardby Hall, Spilsby.*
1876. ‡Gairdner, Charles. Broom, Newton Mearns, Renfrewshire.
1850. ‡Gairdner, Professor W. T., M.D. 225 St. Vincent-street, Glasgow.
1861. ‡Galbraith, Andrew. Glasgow.
GALBRAITH, Rev. J. A., M.A., M.R.I.A. Trinity College, Dublin.
1876. ‡Gale, James M. 23 Miller-street, Glasgow.
1863. ‡Gale, Samuel, F.C.S. 225 Oxford-street, London, W.
1885. *Gallaway, Alexander. Tighnault, Aberfeldy, N.B.
1861. ‡Galloway, Charles John. Knott Mill Iron Works, Manchester.
1861. ‡Galloway, John, jun. Knott Mill Iron Works, Manchester.
1875. ‡GALLOWAY, W. Cardiff.
1860. *GALTON, Captain DOUGLAS, C.B., D.C.L., LL.D., F.R.S., F.L.S., F.G.S., F.R.G.S. (GENERAL SECRETARY.) 12 Chester-street, Grosvenor-place, London, S.W.
1860. *GALTON, FRANCIS, M.A., F.R.S., F.G.S., F.R.G.S. 42 Rutland-gate, Knightsbridge, London, S.W.
1869. ‡GALTON, JOHN C., M.A., F.L.S. 40 Great Marlborough-street, London, W.
1870. §Gamble, Lieut.-Colonel D. St. Helen's, Lancashire.
1870. ‡Gamble, J. C. St. Helen's, Lancashire.
1872. *Gamble, John G., M.A. Capetown. (Care of Messrs. Ollivier and Brown, 37 Sackville-street, Piccadilly, London, W.)
1877. ‡Gamble, William. St. Helen's, Lancashire.
1868. ‡GAMGEE, ARTHUR, M.D., F.R.S., Fullerian Professor of Physiology in the Royal Institution, London. 11 Warrior-square, St. Leonard's-on-Sea.
1883. ‡Gant, Major John Castle. St. Leonard's.
1882. *Gardner, H. Dent, F.R.G.S. 25 Northbrook-road, Lee, Kent.
1882. ‡Gardner, John Starkie, F.G.S. 7 Damer-terrace, Chelsea, London, S.W.
1884. ‡Garman, Samuel. Cambridge, Massachusetts, U.S.A.
1862. ‡GARNER, ROBERT, F.L.S. Stoke-upon-Trent.
1865. ‡Garner, Mrs. Robert. Stoke-upon-Trent.
1882. ‡Garnett, William, D.C.L., Principal of the College of Physical Science, Newcastle-on-Tyne.
1873. ‡Garnham, John. Hazelwood, Crescent-road, St. John's, Brockley, Kent, S.E.
1883. §Garson, J. G., M.D. Royal College of Surgeons, Lincoln's-Inn-fields, London, W.C.
1874. *Garstin, John Ribton, M.A., LL.B., M.R.I.A., F.S.A. Braganstown, Castlebellingham, Ireland.
1882. ‡Garton, William. Woolston, Southampton.
1870. ‡Gaskell, Holbrook. Woolton Wood, Liverpool.
1870. *Gaskell, Holbrook, jun. Clayton Lodge, Aigburth, Liverpool.
1847. *Gaskell, Samuel. Church House, Weybridge.
1842. Gaskell, Rev. William, M.A. Plymouth-grove, Manchester.
1862. *Gatty, Charles Henry, M.A., F.L.S., F.G.S. Felbridge Place, East Grinstead, Sussex.
1875. ‡Gavey, J. 43 Stacey-road, Routh, Cardiff.
1875. ‡Gaye, Henry S., M.D. Newton Abbot, Devon.
1871. ‡Geddes, John. 9 Melville-crescent, Edinburgh.
1883. §Geddes, John. 33 Portland-street, Southport.
1885. §Geddes, Patrick. 6 James-court, Edinburgh.
1859. ‡Geddes, William D., M.A., Professor of Greek in King's College, Old Aberdeen.
1854. ‡Gee, Robert, M.D. 5 Abercromby-square, Liverpool.

Year of
Election.

1867. ‡GEIKIE, ARCHIBALD, LL.D., F.R.S. L. & E., F.G.S., Director-General of the Geological Survey of the United Kingdom. Geological Survey Office, Jermyn-street, London, S.W.
1871. ‡Geikie, James, LL.D., F.R.S. L. & E., F.G.S., Murchison Professor of Geology and Mineralogy in the University of Edinburgh. 10 Bright's-crescent, Mayfield, Edinburgh.
1883. ‡Gell, Mrs. Seedley Lodge, Pendleton, Manchester.
1882. §Genese, R. W., M.A., Professor of Mathematics in University College, Aberystwith.
1875. *George, Rev. Hereford B., M.A., F.R.G.S. New College, Oxford.
1885. ‡Gerard, Robert. Blair-Devenick, Cults, Aberdeen.
1884. *Gerrans, Henry T., B.A. Worcester College, Oxford.
1870. ‡*Gerstl, R., F.C.S. University College, London, W.C.*
1870. *Gervis, Walter S., M.D., F.G.S. Ashburton, Devonshire.
1884. ‡Gibb, Charles. Abbotsford, Quebec, Canada.
1865. ‡Gibbins, William. Battery Works, Digbeth, Birmingham.
1874. ‡Gibson, The Right Hon. Edward, Q.C. 23 Fitzwilliam-square, Dublin.
1876. *Gibson, George Alexander, M.D., D.Sc., F.R.S.E. 17 Alva-street, Edinburgh.
1884. ‡Gibson, Rev. James J. 183 Spadina-avenue, Toronto, Canada.
1885. §Gibson, John, Ph.D. The University, Edinburgh.
1870. ‡*Gibson, Thomas. 51 Oxford-street, Liverpool.*
1870. ‡*Gibson, Thomas, jun. 10 Parkfield-road, Prince's Park, Liverpool.*
1884. ‡Gilbert, E. E. 245 St. Antoine-street, Montreal, Canada.
1842. GILBERT, JOSEPH HENRY, Ph.D., LL.D., F.R.S., F.C.S., Professor of Rural Economy in the University of Oxford. Harpenden, near St. Albans.
1883. §Gilbert, Mrs. Harpenden, near St. Albans.
1857. ‡Gilbert, J. T., M.R.I.A. Villa Nova, Blackrock, Dublin.
1884. *Gilbert, Philip H. 245 St. Antoine-street, Montreal, Canada.
1883. ‡Gilbert, Thomas. Derby-road, Southport.
Gilderdale, Rev. John, M.A. Walthamstow, Essex.
1882. ‡Giles, Alfred, M.P., M.I.C.E. Cosford, Godalming.
1878. ‡Giles, Oliver. Park Side, Cromwell-road, St. Andrew's, Bristol.
Giles, Rev. William. Netherleigh House, near Chester.
1878. ‡Gill, Rev. A. W. H. 44 Eaton-square, London, S.W.
1871. *GILL, DAVID, LL.D., F.R.S. Royal Observatory, Cape Town.
1868. ‡Gill, Joseph. Palermo, Sicily. (Care of W. H. Gill, Esq., General Post Office, St. Martin's-le-Grand, E.C.)
1864. ‡GILL, THOMAS. 4 Sydney-place, Bath.
1884. ‡Gillman, Henry. 79 East Columbia-street, Detroit, Michigan, U.S.A.
1861. *Gilroy, George. Woodlands, Parbold, near Wigan.
1867. ‡Gilroy, Robert. Craigie, by Dundee.
1867. §GINSBURG, Rev. C. D., D.C.L., LL.D. Holmlea, Virginia Water Station, Chertsey.
1884. ‡Girdwood, Dr. G. P. 28 Beaver Hall-terrace, Montreal, Canada.
1874. *Girdwood, James Kennedy. Old Park, Belfast.
1884. ‡Gisborne, Frederick Newton. Ottawa, Canada.
1886. *Gisborne, Hartley. Battleford, Saskatchewan District, Canada.
1883. *Gladstone, Miss. 17 Pembridge-square, London, W.
1883. *Gladstone, Miss E. A. 17 Pembridge-square, London, W.
1850. *Gladstone, George, F.C.S., F.R.G.S. 31 Ventnor-villas, Brighton.
1883. *Gladstone, Miss Isabella M. 17 Pembridge-square, London, W.
1849. *GLADSTONE, JOHN HALL, Ph.D., F.R.S., F.C.S. 17 Pembridge-square, London, W.

Year of
Election.

1861. *GLAISHER, JAMES, F.R.S., F.R.A.S. 1 Dartmouth-place, Blackheath, London, S.E.
1871. *GLAISHER, J. W. L., M.A., F.R.S., Pres.R.A.S. Trinity College, Cambridge.
1883. ‡Glasson, L. T. 2 Roper-street, Penrith.
1881. *GLAZEBROOK, R. T., M.A., F.R.S. Trinity College, Cambridge.
1881. *Gleadow, Frederic. Brunswick House, Beverley-road, Hull.
1870. §Glen, David Corse, F.G.S. 14 Annfield-place, Glasgow.
1867. ‡Gloag, John A. L. 10 Inverleith-place, Edinburgh.
Glover, George. Ranelagh-road, Pimlico, London, S.W.
1874. ‡Glover, George T. 30 Donegall-place, Belfast.
Glover, Thomas. 124 Manchester-road, Southport.
1870. ‡Glynn, Thomas R. 1 Rodney-street, Liverpool.
1872. ‡GODDARD, RICHARD. 16 Booth-street, Bradford, Yorkshire.
1886. §Godlee, Arthur. 3 Greenfield-crescent, Edgbaston, Birmingham.
1878. *Godlee, J. Lister. 3 New-square, Lincoln's Inn, London, W.C.
1880. ‡GODMAN, F. DU CANE, F.R.S., F.L.S., F.G.S. 10 Chandos-street, Cavendish-square, London, W.
1883. ‡Godson, Dr. Alfred. Cheadle, Cheshire.
1852. ‡Godwin, John. Wood House, Rostrevor, Belfast.
1879. ‡GODWIN-AUSTEN, Lieut.-Colonel H. H., F.R.S., F.R.G.S., F.Z.S. Shalford House, Guildford.
1876. ‡Goff, Bruce, M.D. Bothwell, Lanarkshire.
1877. ‡*Goff, James. 11 Northumberland-road, Dublin.*
1886. §GOLDSMID, Major-General Sir F. J., C.B., K.C.S.I., F.R.G.S. 3 Observatory-avenue, London, W.
1881. ‡Goldschmidt, Edward. Nottingham.
1873. ‡Goldthorp, Miss R. F. C. Cleckheaton, Bradford, Yorkshire.
1884. ‡Good, Charles E. 102 St. François Xavier-street, Montreal, Canada.
1878. ‡Good, Rev. Thomas, B.D. 51 Wellington-road, Dublin.
1852. ‡Goodbody, Jonathan. Clare, King's County, Ireland.
1884. ‡Goodbody, Robert. Fairy Hill, Blackrock, Co. Dublin.
1886. §Goodman, F. B. 46 Wheeley's-road, Edgbaston, Birmingham.
1842. *GOODMAN, JOHN, M.D. 8 Leicester-street, Southport.
1885. §GOODMAN, J. D., J.P. Peachfield, Edgbaston, Birmingham.
1865. ‡Goodman, J. D. Minories, Birmingham.
1869. ‡Goodman, Neville, M.A. Peterhouse, Cambridge.
1884. §Goodridge, Richard E. W. Box No. 382, Post Office, Winnipeg, Canada.
1870. *Goodwin, Rev. Henry Albert, M.A., F.R.A.S. Lambourne Rectory, Romford.
1884. ‡Goodwin, Professor W. L. Kingston, Ontario, Canada.
1883. ‡Goouch, B., B.A. 2 Oxford-road, Birkdale, Southport.
1885. ‡Gordon, General the Hon. Sir Alexander Hamilton. 50 Queen's Gate-gardens, London, S.W.
1885. §Gordon, Rev. Cosmo, D.D., F.R.A.S., F.G.S. Chetwynd Rectory, Newport, Salop.
1885. ‡Gordon, Rev. George, LL.D. Birnie, by Elgin, N.B.
1871. *Gordon, Joseph Gordon, F.C.S. Queen Anne's Mansions, Westminster, S.W.
1884. **Gordon, Robert, M.Inst.C.E., F.R.G.S. Hawley Lodge, Maida Hill West, London, W.*
1857. ‡Gordon, Samuel, M.D. 11 Hume-street, Dublin.
1885. §Gordon, Rev. William. Braemar, N.B.
1865. ‡Gore, George, LL.D., F.R.S. 50 Islington-row, Edgbaston, Birmingham.
1875. *Gotch, Francis, B.A., B.Sc. Holywell Cottage, Oxford.

Year of Election.

*Gotch, Rev. Frederick William, LL.D. Stokes Croft, Bristol.
*Gotch, Thomas Henry. Kettering.
1873. §Gott, Charles, M.Inst.C.E. Parkfield-road, Manningham, Bradford, Yorkshire.
1849. ‡Gough, The Hon. Frederick. Perry Hall, Birmingham.
1857. ‡Gough, The Right Hon. George S., Viscount, M.A., F.L.S., F.G.S. St. Helen's, Booterstown, Dublin.
1881. ‡Gough, Thomas, B.Sc., F.C.S. Elmfield College, York.
1868. ‡Gould, Rev. George. Unthank-road, Norwich.
1873. ‡Gourlay, J. McMillan. 21 St. Andrew's-place, Bradford, Yorkshire.
1867. ‡Gourley, Henry (Engineer). Dundee.
1876. ‡Gow, Robert. Cairndowan, Dowanhill, Glasgow.
1883. §Gow, Mrs. Cairndowan, Dowanhill, Glasgow.
Gowland, James. London-wall, London, E.C.
1873. §Goyder, Dr. D. Marley House, 88 Great Horton-road, Bradford, Yorkshire.
1886. §Grabham, Michael C., M.D. Madeira.
1861. ‡Grafton, Frederick W. Park-road, Whalley Range, Manchester.
1867. *GRAHAM, CYRIL, C.M.G., F.L.S., F.R.G.S. Travellers' Club, Pall Mall, London, S.W.
1875. ‡GRAHAME, JAMES. 12 St. Vincent-street, Glasgow.
1852. *GRAINGER, Rev. Canon JOHN, D.D., M.R.I.A. Skerry and Rathcavan Rectory, Broughshane, near Ballymena, Co. Antrim.
1870. ‡GRANT, Colonel JAMES A., C.B., C.S.I., F.R.S., F.L.S., F.R.G.S. 19 Upper Grosvenor-street, London, W.
1855. *GRANT, ROBERT, M.A., LL.D., F.R.S., F.R.A.S., Regius Professor of Astronomy in the University of Glasgow. The Observatory, Glasgow.
1854. ‡GRANTHAM, RICHARD B., M.Inst.C.E., F.G.S. Northumberland-chambers, Northumberland-avenue, London, W.C.
1864. ‡Grantham, Richard F. Northumberland-chambers, Northumberland-avenue, London, W.C.
1881. ‡Graves, E. 22 Trebovir-road, Earl's Court-road, London, S.W.
1874. ‡Graves, Rev. James, B.A., M.R.I.A. Inisnag Glebe, Stonyford, Co. Kilkenny.
1881. ‡Gray, Alan, LL.B. Minster-yard, York.
1870. ‡*Gray, C. B. 5 Rumford-place, Liverpool.*
1864. *Gray, Rev. Charles. The Vicarage, Blyth, Worksop.
1865. ‡Gray, Charles. Swan-bank, Bilston.
1876. ‡Gray, Dr. Newton-terrace, Glasgow.
1881. ‡Gray, Edwin, LL.B. Minster-yard, York.
1864. ‡*Gray, Jonathan. Summerhill House, Bath.*
1859. ‡Gray, Rev. J. H. Bolsover Castle, Derbyshire.
1886. §Gray, Robert Kaye. Lessness Park, Abbey Wood, Kent.
1881. ‡*Gray, Thomas. 21 Haybrom-crescent, Glasgow.*
1883. ‡Gray, Thomas. Spittal Hill, Morpeth.
1873. ‡Gray, William, M.R.I.A. 6 Mount Charles, Belfast.
*GRAY, Colonel WILLIAM. Farley Hall, near Reading.
1883. ‡Gray, William Lewis. 36 Gutter-lane, London, E.C.
1883. ‡Gray, Mrs. W. L. 36 Gutter-lane, London, E.C.
1886. §Greaney, Rev. William. Bishop's House, Bath-street, Birmingham.
1883. §Greathead, J. H. 8 Victoria-chambers, London, S.W.
1866. §Greaves, Charles Augustus, M.B., LL.B. 101 Friar-gate, Derby.
1869. ‡Greaves, William. Station-street, Nottingham.
1872. ‡Greaves, William. 3 South-square, Gray's Inn, London, W.C.
1872. *Grece, Clair J., LL.D. Redhill, Surrey.
1879. ‡Green, A. F. 15 Ashwood-villas, Headingley, Leeds.

Year of Election.

1886. §Green, John M. 43 Waterloo-street, Birmingham.
1858. *Greenhalgh, Thomas. Thornydikes, Sharples, near Bolton-le-Moors.
1882. ‡GREENHILL, A. G., M.A., Professor of Mathematics at the Royal Artillery Institution, Woolwich. Emmanuel College, Cambridge.
1881. §Greenhough, Edward. Matlock Bath, Derbyshire.
1884. ‡Greenish, Thomas, F.C.S. 20 New-street, Dorset-square, London, N.W.
1884. ‡Greenshields, E. B. Montreal, Canada.
1884. ‡Greenshields, Samuel. Montreal, Canada.
1863. ‡Greenwell, G. E. Poynton, Cheshire.
1875. ‡Greenwood, Frederick. School of Medicine, Leeds.
1862. *Greenwood, Henry. 32 Castle-street, and the Woodlands, Anfield-road, Anfield, Liverpool.
1877. ‡Greenwood, Holmes. 78 King-street, Accrington.
1883. ‡GREENWOOD, J. G., LL.D., Vice-Chancellor of Victoria University. Owens College, Manchester.
1849. ‡Greenwood, William. Stones, Todmorden.
1861. *GREG, ROBERT PHILIPS, F.G.S., F.R.A.S. Coles Park, Buntingford, Herts.
1833. Gregg, T. H. 22 Ironmonger-lane, Cheapside, London, E.C.
1860. ‡GREGOR, Rev. WALTER, M.A. Pitsligo, Rosehearty, Aberdeenshire.
1868. ‡Gregory, Sir Charles Hutton, K.C.M.G., M.Inst.C.E. 2 Delahay-street, Westminster, S.W.
1883. ‡Gregson, Edward, Ribble View, Preston.
1883. ‡Gregson, G. E. Ribble View, Preston.
1861. *Gregson, Samuel Leigh. Aigburth-road, Liverpool.
1881. §Gregson, William. Baldersby, Thirsk.
1875. ‡Grenfell, J. Granville, B.A., F.G.S. 5 Albert-villas, Clifton, Bristol.
1875. ‡Grey, Mrs. Maria G. 18 Cadogan-place, London, S.W.
1871. *Grierson, Samuel, Medical Superintendent of the District Asylum, Melrose, N.B.
1859. ‡GRIERSON, THOMAS BOYLE, M.D. Thornhill, Dumfriesshire.
1875. ‡Grieve, David, F.R.S.E., F.G.S. Lockharton-gardens, Slateford, Edinburgh.
1878. ‡Griffin, Robert, M.A., LL.D. Trinity College, Dublin.
1859. *GRIFFITH, GEORGE, M.A., F.C.S. Harrow.
1870. ‡Griffith, Rev. Henry, F.G.S. Barnet, Herts.
1884. §Griffiths, E. H. 12 Park-side, Cambridge.
1884. ‡Griffiths, Mrs. 12 Park-side, Cambridge.
1847. §Griffiths, Thomas. Bradford-street, Birmingham.
1879. §Griffiths, Thomas, F.C.S., F.S.S. Heidelberg House, King's-road, Clapham Park, London, S.W.
1875. ‡Grignon, James, H.M. Consul at Riga. Riga.
1870. ‡Grimsdale, T. F., M.D. 29 Rodney-street, Liverpool.
1884. ‡Grinnell, Frederick. Providence, Rhode Island, U.S.A.
1881. ‡Gripper, Edward. Nottingham.
1864. ‡GROOM-NAPIER, CHARLES OTTLEY. 18 Elgin-road, St. Peter's Park, London, N.W.
GROVE, The Hon. Sir WILLIAM ROBERT, Knt., M.A., D.C.L., LL.D., F.R.S. 115 Harley-street, London, W.
1863. *GROVES, THOMAS B., F.C.S. 80 St. Mary-street, Weymouth.
1869. ‡GRUBB, HOWARD, F.R.S., F.R.A.S. 141 Leinster-road, Rathmines, Dublin.
1886. §Grundy, John. Park Drive, Nottingham.
1867. ‡Guild, John. Bayfield, West Ferry, Dundee.
Guinness, Henry. 17 College-green, Dublin.

Year of
Election.

1842. Guinness, Richard Seymour. 17 College-green, Dublin.
1856. *GUISE, Lieut.-Colonel Sir WILLIAM VERNON, Bart., F.G.S., F.L.S. Elmore Court, near Gloucester.
1862. ‡Gunn, John, M.A., F.G.S. 82 Prince of Wales-road, Norwich.
1885. ‡Gunn, John. Dale, Halkirk, Caithness.
1877. ‡Gunn, William, F.G.S. Office of the Geological Survey of Scotland, Sheriff's Court House, Edinburgh.
1866. ‡GÜNTHER, ALBERT C. L. G., M.A., M.D., Ph.D., F.R.S., Keeper of the Zoological Collections in the British Museum. British Museum, South Kensington, London, S.W.
1880. §Guppy, John J. Ivy-place, High-street, Swansea
1868. *Gurney, John. Sprouston Hall, Norwich.
1876. ‡Guthrie, Francis. Cape Town, Cape of Good Hope.
1883. ‡Guthrie, Malcolm. 2 Parkfield-road, Liverpool.
1857. ‡Gwynne, Rev. John. Tullyagnish, Letterkenny, Strabane, Ireland.
1876. ‡GWYTHER, R. F., M.A. Owens College, Manchester.

1884. ‡Haanel, E., Ph.D. Cobourg, Ontario, Canada.
1886. §Haast, Sir Julius von, K.C.M.G., Ph.D., D.Sc., F.R.S., F.G.S., Director of the Canterbury Museum. New Zealand University, Christchurch, New Zealand.
1865. ‡Hackney, William. 9 Victoria-chambers, Victoria-street, London, S.W.
1884. ‡Hadden, Captain C. F., R.A. Woolwich.
1881. *HADDON, ALFRED CORT, B.A., F.Z.S., Professor of Zoology in the Royal College of Science, Dublin.
Haden, G. N. Trowbridge, Wiltshire.
1842. Hadfield, George. Victoria-park, Manchester.
1870. ‡*Hadivan, Isaac. 3 Huskisson-street, Liverpool.*
1848. ‡Hadland, William Jenkins. Banbury, Oxfordshire.
1870. ‡Haigh, George. Waterloo, Liverpool.
*Hailstone, Edward, F.S.A. Walton Hall, Wakefield, Yorkshire.
1879. ‡HAKE, H. WILSON, Ph.D., F.C.S. Queenwood College, Hants.
1875. ‡Hale, Rev. Edward, M.A., F.G.S., F.R.G.S. Eton College, Windsor.
1883. ‡Haliburton, Robert Grant. National Club, Whitehall, London, S.W.
1872. ‡Hall, Dr. Alfred. 8 Mount Ephraim, Tunbridge Wells.
1879. *Hall, Ebenezer. Abbeydale Park, near Sheffield.
1883. **Hall, Miss Emily. Bowdon, Cheshire.*
1881. ‡Hall, Frederick Thomas, F.R.A.S. 15 Gray's Inn-square, London, W.C.
1854. *HALL, HUGH FERGIE, F.G.S. Greenheys, Wallasey, Birkenhead.
1872. *Hall, Captain Marshall, F.G.S. St. John's, Bovey Tracey, South Devon.
1885. §Hall, Samuel. 19 Aberdeen Park, Highbury, London, N.
*Hall, Thomas B. Australia. (Care of J. P. Hall, Esq., Crane House, Great Yarmouth.)
1884. ‡Hall, Thomas Proctor. School of Practical Science, Toronto, Canada.
1866. *HALL, TOWNSHEND M., F.G.S. Pilton, Barnstaple.
1860. ‡Hall, Walter. 11 Pier-road, Erith.
1883. *Hall, Miss Wilhelmina. The Gore, Eastbourne.
1873. *HALLETT, T. G. P., M.A. Claverton Lodge, Bath.
1868. *HALLETT, WILLIAM HENRY, F.L.S. Buckingham House, Marine Parade, Brighton.
Halsall, Edward. 4 Somerset-street, Kingsdown, Bristol.
886. §Hambleton, G. W. 70 Upper Gloucester-place, London, N.W.

Year of Election.

1858. *Hambly, Charles Hambly Burbridge, F.G.S. Holmeside, Hazelwood, Derby.

1883. *Hamel, Egbert D. de. Bole Hall, Tamworth.

1885. ‡Hamilton, David James. 1A Albyn-place, Aberdeen.

1869. ‡Hamilton, Rowland. Oriental Club, Hanover-square, London, W.

1851. ‡Hammond, C. C. Lower Brook-street, Ipswich.

1881. *Hammond, Robert. Hilldrop, Highgate, London, N.

1878. ‡Hanagan, Anthony. Luckington, Dalkey.

1878. §Hance, Edward M., LL.B. 6 Sea Bank-avenue, Egremont, Cheshire.

1875. ‡Hancock, C. F., M.A. 125 Queen's-gate, London, S.W.

1863. ‡Hancock, John. 4 St. Mary's-terrace, Newcastle-on-Tyne.

1850. ‡Hancock, John, J.P. The Manor House, Lurgan, Co. Armagh.

1861. ‡Hancock, Walter. 10 Upper Chadwell-street, Pentonville, London, N.

1857. ‡Hancock, William J. 23 Synnot-place, Dublin.

1847. ‡HANCOCK, W. NEILSON, LL.D., M.R.I.A. 64 Upper Gardiner-street, Dublin.

1876. ‡Hancock, Mrs. W. Neilson. 64 Upper Gardiner-street, Dublin.

1865. ‡*Hands, M. Coventry.*

1882. ‡Hankinson, R. C. Bassett, Southampton.

1884. ‡Hannaford, E. C. 1591 Catherine-street, Montreal, Canada.

1859. ‡Hannay, John. Montcoffer House, Aberdeen.

1853. ‡*Hansell, Thomas T. 2 Charlotte-street, Sculcoates, Hull.*

1886. §Hansford, Charles. 3 Alexandra-terrace, Dorchester.

*HARCOURT, A. G. VERNON, M.A., LL.D., F.R.S., F.C.S. (GENERAL SECRETARY.) Cowley Grange, Oxford.

1886. *Hardcastle, Basil W., F.S.S. Beechenden, Hampstead, London, N.W.

1884. *Hardcastle, Norman C., M.A., LL.M. Downing College, Cambridge.

1865. ‡Harding, Charles. Harborne Heath, Birmingham.

1869. ‡Harding, Joseph. Millbrooke House, Exeter.

1877. ‡Harding, Stephen. Bower Ashton, Clifton, Bristol.

1869. ‡Harding, William D. Islington Lodge, King's Lynn, Norfolk.

1874. ‡Hardman, E. T., F.C.S. 14 Hume-street, Dublin.

1886. §Hardman, John B. St. John's, Hunter's-lane, Birmingham.

1872. ‡*Hardwicke, Mrs. 192 Piccadilly, London, W.*

1880. ‡Hardy, John. 118 Embden-street, Manchester.

1838. *HARE, CHARLES JOHN, M.D. Berkeley House, 15 Manchester-square, London, W.

1858. ‡Hargrave, James. Burley, near Leeds.

1883. ‡Hargreaves, Miss H. M. 69 Alexandra-road, Southport.

1883. ‡Hargreaves, Thomas. 69 Alexandra-road, Southport.

1881. ‡Hargrove, William Wallace. St. Mary's, Bootham, York.

1876. ‡Harker, Allen, F.L.S., Professor of Natural History in the Royal Agricultural College, Cirencester.

1878. *Harkness, H. W. California Academy of Sciences, San Francisco, California, U.S.A.

1871. ‡Harkness, William, F.C.S. Laboratory, Somerset House, London, W.C.

1875. *Harland, Rev. Albert Augustus, M.A., F.G.S., F.L.S., F.S.A. The Vicarage, Harefield, Middlesex.

1877. *Harland, Henry Seaton. Stanbridge, Staplefield, Crawley, Sussex.

1883. *Harley, Miss Clara. 4 Wellington-square, Oxford.

1862. *HARLEY, GEORGE, M.D., F.R.S., F.C.S. 25 Harley-street, London, W.

1883. *Harley, Harold. 14 Chapel-street, Bedford-row, London, W.C.

1862. *HARLEY, Rev. ROBERT, F.R.S., F.R.A.S. 4 Wellington-square, Oxford.

Year of
Election.

1868. *HARMER, F. W., F.G.S. Oakland House, Cringleford, Norwich.
1881. *HARMER, SIDNEY F., B.Sc. King's College, Cambridge.
1882. ‡Harper, G. T. Bryn Hyfrydd, Portswood, Southampton.
1872. ‡Harpley, Rev. William, M.A. Clayhanger Rectory, Tiverton.
1884. ‡Harrington, B. J., B.A., Ph.D., Professor of Chemistry and Mineralogy in McGill University, Montreal. Wallbrac-place, Montreal, Canada.
1872. *Harris, Alfred. Lunefield, Kirkby-Lonsdale, Westmoreland.
1883. §Harris, Charles, F.R.G.S. Derwent Villa, Whalley Range, Manchester.
1871. ‡HARRIS, GEORGE, F.S.A. Iselipps Manor, Northolt, Southall, Middlesex.
1842. *Harris, G. W., M.Inst.C.E. Mount Gambier, South Australia.
1884. §Harris, Miss Katherine E. 75 Linden-gardens, Bayswater, London, W.
1860. ‡*Harrison, Rev. Francis, M.A. Oriel College, Oxford.*
1885. ‡Harrison, Sir George. 7 Whitehouse-terrace, Edinburgh.
1864. ‡Harrison, George. Barnsley, Yorkshire.
1873. ‡*Harrison, George, Ph.D., F.L.S., F.C.S.* 96, *Northgate, Huddersfield.*
1874. ‡Harrison, G. D. B. 3 Beaufort-road, Clifton, Bristol.
1858. *HARRISON, JAMES PARK, M.A. 22 Connaught-street, Hyde Park, London, W.
1870. ‡HARRISON, REGINALD. 51 Rodney-street, Liverpool.
1853. ‡Harrison, Robert. 36 George-street, Hull.
1883. ‡Harrison, Thomas. 34 Ash-street, Southport.
1863. ‡Harrison, T. E. Engineers' Office, Central Station, Newcastle-on-Tyne.
1886. §Harrison, William. The Horsehills, Wolverhampton.
1886. §Harrison, W. Jerome, F.G.S. 365 Lodge-road, Hockley, Birmingham.
1854. ‡Harrowby, The Right Hon. the Earl of. 39 Grosvenor-square, London, W.; and Sandon Hall, Lichfield.
1885. §HART, CHARLES J. 28 George-road, Edgbaston, Birmingham.
1876. *Hart, Thomas. Brooklands, Blackburn.
1881. §Hart, Thomas, F.G.S. Yewbarrow, Grange-over-Sands, Carnforth.
1875. ‡Hart, W. E. Kilderry, near Londonderry.
Hartley, James. Sunderland.
1871. ‡HARTLEY, WALTER NOEL, F.R.S. L. & E., F.C.S., Professor of Chemistry in the Royal College of Science, Dublin.
1886. §HARTOG, Professor M. M., D.Sc. Queen's College, Cork.
1870. ‡Harvey, Enoch. Riversdale-road, Aigburth, Liverpool.
Harvey, J. R., M.D. St. Patrick's-place, Cork.
1885. ‡Harvey, Surgeon Major Robert, M.D. Calcutta.
1885. ‡Harvie-Brown, J. A. Dunipace, Larbert, N.B.
1862. *Harwood, John, jun. Woodside Mills, Bolton-le-Moors.
1884. ‡Haslam, Rev. George, M.A. Trinity College, Toronto, Canada.
1882. ‡Haslam, George James, M.D. Owens College, Manchester.
1875. ‡HASTINGS, G. W., M.P. Barnard's Green House, Malvern.
1886. §Hatherton, The Right Hon. Lord, C.B. Haws Hall, Birmingham.
1857. ‡HAUGHTON, Rev. SAMUEL, M.A., M.D., D.C.L., LL.D., F.R.S., M.R.I.A., F.G.S., Senior Fellow of Trinity College, Dublin. Dublin.
1874. ‡Hawkins, B. Waterhouse, F.G.S. Century Club, East Fifteenth-street, New York, U.S.A.
1872. *Hawkshaw, Henry Paul. 58 Jermyn-street, St. James's, London, S.W.

Year of
Election.

*HAWKSHAW, Sir JOHN, M.Inst.C.E., F.R.S., F.G.S., F.R.G.S. Hollycombe, Liphook, Petersfield; and 33 Great George-street, London, S.W.
1864. *HAWKSHAW, JOHN CLARKE, M.A., M.Inst.C.E., F.G.S. 50 Harrington-gardens, South Kensington, S.W.; and 33 Great George-street London, S.W.
1868. ‡HAWKSLEY, THOMAS, M.Inst.C.E., F.R.S., F.G.S. 30 Great George-street, London, S.W.
1884. *Haworth, Abraham. Hilston House, Altrincham.
1886. §Haworth, Rev. T. J. Albert Cottage, Saltley, Birmingham.
1863. ‡Hawthorn, William. The Cottage, Benwell, Newcastle-upon-Tyne.
1859. ‡Hay, Sir Andrew Leith, Bart. Rannes, Aberdeenshire.
1877. ‡Hay, Arthur J. Lerwick, Shetland.
1861. *HAY, Admiral the Right Hon. Sir JOHN C. D., Bart., K.C.B., D.C.L., F.R.S. 108 St. George's-square, London, S.W.
1858. ‡Hay, Samuel. Albion-place, Leeds.
1867. ‡Hay, William. 21 Magdalen-yard-road, Dundee.
1885. *Haycraft, John Berry, M.B., B.Sc., F.R.S.E., Professor of Physiology in Mason Science College, Birmingham.
1873. *Hayes, Rev. William A., M.A. Dromore, Co. Down, Ireland.
1869. ‡Hayward, J. High-street, Exeter.
1858. *HAYWARD, ROBERT BALDWIN, M.A., F.R.S. The Park, Harrow.
1879. *Hazlehurst, George S. Rhyl, North Wales.
1851. §HEAD, JEREMIAH, M.Inst.C.E., F.C.S. Middlesbrough, Yorkshire.
1869. ‡Head, R. T. The Briars, Alphington, Exeter.
1883. ‡Headley, Frederick Halcombe. Manor House, Petersham, S.W.
1883. ‡Headley, Mrs. Marian. Manor House, Petersham, S.W.
1883. §Headley, Rev. Tanfield George. Manor House, Petersham, S.W.
1871. §Healey, George. Brantfield, Bowness, Windermere.
1883. *Heap, Ralph, jun. 1 Brick-court, Temple, London, E.C.
1861. *Heape, Benjamin. Northwood, Prestwich, near Manchester.
1883. ‡*Heape, Charles.* 14 *Hawkshead-street, Southport.*
1883. ‡Heape, Joseph R. 96 Mereland-terrace, Rochdale.
1882. *Heape, Walter. Royal Western Yacht Club, Plymouth.
1877. ‡Hearder, Henry Pollington. Westwell-street, Plymouth.
1865. ‡Hearder, William. Rocombe, Torquay.
1877. ‡Hearder, William Keep, F.S.A. 195 Union-street, Plymouth.
1883. ‡Heath, Dr. 46 Hoghton-street, Southport.
1866. ‡Heath, Rev. D. J. Esher, Surrey.
1863. ‡Heath, G. Y., M.D. Westgate-street, Newcastle-on-Tyne.
1884. ‡Heath, Thomas, B.A. Royal Observatory, Calton Hill, Edinburgh.
1861. ‡HEATHFIELD, W. E., F.C.S., F.R.G.S., F.R.S.E. 1 Powis-grove, Brighton; and Arthur's Club, St. James's, London, S.W.
1883. ‡Heaton, Charles. Marlborough House, Hesketh Park, Southport.
1886. §Heaton, C. W. Tower House, Belvedere, Kent.
1886. §Heaton, Miss Ellen. Woodhouse-square, Leeds.
1865. ‡Heaton, Harry. Harborne House, Harborne, near Birmingham.
1884. §Heaviside, Rev. George, B.A., F.R.G.S. The Hollies, Stoke Green, Coventry.
1833. ‡HEAVISIDE, Rev. Canon J. W. L., M.A. The Close, Norwich.
1855. ‡HECTOR, JAMES, M.D., F.R.S., F.G.S., F.R.G.S., Director of the Geological Survey of New Zealand. Wellington, New Zealand.
1867. ‡Heddle, M. Forster, M.D., F.R.S.E. St. Andrews, N.B.
1869. ‡Hedgeland, Rev. W. J. 21 Mount Radford, Exeter.
1882. ‡Hedger, Philip. Cumberland-place, Southampton.
1863. ‡Hedley, Thomas. Cox Lodge, near Newcastle-on-Tyne.

Year of Election.
1867. ‡Henderson, Alexander. Dundee.
1873. *Henderson, A. L. 49 King William-street, London, E.C.
1883. §Henderson, Mrs. A. L. 49 King William-street, London, E.C.
1880. *Henderson, Captain W. H., R.N. 21 Albert Hall Mansions, London, S.W.
1876. *Henderson, William. Williamfield, Irvine, N.B.
1885. ‡Henderson, William. Devanha House, Aberdeen.
1856. ‡HENNESSY, HENRY G., F.R.S., M.R.I.A., Professor of Applied Mathematics and Mechanics in the Royal College of Science for Ireland. Brookvale, Donnybrook, Co. Dublin.
1857. ‡Hennessy, Sir John Pope, K.C.M.G., Governor and Commander-in-Chief of Mauritius.
1873. *HENRICI, OLAUS M. F. E., Ph.D., F.R.S., Professor of Mechanics and Mathematics in the City and Guilds of London Institute. Central Institution, Exhibition-road, London, S.W.
Henry, Franklin. Portland-street, Manchester.
1873. Henry, J. Snowdon. East Dene, Bonchurch, Isle of Wight.
Henry, Mitchell, M.P. Stratheden House, Hyde Park, London, W.
*HENRY, WILLIAM CHARLES, M.D., F.R.S., F.G.S., F.R.G.S., F.C.S. Haffield, near Ledbury, Herefordshire.
1884. ‡Henshaw, George H. 43 Victoria-street, Montreal, Canada.
1870. ‡Henty, William. 12 Medina-villas, Brighton.
1855. *Hepburn, J. Gotch, LL.B., F.C.S. Dartford, Kent.
1855. ‡Hepburn, Robert. 9 Portland-place, London, W.
Hepburn, Thomas. Clapham, London, W.
1866. ‡Herrick, Perry. Bean Manor Park, Loughborough.
1871. *HERSCHEL, Professor ALEXANDER S., M.A., F.R.S., F.R.A.S. College of Science, Newcastle-on-Tyne.
1883. ‡Herschel, Miss F. Collingwood, Hawkhurst, Kent.
1874. §HERSCHEL, Lieut.-Colonel JOHN, R.E., F.R.S., F.R.A.S. Collingwood, Hawkhurst, Kent.
1883. ‡Hesketh, Colonel E. Fleetwood. Meol's Hall, Southport.
1865. ‡Heslop, Dr. Birmingham.
1884. §Hewett, George Edwin. The Leasowe, Cheltenham.
1883. §Hewson, Thomas. Care of J. C. C. Payne, Esq., Botanic-avenue, The Plains, Belfast.
1881. ‡Hey, Rev. William Croser, M.A. Clifton, York.
1882. ‡Heycock, Charles T., B.A. King's College, Cambridge.
1883. §Heyes, John Frederick, M.A., F.C.S., F.R.G.S. 12 Merton-street, Oxford; and 5 Rufford-road, Fairfield, Liverpool.
1866. *Heymann, Albert. West Bridgford, Nottinghamshire.
1866. ‡Heymann, L. West Bridgford, Nottinghamshire.
1879. ‡Heywood, A. Percival. Duffield Bank, Derby.
1861. *Heywood, Arthur Henry. Elleray, Windermere.
1886. §Heywood, Henry. Cardiff.
*HEYWOOD, JAMES, F.R.S., F.G.S., F.S.A., F.R.G.S., F.S.S. 26 Kensington Palace-gardens, London, W.
1861. *HEYWOOD, OLIVER. Claremont, Manchester.
Heywood, Thomas Percival. Claremont, Manchester.
1881. §Hick, Thomas, B.A., B.Sc. Owens College, Manchester.
1875. ‡HICKS, HENRY, M.D., F.R.S., F.G.S. Hendon Grove, Hendon, Middlesex, N.W.
1877. §HICKS, Professor W. M., M.A., F.R.S., Principal of Firth College, Sheffield. Endcliffe-crescent, Sheffield.
1884. ‡Hickson, Joseph. Montreal, Canada.
1864. *HIERN, W. P., M.A. Castle House, Barnstaple.
1861. *Higgin, James. Lancaster-avenue, Fennel-street, Manchester.

Year of Election

1875. ‡Higgins, Charles Hayes, M.D., M.R.C.P., F.R.C.S., F.R.S.E. Alfred House, Birkenhead.

1871. ‡HIGGINS, CLEMENT, B.A., F.C.S. 103 Holland-road, Kensington, London, W.

1854. HIGGINS, Rev. HENRY H., M.A. The Asylum, Rainhill, Liverpool.

Hildyard, Rev. James, B.D., F.C.P.S. Ingoldsby, near Grantham, Lincolnshire.

1885. *Hill, Alexander, M.A., M.B. Grantchester, near Cambridge.

Hill, Arthur. Bruce Castle, Tottenham, Middlesex.

1880. ‡Hill, Benjamin. Cwmdwr, near Clydach, Swansea.

1883. §Hill, Berkeley, M.B., Professor of Clinical Surgery in University College, London. 66 Wimpole-street, London, W.

1872. §Hill, Charles, F.S.A. Rockhurst, West Hoathley, East Grinstead.

1881. §HILL, Rev. EDWIN, M.A., F.G.S. St. John's College, Cambridge.

1884. ‡Hill, Rev. James Edgar, M.A., B.D. 1516 St. Catherine-street, Montreal, Canada.

1857. §Hill, John, C.E., M.R.I.A., F.R.G.S.I. County Surveyor's Office, Ennis, Ireland.

1871. ‡Hill, Lawrence. The Knowe, Greenock.

1886. §Hill, M. J. M. 16 Pembury-road, Lower Clapton, London, E.

1881. ‡Hill, Pearson. 50 Belsize Park, London, N.W.

1872. *Hill, Rev. Canon, M.A., F.G.S. Sheering Rectory, Harlow.

1885. *Hill, Sidney. Langford House, Langford, Bristol.

1876. ‡Hill, William H. Barlanark, Shettleston, N.B.

1885. *Hillhouse, William, M.A., Professor of Botany in Mason Science College, Birmingham. 95 Harborne-road, Edgbaston, Birmingham.

1886. §Hillier, Rev. E. J. Cardington Vicarage, Bedford.

1863. ‡Hills, F. C. Chemical Works, Deptford, Kent, S.E.

1871. *Hills, Thomas Hyde. 225 Oxford-street, London, W.

1858. ‡HINCKS, Rev. THOMAS, B.A., F.R.S. Stancliff House, Clevedon, Somerset.

1870. ‡HINDE, G. J., Ph.D., F.G.S. 11 Glebe-villas, Mitcham, Surrey.

1883. *Hindle, James Henry. 67 Avenue-parade, Accrington.

*Hindmarsh, Luke. Alnbank House, Alnwick.

1865. ‡Hinds, James, M.D. Queen's College, Birmingham.

1886. §Hingley, Benjamin, M.P. Hatherton Lodge, Cradley, Worcestershire.

1881. ‡Hingston, J. T. Clifton, York.

1884. ‡HINGSTON, WILLIAM HALES, M.D., D.C.L. 37 Union-avenue, Montreal, Canada.

1884. ‡Hirschfilder, C. A. Toronto, Canada.

1858. ‡Hirst, John, jun. Dobcross, near Manchester.

1861. *HIRST, T. ARCHER, Ph.D., F.R.S., F.R.A.S. 7 Oxford and Cambridge Mansions, Marylebone-road, London, N.W.

1870. ‡Hitchman, William, M.D., LL.D., F.L.S. 29 Erskine-street, Liverpool.

1884. ‡Hoadrey, John Chipman. Boston, Massachusetts, U.S A.

Hoare, J. Gurney. Hampstead, London, N.W.

1881. §Hobbes, Robert George. 285 Lavender-hill, London, S.W.

1864. ‡Hobhouse, Arthur Fane. 24 Cadogan-place, London, S.W.

1864. ‡Hobhouse, Charles Parry. 24 Cadogan-place, London, S.W.

1864. ‡Hobhouse, Henry William. 24 Cadogan-place, London, S.W.

1879. §Hobkirk, Charles P., F.L.S. West Riding Union Bank, Dewsbury

1883. ‡Hobson, Rev. E. W. 55 Albert-road, Southport.

1879. §Hobson, John. Tapton Elms, Sheffield.

1877. ‡Hockin, Edward. Poughill, Stratton, Cornwall.

Year of Election.

1883. ‡Hocking, Rev. Silas K. 21 Scarisbrick New-road, Southport.
1877. ‡Hodge, Rev. John Mackey, M.A. 38 Tavistock-place, Plymouth.
1876. ‡Hodges, Frederick W. Queen's College, Belfast.
1852. ‡Hodges, John F., M.D., F.C.S., Professor of Agriculture in Queen's College, Belfast.
1863. *HODGKIN, THOMAS. Benwell Dene, Newcastle-on-Tyne.
1880. ‡Hodgkinson, W. R. Eaton, Ph.D. Science Schools, South Kensington Museum, London, S.W.
1873. *Hodgson, George. Thornton-road, Bradford, Yorkshire.
1873. ‡Hodgson, James. Oakfield, Manningham, Bradford, Yorkshire.
1884. ‡Hodgson, Jonathan. Montreal, Canada.
1863. ‡Hodgson, Robert. Whitburn, Sunderland.
1863. ‡Hodgson, R. W. North Dene, Gateshead.
1865. *HOFMANN, AUGUST WILHELM, M.D., LL.D., Ph.D., F.R.S., F.C.S. 10 Dorotheen Strasse, Berlin.
1854. *Holcroft, George. Byron's-court, St. Mary's-gate, Manchester.
1883. ‡Holden, Edward. Laurel Mount, Shipley, Yorkshire.
1873. *Holden, Isaac, M.P. Oakworth House, near Keighley, Yorkshire.
1883. ‡Holden, James. 12 Park-avenue, Southport.
1883. ‡Holden, John J. 23 Duke-street, Southport.
1884. ‡Holden, Mrs. Mary E. Dunham Ladies' College, Quebec, Canada.
1879. ‡*Holland, Calvert Bernard. Ashdell, Broomhill, Sheffield.*
*Holland, Philip H. 3 Heath-rise, Willow-road, Hampstead, London, N.W.
1886. §Holliday, J. R. 101 Harborne-road, Birmingham.
1865. ‡Holliday, William. New-street, Birmingham.
1883. ‡Hollingsworth, Dr. T. S. Elford Lodge, Spring-grove, Isleworth, Middlesex.
1866. *Holmes, Charles. 59 London-road, Derby.
1873. ‡Holmes, J. R. Southbrook Lodge, Bradford, Yorkshire.
1882. *Holmes, Thomas Vincent, F.G.S. 28 Croom's-hill, Greenwich, S.E.
1876. ‡*Holms, Colonel William, M.P.* 95 *Cromwell-road, South Kensington, London, S.W.*
1870. ‡Holt, William D. 23 Edge-lane, Liverpool.
1875. *Hood, John. The Elms, Cotham Hill, Bristol.
1847. ‡HOOKER, Sir JOSEPH DALTON, K.C.S.I., C.B., M.D., D.C.L., LL.D., F.R.S., V.P.L.S., F.G.S., F.R.G.S. The Camp, Sunningdale.
1865. *Hooper, John P. Coventry Park, Streatham, London, S.W.
1877. *Hooper, Rev. Samuel F., M.A. 39 Lorrimore-square, London, S.E.
1856. ‡Hooton, Jonathan. 80 Great Ducie-street, Manchester.
1842. Hope, Thomas Arthur. Stanton, Bebington, Cheshire.
1884. *Hopkins, Edward M. 3 Upper Berkeley-street, Portman-square, London, W.
1865. ‡Hopkins, J. S. Jesmond Grove, Edgbaston, Birmingham.
1884. *HOPKINSON, CHARLES. 29 Princess-street, Manchester.
1882. *Hopkinson, Edward, D.Sc. Ireton Bank, Platt-lane, Rusholme, Manchester.
1870. *HOPKINSON, JOHN, M.A., D.Sc., F.R.S. 3 Holland Villas-road, Kensington, London, W.
1871. *HOPKINSON, JOHN, F.L.S., F.G.S., F.R.Met.Soc. 95 New Bond-street, London, W.; and The Grange, St. Albans.
1858. ‡Hopkinson, Joseph, jun. Britannia Works, Huddersfield.
Hornby, Hugh. Sandown, Liverpool.
1886. §Horne, Edward H. Innisfail, Beulah Hill, Norwood, S.E.
1885. §Horne, John, F.R.S.E., F.G.S. 41 Southside-road, Inverness.

Year of
Election.

1876. *Horne, Robert R. 150 Hope-street, Glasgow.
1875. *Horniman, F. J., F.R.G.S., F.L.S. Surrey Mount, Forest Hill, London, S.E.
1884. *Horsfall, Richard. Post Office-buildings, George-street, Halifax.
1856. ‡Horsley, John H. 1 Ormond-terrace, Cheltenham.
1884. *Hotblach, G. S. Prince of Wales-road, Norwich.
1868. ‡Hotson, W. C. Upper King-street, Norwich.
1859. ‡Hough, Joseph, M.A., F.R.A.S. Codsall Wood, Wolverhampton.
1886. §Houghton, F. T. S., M.A. 119 Gough-road, Edgbaston, Birmingham.
1858. ‡Hounsfield, James. Hemsworth, Pontefract.
1884. ‡Houston, William. Legislative Library, Toronto, Canada.
1883. *Hovenden, Frederick, F.L.S., F.G.S. Glenlea, Thurlow Park-road, West Dulwich, Surrey, S.E.
Hovenden, W. F., M.A. Bath.
1879. *Howard, D. 60 Belsize Park, London, N.W.
1883. §Howard, James Fielden, M.D., M.R.C.S. Sandycroft, Shaw.
1886. §Howard, James L., B.Sc. 20 Oxford-road, Waterloo, near Liverpool.
1882. ‡Howard, William Frederick, Assoc.M.Inst.C.E. 13 Cavendish-street, Chesterfield, Derbyshire.
1883. ‡Howarth, Richard. York-road, Birkdale, Southport.
1886. §Howatt, David. 3 Birmingham-road, Dudley.
1876. ‡Howatt, James. 146 Buchanan-street, Glasgow.
1885. §Howden, James C., M.D. Sunnyside, Montrose, N.B.
1857. ‡Howell, Henry H., F.G.S., Director of the Geological Survey of Scotland. Geological Survey Office, Victoria-street, Edinburgh.
1868. ‡HOWELL, Rev. Canon HINDS. Drayton Rectory, near Norwich.
1886. §Howes, Professor G. B., F.L.S. Science Schools, South Kensington, London, S.W.
1884. ‡Howland, Edward P., M.D. 211 41½-street, Washington, U.S.A.
1884. §Howland, Oliver Aiken. Toronto, Canada.
1865. *HOWLETT, Rev. FREDERICK, F.R.A.S. East Tisted Rectory, Alton, Hants.
1863. ‡HOWORTH, H. H., M.P., F.S.A. Derby House, Eccles, Manchester.
1883. ‡Howorth, John, J.P. Springbank, Burnley, Lancashire.
1883. ‡Hoyle, James. Blackburn.
1883. ‡Hoyle, William. Claremont, Bury, Lancashire.
1870. ‡Hubback, Joseph. 1 Brunswick-street, Liverpool.
1835. *HUDSON, HENRY, M.D., M.R.I.A. Glenville, Fermoy, Co. Cork.
1879. ‡Hudson, Robert S., M.D. Redruth, Cornwall.
1883. ‡*Hudson, Rev. W. C. 58 Belmont-street, Southport.*
1867. *HUDSON, WILLIAM H. H., M.A., Professor of Mathematics in King's College, London. 15 Altenburg-gardens, Clapham Common, London, S.W.
1858. *HUGGINS, WILLIAM, D.C.L. Oxon., LL.D. Camb., F.R.S., F.R.A.S. Upper Tulse Hill, Brixton, London, S.W.
1857. ‡Huggon, William. 30 Park-row, Leeds.
1883. ‡Hughes, Miss E. P. Newnham College, Cambridge.
1871. *Hughes, George Pringle, J.P. Middleton Hall, Wooler, Northumberland.
1870. *Hughes, Lewis. Fenwick-court, Liverpool.
1876. *Hughes, Rev. Thomas Edward. Wallfield House, Reigate.
1868. §HUGHES, T. M'K., M.A., F.G.S., Woodwardian Professor of Geology in the University of Cambridge.
1865. ‡Hughes, W. R., F.L.S., Treasurer of the Borough of Birmingham, Birmingham.

Year of Election.
1883. ‡HULKE, JOHN WHITAKER, F.R.S., F.R.C.S., F.G.S. 10 Old Burlington-street, London, W.
1867. §HULL, EDWARD, M.A., LL.D., F.R.S., F.G.S., Director of the Geological Survey of Ireland and Professor of Geology in the Royal College of Science. 14 Hume-street, Dublin.
*Hulse, Sir Edward, Bart., D.C.L. 47 Portland-place, London, W.; and Breamore House, Salisbury.
1884. *Humphreys, A. W. 45 William-street, New York, U.S.A.
1878. ‡Humphreys, H. Castle-square, Carnarvon.
1880. ‡Humphreys, Noel A., F.S.S. Ravenhurst, Hook, Kingston-on-Thames.
1856. ‡Humphries, David James. 1 Keynsham-parade, Cheltenham.
1862. *HUMPHRY, GEORGE MURRAY, M.D., F.R.S., Professor of Surgery in the University of Cambridge. Grove Lodge, Cambridge.
1877. *HUNT, ARTHUR ROOPE, M.A., F.G.S. Southwood, Torquay.
1886. §Hunt, Charles. The Gas Works, Windsor-street, Birmingham.
1865. ‡Hunt, J. P. Gospel Oak Works, Tipton.
1884. ‡HUNT, T. STERRY, M.A., D.Sc., LL.D., F.R.S. 105 Union-avenue, Montreal, Canada.
1864. ‡*Hunt, W. 72 Pulteney-street, Bath.*
1875. *Hunt, William. Northcote, Westbury-on-Trym, Bristol.
1868. ‡Hunter, Christopher. Alliance Insurance Office, North Shields.
1867. ‡Hunter, David. Blackness, Dundee.
1881. ‡Hunter, F. W. 4 Westmoreland-road, Newcastle-on-Tyne.
1881. ‡Hunter, Rev. John. 38 The Mount, York.
1884. *Hunter, Michael, jun. Greystones, Sheffield.
1869. *Hunter, Rev. Robert, LL.D., F.G.S. Forest Retreat, Staples-road, Loughton, Essex.
1879. ‡HUNTINGTON, A. K., F.C.S., Professor of Metallurgy in King's College, London. King's College, London, W.C.
1885. ‡Huntly, The Right Hon. the Marquis of. Aboyne Castle, Aberdeenshire.
1863. ‡Huntsman, Benjamin. West Retford Hall, Retford.
1883. *Hurst, Charles Herbert. Owens College, Manchester.
1869. ‡Hurst, George. Bedford.
1882. §Hurst, Walter, B.Sc. West Lodge, Todmorden.
1861. *Hurst, William John. Drumaness Mills, Ballynahinch, Lisburn, Ireland.
1870. ‡Hurter, Dr. Ferdinand. Appleton, Widnes, near Warrington.
Husband, William Dalla. May Bank, Bournemouth.
1882. ‡Hussey, Captain E. R., R.E. 24 Waterloo-place, Southampton.
1876. ‡Hutchinson, John. 22 Hamilton Park-terrace, Glasgow.
1868. *Hutchison, Robert, F.R.S.E. 29 Chester-street, Edinburgh.
Hutton, Crompton. Putney Park, Surrey, S.W.
1864. *Hutton, Darnton. 14 Cumberland-terrace, Regent's Park, London, N.W.
1857. ‡Hutton, Henry D. 17 Palmerston-road, Dublin.
1861. *HUTTON, T. MAXWELL. Summerhill, Dublin.
1852. ‡HUXLEY, THOMAS HENRY, Ph.D., LL.D., D.C.L., F.R.S., F.L.S., F.G.S. 4 Marlborough-place, London, N.W.
Hyde, Edward. Dukinfield, near Manchester.
1883. ‡Hyde, George H. 23 Arbour-street, Southport.
1871. *Hyett, Francis A. Painswick House, Stroud, Gloucestershire.

1882. *I'Anson, James, F.G.S. Fairfield House, Darlington.
1879. ‡Ibbotson, H. J. 26 Collegiate-crescent, Sheffield.
Ihne, William, Ph.D. Heidelberg.

Year of Election.

1873. ‡*Ikin, J. I. 19 Park-place, Leeds.*
1861. ‡Iles, The Ven. Archdeacon, M.A. The Close, Lichfield.
1884. §Iles, George. Windsor Hotel, Montreal, Canada.
1885. ‡im-Thurn, Everard F. British Guiana.
1858. ‡Ingham, Henry. Wortley, near Leeds.
1876. ‡Inglis, Anthony. Broomhill, Partick, Glasgow.
1871. ‡INGLIS, The Right Hon. JOHN, D.C.L., LL.D., Lord Justice-General of Scotland. Edinburgh.
1876. ‡Inglis, John, jun. Prince's-terrace, Dowanhill, Glasgow.
1883. ‡*Ingram, Rev. D. C. Church-street, Southport.*
1852. ‡INGRAM, J. K., LL.D., M.R.I.A., Librarian to the University of Dublin. 2 Wellington-road, Dublin.
1885. ‡Ingram, William, M.A. Gamrie, Banff.
1886. §Innes, John. The Limes, Alcester-road, Moseley, Birmingham.
1882. ‡Irving, Rev. A., B.A., B.Sc., F.G.S. Wellington College, Wokingham, Berks.
1883. ‡Isherwood, James. 18 York-road, Birkdale, Southport.
1881. ‡Ishiguro, Isoji. Care of the Japanese Legation, 9 Cavendish-square, London, W.
1886. §Izod, William. Church-road, Edgbaston, Birmingham.

1870. ‡Jack, James. 26 Abercromby-square, Liverpool.
1859. ‡Jack, John, M.A. Belhelvie-by-Whitecairns, Aberdeenshire.
1884. ‡Jack, Peter. People's Bank, Halifax, Nova Scotia, Canada.
1876. *Jack, William, LL.D., Professor of Mathematics in the University of Glasgow. 10 The College, Glasgow.
1883. §JACKSON, A. H. New Bridge-street, Strangeways, Manchester.
1879. ‡Jackson, Arthur, F.R.C.S. Wilkinson-street, Sheffield.
1883. ‡Jackson, Mrs. Esther. 16 East Park-terrace, Southampton.
1883. ‡Jackson, Frank. 11 Park-crescent, Southport.
1883. *Jackson, F. J. Brooklands, Alderley Edge, Manchester.
1883. ‡Jackson, Mrs. F. J. Brooklands, Alderley Edge, Manchester.
1874. *Jackson, Frederick Arthur. Belmont, Lyme Regis, Dorset.
1886. §Jackson, George. 51 Heathfield-road, Birmingham.
1885. ‡Jackson, Henry. 19 Golden-square, Aberdeen.
1866. ‡Jackson, H. W., F.R.A.S., F.G.S. 15 The Terrace, High-road, Lewisham, S.E.
1869. §Jackson, Moses. The Vale, Ramsgate.
1863. *Jackson-Gwilt, Mrs. H. Moonbeam Villa, The Grove, New Wimbledon, Surrey.
1874. *Jaffe, John. Edenvale, Strandtown, near Belfast.
1865. *Jaffray, John. Park-grove, Edgbaston, Birmingham.
1872. ‡James, Christopher. 8 Laurence Pountney-hill, London, E.C.
1860. ‡James, Edward H. Woodside, Plymouth.
1886. §James, Frank. Portland House, Aldridge, near Walsall.
1886. *James, Harry Berkeley, F.R.G.S. Valparaiso, Chili.
1863. *JAMES, Sir WALTER, Bart., F.G.S. 6 Whitehall-gardens, London, S.W.
1884. §James, W. Culver, M.D. 11 Marloes-road, London, W.
1858. ‡James, William C. Woodside, Plymouth.
1884. §Jameson, W. C. 48 Baker-street, Portman-square, London, W.
1881. ‡Jamieson, Andrew, Principal of the College of Science and Arts, Glasgow.
1885. ‡Jamieson, Patrick. Peterhead, N.B.
1885. ‡Jamieson, Thomas. 140 Union-street, Aberdeen.
1859. *Jamieson, Thomas F., F.G.S. Ellon, Aberdeenshire.
1850. ‡Jardine, Alexander. Jardine Hall, Lockerby, Dumfriesshire

Year of Election.

1870. ‡Jardine, Edward. Beach Lawn, Waterloo, Liverpool.
1853. *Jarratt, Rev. Canon J., M.A. North Cave, near Brough, Yorkshire.
1870. ‡Jarrold, John James. London-street, Norwich.
1886. §Jeffcock, Rev. John Thomas. The Rectory, Wolverhampton.
1856. §JEFFERY, HENRY M., M.A., F.R.S. 9 Dunstanville-terrace, Falmouth.
1855. *Jeffray, John. Winton House, Kelvinside, Glasgow.
1883. ‡Jeffreys, Miss Gwyn. 1 The Terrace, Kensington, London, W.
1867. ‡Jeffreys, Howel, M.A., F.R.A.S. Pump-court, Temple, London, E.C.
1885. §Jeffreys, Dr. Richard Parker. Eastwood House, Chesterfield.
1852. ‡JELLETT, Rev. JOHN H., D.D., M.R.I.A., Provost of Trinity College, Dublin.
1881. §JELLICOE, C. W. A. Southampton.
1864. ‡Jelly, Dr. W. Aveleanas, 11, Valencia, Spain.
1873. §Jenkins, Major-General J. J. 14 St. James's-square, London, S.W.
1880. *JENKINS, Sir JOHN JONES. The Grange, Swansea.
Jennette, Matthew. 102A Conway-street, Birkenhead.
1852. ‡Jennings, Francis M., F.G.S., M.R.I.A. Brown-street, Cork.
1872. ‡Jennings, W. 13 Victoria-street, London, S.W.
1878. ‡Jephson, Henry L. Chief Secretary's Office, The Castle, Dublin.
*Jerram, Rev. S. John, M.A. 2 Kent-avenue, Castle Hill, Ealing, Middlesex, W.
1872. ‡*Jesson, Thomas. 7 Upper Wimpole-street, Cavendish-square, London, W.*
Jessop, William, jun. Butterley Hall, Derbyshire.
1884. ‡Jewell, Lieutenant Theo. F. Torpedo Station, Newport, Rhode Island, U.S.A.
1884. ‡Johns, Thomas W. Yarmouth, Nova Scotia, Canada.
1884. §Johnson, Alexander, M.A., LL.D., Professor of Mathematics in McGill College, Montreal. 5 Prince of Wales-terrace, Montreal, Canada.
1883. ‡Johnson, Miss Alice. Llandaff House, Cambridge.
1883. ‡Johnson, Ben. Micklegate, York.
1871. *Johnson, David, F.C.S., F.G.S. 52 Fitzjohn's-avenue, South Hampstead, London, N.W.
1881. ‡Johnson, Major E. Cecil. Junior United Service Club, Charles-street, London, S.W.
1883. ‡Johnson, Edmund Litler. 73 Albert-road, Southport.
Johnson, Edward. 22 Talbot-street, Southport.
1865. *Johnson, G. J. 36 Waterloo-street, Birmingham.
1875. §Johnson, James Henry, F.G.S. 73 Albert-road, Southport.
1866. ‡*Johnson, John G. 18A Basinghall-street, London, E.C.*
1872. ‡Johnson, J. T. 27 Dale-street, Manchester.
1861. ‡Johnson, Richard. 27 Dale-street, Manchester.
1870. ‡Johnson, Richard C., F.R.A.S. 19 Catherine-street, Liverpool.
1863. ‡Johnson, R. S. Hanwell, Fence Houses, Durham.
1881. ‡Johnson, Samuel George. Municipal Offices, Nottingham.
1883. ‡Johnson, W. H. F. Llandaff House, Cambridge.
1883. ‡Johnson, William. Harewood, Roe-lane, Southport.
1861. ‡Johnson, William Beckett. Woodlands Bank, near Altrincham, Cheshire.
1883. ‡Johnston, H. H. Tudor House, Champion Hill, London, S.E.
1859. ‡Johnston, James. Newmill, Elgin, N.B.
1864. ‡Johnston, James. Manor House, Northend, Hampstead, London, N.W.

Year of Election.

1884. ‡Johnston, John L. 27 St. Peter-street, Montreal, Canada.
1883. §Johnston, Thomas. Broomsleigh, Seal, Sevenoaks.
1884. ‡Johnston, Walter R. Fort Qu'Appele, N.W. Territory, Canada.
1884. *Johnston, W. H. 6 Latham-street, Preston, Lancashire.
1885. ‡Johnston-Lavis, H. J., M.D., F.G.S. Palazzo Caramanico, Chiatomone, Naples.
1886. §Johnstone, G. H. Northampton-street, Birmingham.
1864. *Johnstone, James. Alva House, Alva, by Stirling, N.B.
1864. ‡*Johnstone, John. 1 Barnard-villas, Bath.*
1876. ‡Johnstone, William. 5 Woodside-terrace, Glasgow.
1864. ‡Jolly, Thomas. Park View-villas, Bath.
1871. §JOLLY, WILLIAM, F.R.S.E., F.G.S., H.M. Inspector of Schools. St. Andrew's-road, Pollokshields, Glasgow.
1881. ‡Jones, Alfred Orlando, M.D. Belton House, Harrogate.
1849. ‡Jones, Baynham. Walmer House, Cheltenham.
1856. ‡Jones, C. W. 7 Grosvenor-place, Cheltenham.
1883. §Jones, George Oliver, M.A. 11 Cambridge-road, Waterloo, Liverpool.
1884. §Jones, Rev. Harry, M.A. Bartonmere, Bury St. Edmunds; and Savile Club, Piccadilly, London, W.
1877. ‡Jones, Henry C., F.C.S. Normal School of Science, South Kensington, London, S.W.
1883. ‡Jones, Rev. Canon Herbert. Waterloo, Liverpool.
1881. ‡Jones, J. Viriamu, M.A., B.Sc., Principal of the University College of South Wales and Monmouthshire. Cardiff.
1873. ‡Jones, Theodore B. 1 Finsbury-circus, London, E.C.
1880. ‡Jones, Thomas. 15 Gower-street, Swansea.
1860. ‡JONES, THOMAS RUPERT, F.R.S., F.G.S. 10 Uverdale-road, King's-road, Chelsea, London, S.W.
1883. ‡Jones, William. Elsinore, Birkdale, Southport.
1875. *Jose, J. E. 11 Cressington Park, Liverpool.
1884. ‡Joseph, J. H. 738 Dorchester-street, Montreal, Canada.
1875. *Joule, Benjamin St. John B., J.P. 12 Wardle-road, Sale, near Manchester.
1842. *JOULE, JAMES PRESCOTT, LL.D., F.R.S., F.C.S. 12 Wardle-road, Sale, near Manchester.
1847. ‡JOWETT, Rev. B., M.A., Regius Professor of Greek in the University of Oxford. Balliol College, Oxford.
1858. ‡Jowett, John. Leeds.
1879. ‡Jowitt, A. Hawthorn Lodge, Clarkehouse-road Sheffield.
1872. ‡Joy, Algernon. Junior United Service Club, St. James's, London, S.W.
1848. *Joy, Rev. Charles Ashfield. Grove Parsonage, Wantage, Berkshire.
1883. §Joyce, Rev. A. G., B.A. St. John's Croft, Winchester.
1886. §Joyce, The Hon. Mrs. St. John's Croft, Winchester.
1848. *Jubb, Abraham. Halifax.
1870. ‡JUDD, JOHN WESLEY, F.R.S., Sec. G.S., Professor of Geology in the Royal School of Mines. Hurstleigh, Kew.
1883. ‡Justice, Philip M. 14 Southampton-buildings, Chancery-lane, London, W.C.

1868. *Kaines, Joseph, M.A., D.Sc. 8 Osborne-road, Stroud Green-road, London, N.
KANE, Sir ROBERT, M.D., LL.D., F.R.S., M.R.I.A., F.C.S. Fortlands, Killiney, Co. Dublin.
1857. ‡Kavanagh, James W. Grenville, Rathgar, Ireland.
1859. ‡Kay, David, F.R.G.S. 19 Upper Phillimore-place, Kensington, London, W.

Year of Election.
Kay, John Cunliff. Fairfield Hall, near Skipton.
1847. *Kay, Rev. William, D.D. Great Leghs Rectory, Chelmsford.
1883. ‡Kearne, John H. Westcliffe-road, Birkdale, Southport.
1884. ‡Keefer, Samuel. Brockville, Ontario, Canada
1884. §Keefer, Thomas Alexander. Port Arthur, Ontario, Canada.
1875. ‡Keeling, George William. Tuthill, Lydney.
1886. §Keen, Arthur, J.P. Sandyford, Augustus-road, Birmingham.
1878. *Kelland, William Henry. 110 Jermyn-street, London, S.W.; and Grettans, Bow, North Devon.
1884. ‡Kellogg, J. H., M.D. Battle Creek, Michigan, U.S.A.
1876. ‡*Kelly, Andrew G. The Manse, Alloa, N.B.*
1864. *Kelly, W. M., M.D. 11 The Crescent, Taunton, Somerset.
1885. §Keltie, J. Scott, Librarian R.G.S. 1 Savile-row, London, W.
1853. ‡Kemp, Rev. Henry William, B.A. The Charter House, Hull.
1884. §Kemper, Andrew C., A.M., M.D. 101 Broadway, Cincinnati, U.S.A.
1875. ‡KENNEDY, ALEXANDER B. W., M.Inst.C.E., Professor of Engineering in University College, London.
1884. §Kennedy, George L., M.A., F.G.S., Professor of Chemistry and Geology in King's College, Windsor, Nova Scotia, Canada.
1876. §Kennedy, Hugh. Redclyffe, Partickhill, Glasgow.
1884. ‡Kennedy, John. 113 University-street, Montreal, Canada.
1884. §Kennedy, William. Hamilton, Ontario, Canada.
1886. §Kenrick, George Hamilton. Whetstone, Somerset-road, Edgbaston, Birmingham.
Kent, J. C. Levant Lodge, Earl's Croome, Worcester.
1886. §Kenward, James, F.S.A. Eddystone House, Harborne, Birmingham.
1857. *Ker, André Allen Murray. Newbliss House, Newbliss, Ireland.
1855. *Ker, Robert. Dougalston, Milngavie, N.B.
1876. ‡Ker, William. 1 Windsor-terrace West, Glasgow.
1881. ‡Kermode, Philip M. C. Ramsay, Isle of Man.
1884. ‡Kerr, James, M.D. Winnipeg, Canada.
1883. §Kerr, Dr. John. Garscadden House, near Kilpatrick, Glasgow.
1869. *Kesselmeyer, Charles A. Villa 'Mon Repos,' Altrincham, Cheshire.
1869. *Kesselmeyer, William Johannes. Villa 'Mon Repos,' Altrincham, Cheshire.
1861. *Keymer, John. Parker-street, Manchester.
1883. *Keynes, J. N., M.A., B.Sc., F.S.S. 6 Harvey-road, Cambridge.
1876. ‡Kidston, J. B. West Regent-street, Glasgow.
1886. §Kidston, Robert, F.R.S.E., F.G.S. 24 Victoria-place, Stirling.
1876. ‡Kidston, William. Ferniegair, Helensburgh, N.B.
1885. *Kilgour, Alexander. Loirston House, Cove, near Aberdeen.
1865. *Kinahan, Edward Hudson, M.R.I.A. 11 Merrion-square North Dublin.
1878. ‡Kinahan, Edward Hudson, jun. 11 Merrion-square North, Dublin.
1860. ‡KINAHAN, G. HENRY, M.R.I.A. Geological Survey of Ireland, 14 Hume-street, Dublin.
1875. *KINCH, EDWARD, F.C.S. Agricultural College, Cirencester.
1872. *King, Mrs. E. M. 34 Cornwall-road, Westbourne Park, London, W.
1875. *King, F. Ambrose. Avonside, Clifton, Bristol.
1883. *King, Francis. Rose Bank, Penrith.
1871. *King, Rev. Herbert Poole. Royal Thames Yacht Club, 7 Albemarle-street, London, W.
1855. ‡King, James. Levernholme, Hurlet, Glasgow.
1883. *King, John Godwin. Welford House, Greenhill, Hampstead, London, N.W.

Year of Election.

1870. §King, John Thomson. 4 Clayton-square, Liverpool.
King, Joseph. Welford House, Greenhill, Hampstead, London, N.W.
1883. *King, Joseph, jun. Welford House, Greenhill, Hampstead, London, N.W.
1864. ‡KING, KELBURNE, M.D. 6 Albion-street, and Royal Institution, Hull.
1860. *King, Mervyn Kersteman. 1 Vittoria-square, Clifton, Bristol.
1875. *King, Percy L. Avonside, Clifton, Bristol.
1870. ‡King, William. 13 Adelaide-terrace, Waterloo, Liverpool.
King, William Poole, F.G.S. Avonside, Clifton, Bristol.
1869. ‡Kingdon, K. Taddiford, Exeter.
1861. ‡Kingsley, John. Ashfield, Victoria Park, Manchester.
1883. ‡Kingston, Mrs. Sarah B. The Limes, Clewer, near Windsor.
1876. §Kingston, Thomas. The Limes, Clewer, near Windsor.
1835. Kingstone, A. John, M.A. Mosstown, Longford, Ireland.
1875. §KINGZETT, CHARLES T., F.C.S. Trevena, Amhurst Park, London, N.
1867. ‡Kinloch, Colonel. Kirriemuir, Logie, Scotland.
1867. *KINNAIRD, The Right Hon. Lord. 2 Pall Mall East, London, S.W.; and Rossie Priory, Inchture, Perthshire.
1870. ‡Kinsman, William R. Branch Bank of England, Liverpool.
1860. ‡KIRKMAN, Rev. THOMAS P., M.A., F.R.S. Croft Rectory, near Warrington.
Kirkpatrick, Rev. W. B., D.D. 48 North Great George-street, Dublin.
1876. *Kirkwood, Anderson, LL.D., F.R.S.E. 7 Melville-terrace, Stirling, N.B.
1875. ‡Kirsop, John. 6 Queen's-crescent, Glasgow.
1883. ‡Kirsop, Mrs. 6 Queen's-crescent, Glasgow.
1870. ‡Kitchener, Frank E. Newcastle, Staffordshire.
1881. ‡*Kitching, Langley.* 50 *Caledonian-road, Leeds.*
1886. §Klein, Rev. L. Martial. University College, Dublin.
1869. ‡Knapman, Edward. The Vineyard, Castle-street, Exeter.
1886. §Knight, J. M. Bushwood, Wanstead, Essex.
1883. ‡Knight, J. R. 32 Lincoln's Inn-fields, London, W.C.
1872. *Knott, George, LL.B., F.R.A.S. Knowles Lodge, Cuckfield, Hayward's Heath, Sussex.
1873. *Knowles, George. Moorhead, Shipley, Yorkshire.
1872. ‡Knowles, James. The Hollies, Clapham Common, S.W.
1870. ‡Knowles, Rev. J. L. 103 Earl's Court-road, Kensington, London, W.
1874. ‡Knowles, William James. Flixton-place, Ballymena, Co. Antrim.
1883. ‡Knowlys, Rev. C. Hesketh. The Rectory, Roe-lane, Southport.
1883. ‡Knowlys, Mrs. C. Hesketh. The Rectory, Roe-lane, Southport.
1876. ‡Knox, David N., M.A., M.B., 24 Elmbank-crescent, Glasgow.
*Knox, George James. 29 Portland-terrace, Regent's Park, London, N.W.
1875. *Knubley, Rev. E. P. Staveley Rectory, Leeds.
1883. ‡Knubley, Mrs. Staveley Rectory, Leeds.
1881. ‡Kurobe, Hiroo. Legation of Japan, 9 Cavendish-square, London, W.
1870. ‡Kynaston, Josiah W., F.C.S. Kensington, Liverpool.
1865. ‡Kynnersley, J. C. S. The Leveretts, Handsworth, Birmingham.
1882. ‡*Kyshe, John B.* 19 *Royal-avenue, Sloane-square, London, S.W.*

1858. ‡Lace, Francis John. Stone Gapp, Cross-hill, Leeds.

Year of Election.

1884. ‡Laflamme, Rev. Professor J. C. K. Laval University, Quebec, Canada.

1885. *Laing, J. Gerard. 1 Elm-court, Temple, London, E.C.

1870. ‡Laird, H. H. Birkenhead.

1870. §Laird, John. Grosvenor-road, Claughton, Birkenhead.

1882. ‡Lake, G. A. K., M.D. East Park-terrace, Southampton.

1880. ‡Lake, Samuel. Milford Docks, Milford Haven.

1877. ‡Lake, W. C., M.D. Teignmouth.

1859. ‡Lalor, John Joseph, M.R.I.A. City Hall, Cork Hill, Dublin.

1883. §Lamb, W. J. 11 Gloucester-road, Birkdale, Southport.

1883. §LAMBERT, Rev. BROOKE, LL.B. The Vicarage, Greenwich, Kent, S.E.

1884. ‡Lamborn, Robert H. Montreal, Canada.

1884. ‡Lancaster, Alfred. Manchester-road, Burnley, Lancashire.

1871. ‡Lancaster, Edward. Karesforth Hall, Barnsley, Yorkshire.

1886. §Lancaster, W. J., F.G.S. Colmore-row, Birmingham.

1877. ‡Landon, Frederic George, M.A., F.R.A.S. 59 Tresillian-road, St. John's, S.E.

1883. ‡Lang, Rev. Gavin. Inverness.

1859. ‡Lang, Rev. John Marshall, D.D. Barony, Glasgow.

1864. ‡*Lang, Robert. Langford Lodge, College-road, Clifton, Bristol.*

1886. *Langley, J. N., M.A., F.R.S. Trinity College, Cambridge.

1882. ‡*Langstaff, Dr. Bassett, Southampton.*

1870. ‡Langton, Charles. Barkhill, Aigburth, Liverpool.

*Langton, William. Docklands, Ingatestone, Essex.

1865. ‡LANKESTER, E. RAY, M.A., LL.D., F.R.S., Professor of Comparative Anatomy and Zoology in University College, London. 11 Wellington Mansions, North Bank, London, N.W.

1880. *LANSDELL, Rev. HENRY, D.D., F.R.A.S., F.R.G.S. Eyre Cottage, The Grove, Blackheath, London, S.E.

Lanyon, Sir Charles. The Abbey, White Abbey, Belfast.

1884. §Lanza, Professor G. Massachusetts Institute of Technology, Boston, U.S.A.

1878. ‡Lapper, E., M.D. 61 Harcourt-street, Dublin.

1886. §Lapraik, W. 9 Malfort-road, Denmark Hill, London, S.E.

1885. §LAPWORTH, CHARLES, LL.D., F.G.S., Professor of Geology and Mineralogy in the Mason Science College, Birmingham. 46 George-road, Edgbaston, Birmingham.

1881. ‡Larmor, Joseph, M.A., Professor of Natural Philosophy in Queen's College, Galway.

1883. §Lascelles, B. P. Harrow.

1870. *LATHAM, BALDWIN, M.Inst.C.E., F.G.S. 7 Westminster-chambers, Westminster, S.W.

1870. ‡LAUGHTON, JOHN KNOX, M.A., F.R.G.S. 130 Sinclair-road, West Kensington Park, London, W.

1883. ‡Laurie, Major-General. Oakfield, Nova Scotia.

1870. *Law, Channell. Sydney Villa, 36 Outram-road, Addiscombe, Croydon.

1878. ‡Law, Henry, M.Inst.C.E. 5 Queen Anne's-gate, London, S.W.

1862. ‡Law, Rev. James Edmund, M.A. Little Shelford, Cambridgeshire.

1884. §Law, Robert. Hollingsworth, Walsden, near Todmorden.

1870. ‡Lawrence, Edward. Aigburth, Liverpool.

1881. §Lawrence, Rev. F., B.A. The Vicarage, Westow, York.

1875. ‡Lawson, George, Ph.D., LL.D., Professor of Chemistry and Botany. Halifax, Nova Scotia.

1885. ‡Lawson, James. 8 Church-street, Huntly, N.B.

Year of Election.

1857. ‡Lawson, The Right Hon. James A., LL.D., D.C.L., M.R.I.A. 27 Fitzwilliam-street, Dublin.
1868. *Lawson, M. Alexander, M.A., F.L.S. Ootâcamund, Bombay.
1853. ‡Lawton, William. 5 Victoria-terrace, Derringham, Hull.
1856. ‡Lea, Henry. 38 Bennett's-hill, Birmingham.
1875. ‡Leach, Colonel R. E. Mountjoy, Phœnix Park, Dublin.
1883. *Leach, Charles Catterall. 18 Lord-street, Liverpool.
1883. §Leach, John. Haverhill House, Bolton.
1870. *Leaf, Charles John, F.L.S., F.G.S., F.S.A. Old Change, London, E.C.; and Painshill, Cobham.
1884. *Leahy, John White, J.P. South Hill, Killarney, Ireland.
1884. ‡Learmont, Joseph B. 120 Mackay-street, Montreal, Canada.
1847. *LEATHAM, EDWARD ALDAM, M.P. Whitley Hall, Huddersfield; and 46 Eaton-square, London, S.W.
1863. ‡Leavers, J. W. The Park, Nottingham.
1884. *Leavitt, Erasmus Darwin. 604 Main-street, Cambridgeport, Massachusetts, U.S.A.
1872. ‡LEBOUR, G. A., M.A., F.G.S., Professor of Geology in the College of Physical Science, Newcastle-on-Tyne.
1884. ‡Leckie, R. G. Springhill, Cumberland County, Nova Scotia.
1883. ‡Lee, Daniel W. Halton Bank, Pendleton, near Manchester.
1861. ‡Lee, Henry, M.P. Sedgeley Park, Manchester.
1883. ‡Lee, J. H. Warburton. Rossall, Fleetwood.
1853. *LEE, JOHN EDWARD, F.G.S., F.S.A. Villa Syracusa, Torquay.
1884. *Leech, Bosdin T. Oak Mount, Temperley, Cheshire.
1886. *Lees, Lawrence W. Claregate, Tettenhall, Wolverhampton.
1882. ‡Lees, R. W. Moira-place, Southampton.
1859. ‡Lees, William, M.A. St. Leonard's, Morningside-place, Edinburgh.
1883. *Leese, Miss H. K. Fylde-road Mills, Preston, Lancashire.
*Leese, Joseph. Fylde-road Mills, Preston, Lancashire.
1883. ‡Leese, Mrs. Hazeldene, Fallowfield, Manchester.
1881. ‡LE FEUVRE, J. E. Southampton.
1872. ‡LEFEVRE, The Right Hon. G. SHAW, F.R.G.S. 18 Bryanston-square, London, W.
*LEFROY, General Sir JOHN HENRY, R.A., K.C.M.G., C.B., LL.D., F.R.S., F.R.G.S. 82 Queen's-gate, London, S.W.
*Legh, Lieut.-Colonel George Cornwall. High Legh Hall, Cheshire.
1869. ‡Le Grice, A. J. Trereife, Penzance.
1868. ‡LEICESTER, The Right Hon. the Earl of, K.G. Holkham, Norfolk.
1861. *Leigh, Henry. Moorfield, Swinton, near Manchester.
1856. ‡LEIGH, The Right Hon. Lord, D.C.L. 37 Portman-square, London, W.; and Stoneleigh Abbey, Kenilworth.
1870. ‡Leighton, Andrew. 35 High-park-street, Liverpool.
1880. ‡Leighton, William Henry, F.G.S. 2 Merton-place, Chiswick.
1886. §Leipner, Adolph, Professor of Botany in University College, Bristol. 47 Hampton Park, Bristol.
1867. ‡Leishman, James. Gateacre Hall, Liverpool.
1870. ‡Leister, G. F. Gresbourn House, Liverpool.
1859. ‡Leith, Alexander. Glenkindie, Inverkindie, N.B.
1882. §Lemon, James, M.Inst.C.E. 11 The Avenue, Southampton.
1863. *LENDY, Major AUGUSTE FREDERIC, F.L.S., F.G.S. Sunbury House, Sunbury, Middlesex.
1867. ‡Leng, John. 'Advertiser' Office, Dundee.
1878. ‡Lennon, Rev. Francis. The College, Maynooth, Ireland.
1861. ‡*Lennox, A. C. W. 7 Beaufort-gardens, Brompton, London, S.W.*

Year of Election.

Lentaigne, Joseph. 12 Great Denmark-street, Dublin.
1871. ‡LEONARD, HUGH, F.G.S., M.R.I.A., F.R.G.S.I. St. David's, Malahide-road, Co. Dublin.
1874. ‡Lepper, Charles W. Laurel Lodge, Belfast.
1872. ‡*Lermit, Rev. Dr. School House, Dedham.*
1884. ‡Lesage, Louis. City Hall, Montreal, Canada.
1871. ‡Leslie, Alexander, M.Inst.C.E. 72 George-street, Edinburgh.
1883. §Lester, Thomas. Fir Bank, Penrith.
1880. ‡LETCHER, R. J. Lansdowne-terrace, Walters-road, Swansea.
1866. §LEVI, Dr. LEONE, F.S.A., F.S.S., F.R.G.S., Professor of Commercial Law in King's College, London. 5 Crown Office-row, Temple, London, E.C.
1879. ‡Lewin, Colonel, F.R.G.S. Garden Corner House, Chelsea Embankment, London, S.W.
1870. ‡LEWIS, ALFRED LIONEL. 35 Colebrooke-row, Islington, London, N.
1884. *Lewis, W. T. The Mardy, Aberdare.
1853. ‡Liddell, George William Moore. Sutton House, near Hull.
1860. ‡LIDDELL, The Very Rev. H. G., D.D., Dean of Christ Church, Oxford.
1876. ‡Lietke, J. O. 30 Gordon-street, Glasgow.
1862. ‡LILFORD, The Right Hon. Lord, F.L.S. Lilford Hall, Oundle, Northamptonshire.
*LIMERICK, The Right Rev. CHARLES GRAVES, Lord Bishop of, D.D., F.R.S., M.R.I.A. The Palace, Henry-street, Limerick.
1883. ‡*Lincoln, Frank. 111 Marylebone-road, London, N.W.*
1878. ‡Lincolne, William. Ely, Cambridgeshire.
1881. *Lindley, William, C.E., F.G.S. 10 Kidbrooke-terrace, Blackheath, London, S.E.
*Lindsay, Charles. Ridge Park, Lanark, N.B.
1870. ‡Lindsay, Thomas, F.C.S. Maryfield College, Maryhill, by Glasgow.
1871. ‡Lindsay, Rev. T. M., M.A., D.D. Free Church College, Glasgow.
Lingwood, Robert M., M.A., F.L.S., F.G.S. 6 Park-villas, Cheltenham.
1876. ‡Linn, James. Geological Survey Office, India-buildings, Edinburgh.
1883. §Lisle, H. Claud. Nantwich.
1882. *Lister, Rev. Henry, M.A. Hawridge Rectory, Berkhampstead.
1870. §Lister, Thomas. Victoria-crescent, Barnsley, Yorkshire.
1876. ‡Little, Thomas Evelyn. 42 Brunswick-street, Dublin.
Littledale, Harold. Liscard Hall, Cheshire.
1881. ‡Littlewood, Rev. B. C., M.A. Holmdale, Cheltenham.
1861. *LIVEING, G. D., M.A., F.R.S., F.C.S., Professor of Chemistry in the University of Cambridge. Cambridge.
1876. *Liversidge, Archibald, F.R.S., F.C.S., F.G.S., F.R.G.S., Professor of Chemistry and Mineralogy in the University of Sydney, N.S.W. (Care of Messrs. Trübner & Co., Ludgate Hill, London, E.C.)
1864. §Livesay, J. G. Cromartie House, Ventnor, Isle of Wight.
1880. ‡Llewelyn, John T. D. Penllegare, Swansea.
Lloyd, Rev. A. R. Hengold, near Oswestry.
1842. Lloyd, Edward. King-street, Manchester.
1865. ‡Lloyd, G. B., J.P. Edgbaston-grove, Birmingham.
*Lloyd, George, M.D., F.G.S. Birmingham.
1865. ‡Lloyd, John. Queen's College, Birmingham.
1886. §Lloyd, John Henry. Ferndale, Carpenter-road, Edgbaston, Birmingham.
Lloyd, Rev. Rees Lewis. Belper, Derbyshire.
1877. **Lloyd, Sampson Samuel. Moor Hall, Sutton Coldfield.*
1886. §Lloyd, Samuel. Farm, Sparkbrook, Birmingham.

Year of Election.
1865. *Lloyd, Wilson, F.R.G.S. Myvod House, Wednesbury.
1854. *LOBLEY, JAMES LOGAN, F.G.S., F.R.G.S. 19 Stonebridge Park, Willesden, N.W.
1853. *Locke, John. 133 Leinster-road, Dublin.
1867. *Locke, John. 83 Addison-road, Kensington, London, W.
1863. ‡LOCKYER, J. NORMAN, F.R.S., F.R.A.S. Science Schools, South Kensington, London, S.W.
1886. *Lodge, Alfred H., M.A. Cooper's Hill, Staines.
1875. *LODGE, OLIVER J., D.Sc., Professor of Physics in University College, Liverpool. 21 Waverley-road, Sefton Park, Liverpool.
1883. ‡Lofthouse, John. West Bank, Rochdale.
1883. ‡London, Rev. H. High Lee, Knutsford.
1862. ‡Long, Andrew, M.A. King's College, Cambridge.
1876. ‡Long, H. A. Charlotte-street, Glasgow.
1872. ‡Long, Jeremiah. 50 Marine Parade, Brighton.
1871. *Long, John Jex. 11 Doune-terrace, Kelvinside, Glasgow.
1851. ‡Long, William, F.G.S. Hurts Hall, Saxmundham, Suffolk.
1883. *Long, William. Thelwall Heys, near Warrington.
1883. ‡Long, Mrs. Thelwall Heys, near Warrington.
1883. ‡Long, Miss. Thelwall Heys, near Warrington.
1866. §Longdon, Frederick. Osmaston-road, Derby.
1883. ‡Longe, Francis D. Coddenham Lodge, Cheltenham.
1883. ‡Longmaid, William Henry. 4 Rawlinson-road, Southport.
1875. *Longstaff, George Blundell, M.A., M.B., F.C.S., F.S.S. Southfield Grange, Wandsworth, S.W.
1871. §Longstaff, George Dixon, M.D., F.C.S. Butterknowle, Wandsworth, S.W.; and 9 Upper Thames-street, London, E.C.
1872. *Longstaff, Llewellyn Wood, F.R.G.S. Ridgelands, Wimbledon, Surrey.
1881. *Longstaff, Mrs. Ll. W. Ridgelands, Wimbledon, Surrey.
1883. *Longton, E. J., M.D. Lord-street, Southport.
1861. *Lord, Edward. Adamroyd, Todmorden.
1863. ‡Losh, W. S. Wreay Syke, Carlisle.
1883. *Louis, D. A., F.C.S. Harpenden.
1886. *Love, E. F. J. Mason College, Birmingham.
1876. *Love, James, F.R.A.S., F.G.S., F.Z.S. 75 Oval road, Croydon.
1883. §Love, James Allen. 8 Eastbourne-road West, Southport.
1875. *Lovett, W. Jesse, F.I.C. Jessamine Cottage, Thornes, Wakefield.
1867. *Low, James F. Monifieth, by Dundee.
1885. §Lowdell, Sydney Poole. Baldwyn's Hill, East Grinstead, Sussex.
1885. *Lowe, Arthur C. W. Gosfield Hall, Halstead, Essex.
1863. *Lowe, Colonel Arthur S. H., F.R.A.S. 76 Lancaster-gate, London, W.
1861. *LOWE, EDWARD JOSEPH, F.R.S., F.R.A.S., F.L.S., F.G.S., F.R.M.S. Shirenewton Hall, near Chepstow.
1884. ‡Lowe, F. J. Elm-court, Temple, London, E.C.
1870. ‡*Lowe, G. C. 67 Cecil-street, Greenheys, Manchester.*
1868. ‡*Lowe, John, M.D. King's Lynn.*
1886. *Lowe, John Lander. 132 Bath-row, Birmingham.
1850. ‡Lowe, William Henry, M.D., F.R.S.E. Balgreen, Slateford, Edinburgh.
1881. ‡Lubbock, Arthur Rolfe. High Elms, Hayes, Kent.
1853. *LUBBOCK, Sir JOHN, Bart., M.P., D.C.L., LL.D., F.R.S., F.L.S., F.G.S. High Elms, Hayes, Kent.
1881. ‡Lubbock, John B. High Elms, Hayes, Kent.
1870. ‡Lubbock, Montague, M.D. 19 Grosvenor-street, London, W.

Year of Election.

1878. ‡Lucas, Joseph. Tooting Graveney, London, S.W.
1849. *Luckcock, Howard. Oak-hill, Edgbaston, Birmingham.
1875. ‡Lucy, W. C., F.G.S. The Winstones, Brookthorpe, Gloucester.
1881. ‡Luden, C. M. 4 Bootham-terrace, York.
1867. *Luis, John Henry. Cidhmore, Dundee.
1873. ‡Lumley, J. Hope Villa, Thornbury, near Bradford, Yorkshire.
1884. ‡*Lumsden, Miss L. J.*
1885. ‡LUMSDEN, ROBERT. Ferryhill House, Aberdeen.
1866. *Lund, Charles. Ilkley, Yorkshire.
1873. ‡Lund, Joseph. Ilkley, Yorkshire.
1850. *Lundie, Cornelius. Teviot Bank, Newport-road, Cardiff.
1853. ‡Lunn, William Joseph, M.D. 23 Charlotte-street, Hull.
1883. *Lupton, Arnold, M.Inst.C.E., F.G.S., Instructor in Coal Mining in Yorkshire College. 4 Albion-place, Leeds.
1858. *Lupton, Arthur. Headingley, near Leeds.
1874. *LUPTON, SYDNEY, M.A. The Harehills, near Leeds.
1864. *Lutley, John. Brockhampton Park, Worcester.
1871. ‡Lyell, Leonard, F.G.S. 92 Onslow-gardens, London, S.W.
1884. ‡Lyman, A. Clarence. 84 Victoria-street, Montreal, Canada.
1884. ‡Lyman, H. H. 74 McTavish-street, Montreal, Canada.
1884. ‡Lyman, Roswell C. 74 McTavish-street, Montreal, Canada.
1874. ‡Lynam, James. Ballinasloe, Ireland.
1885. §Lyon, Alexander, jun. 52 Carden-place, Aberdeen.
1857. ‡Lyons, Robert D., M.B., M.R.I.A. 8 Merrion-square West, Dublin.
1878. ‡Lyte, Cecil Maxwell. Cotford, Oakhill-road, Putney, S.W.
1862. *LYTE, F. MAXWELL, F.C.S. Cotford, Oakhill-road, Putney, S.W.

1852. ‡McAdam, Robert. 18 College-square East, Belfast.
1854. *MACADAM, STEVENSON, Ph.D., F.R.S.E., F.C.S., Lecturer on Chemistry. Surgeons' Hall, Edinburgh; and Brighton House, Portobello, by Edinburgh.
1876. *MACADAM, WILLIAM IVISON. Surgeons' Hall, Edinburgh.
1868. ‡MACALISTER, ALEXANDER, M.D., F.R.S., Professor of Anatomy in the University of Cambridge. Strathmore House, Harvey-road, Cambridge.
1878. §MACALISTER, DONALD, M.A., M.D., B.Sc. St. John's College, Cambridge.
1879. §MacAndrew, James J. Lukesland, Ivybridge, South Devon.
1883. §MacAndrew, Mrs. J. J. Lukesland, Ivybridge, South Devon.
1883. §MacAndrew, William. Westwood House, near Colchester.
1866. *M'Arthur, Alexander, M.P., F.R.G.S. Raleigh Hall, Brixton Rise, London, S.W.
1884. ‡Macarthur, Alexander. Winnipeg, Canada.
1884. ‡Macarthur, D. Winnipeg, Canada.
1840. MACAULAY, JAMES, A.M., M.D. 25 Carlton-road, Maida Vale, London, N.W.
1871. *MacBrayne, Robert. Messrs. Black and Wingate, 5 Exchange-square, Glasgow.
1884. ‡McCabe, T., Chief Examiner of Patents. Patent Office, Ottawa, Canada.
1866. ‡M'CALLAN, Rev. J. F., M.A. Basford, near Nottingham.
1855. ‡M'Cann, Rev. James, D.D., F.G.S. The Lawn, Lower Norwood, Surrey, S.E.
1886. §MacCarthy, Rev. E. F. M., M.A. 93 Hagley-road, Birmingham.
1884. *McCarthy, J. J., M.D. Junior Army and Navy Club, London, S.W.
1884. ‡McCausland, Orr. Belfast.
1876. *M'CLELLAND, A. S. 4 Crown-gardens, Dowanhill, Glasgow.

Year of Election.

1868. ‡M‘CLINTOCK, Admiral Sir FRANCIS L., R.N., F.R.S., F.R.G.S. United Service Club, Pall Mall, London, S.W.
1872. *M‘Clure, J. H., F.R.G.S. Chavoire, Annecy, Haute Savoie, France.
1874. ‡M‘Clure, Sir Thomas, Bart. Belmont, Belfast.
1878. *M‘Comas, Henry. Homestead, Dundrum, Co. Dublin.
1858. ‡M‘Connell, J. E. Woodlands, Great Missenden.
1883. ‡*McCrossan, James. 29 Albert-road, Southport.*
1876. ‡M‘Culloch, Richard. 109 Douglas-street, Blythswood-square, Glasgow.
1884. ‡MACDONALD, The Right Hon. Sir JOHN ALEXANDER, G.C.B., D.C.L., LL.D. Ottawa, Canada.
1886. §McDonald, John Allen. 6 Holly-place, Hampstead, London, N.W.
1884. ‡MacDonald, Kenneth. Town Hall, Inverness.
1884. *McDonald, W. C. 891 Sherbrooke-street, Montreal, Canada.
1878. ‡McDonnell, Alexander. St. John's, Island Bridge, Dublin.
1884. ‡MacDonnell, Mrs. F. H. 1433 St. Catherine-street, Montreal, Canada.
MacDonnell, Hercules H. G. 2 Kildare-place, Dublin.
1883. ‡MacDonnell, Rev. Canon J. C., D.D. Maplewell, Loughborough.
1878. ‡McDonnell, James. 32 Upper Fitzwilliam-street, Dublin.
1878. ‡McDonnell, Robert, M.D., F.R.S., M.R.I.A. 89 Merrion-square West, Dublin.
1884. ‡Macdougall, Alan. Toronto, Canada.
1884. ‡McDougall, John. 35 St. François Xavier-street, Montreal, Canada.
1878. *M‘Ewan, John. Park-place, Stirling, N.B.
1881. ‡Macfarlane, Alexander, D.Sc., F.R.S.E., Professor of Physics in the University of Texas. Austin, Texas, U.S.A.
1871. ‡M‘Farlane, Donald. The College Laboratory, Glasgow.
1885. §Macfarlane, J. M., D.Sc. 3 Bellevue-terrace, Edinburgh.
1879. ‡Macfarlane, Walter, jun. 12 Lynedoch-crescent, Glasgow.
1884. ‡Macfie, K. N., B.A., B.C.L. Winnipeg, Canada.
1854. *Macfie, Robert Andrew. Dreghorn, Colinton, Edinburgh.
1867. *M‘Gavin, Robert. Ballumbie, Dundee.
1855. ‡MacGeorge, Andrew, jun. 21 St. Vincent-place, Glasgow.
1872. ‡*M‘George, Mungo. Nithsdale, Laurie Park, Sydenham, S.E.*
1884. ‡MacGillivray, James. 42 Catchurt-street, Montreal, Canada.
1884. ‡MacGoun, Archibald, jun., B.A., B.C.L. 19 Place d'Armes, Montreal, Canada.
1873. ‡McGowen, William Thomas. Oak-avenue, Oak Mount, Bradford, Yorkshire.
1885. ‡Macgregor, Alexander, M.D. 256 Union-street, Aberdeen.
1884. *MACGREGOR, JAMES GORDON, M.A., D.Sc., F.R.S.E., Professor of Physics in Dalhousie College, Halifax, Nova Scotia, Canada.
1886. §McGregor, William. Kohima Lodge, Bedford.
1885. ‡M‘Gregor-Robertson, J., M.A., M.B. 400 Great Western-road, Glasgow.
1876. ‡M‘Grigor, Alexander B., LL.D. 19 Woodside-terrace, Glasgow.
1867. *M‘INTOSH, W. C., M.D., LL.D., F.R.S. L. & E., F.L.S., Professor of Natural History in the University of St. Andrews. 2 Abbotsford-crescent, St. Andrews, N.B.
1884. ‡McIntyre, John, M.D. Odiham, Hants.
1883. ‡Mack, Isaac A. Trinity-road, Bootle.
1884. §Mackay, Alexander Howard, B.A., B.Sc. The Academy, Pictou, Nova Scotia, Canada.
1885. §Mackay, John Yule, M.D. The University, Glasgow.
1873. ‡MCKENDRICK, JOHN G., M.D., F.R.S. L. & E., Professor of Physiology in the University of Glasgow. The University, Glasgow.

Year of Election.

1883. ‡McKendrick, Mrs. The University, Glasgow.
1880. *Mackenzie, Colin. Junior Athenæum Club, Piccadilly, London, W.
1885. ‡*Mackenzie, J. T. Glenmuick, Ballater, N.B.*
1884. §McKenzie, Stephen, M.D. 26 Finsbury-circus, London, E.C.
1884. ‡McKenzie, Thomas, B.A. School of Science, Toronto, Canada.
1883. ‡Mackeson, Henry. Hythe, Kent.
1865. ‡Mackeson, Henry B., F.G.S. Hythe, Kent.
1872. *Mackey, J. A. 1 Westbourne-terrace, Hyde Park, London, W.
1867. ‡MACKIE, SAMUEL JOSEPH. 17 Howley-place, London, W.
1884. ‡McKilligan, John B. 387 Main-street, Winnipeg, Canada.
1867. *Mackinlay, David. 6 Great Western-terrace, Hillhead, Glasgow.
1865. ‡Mackintosh, Daniel, F.G.S. 32 Glover-street, Birkenhead.
1884. ‡Mackintosh, James B. Lehigh University, South Bethlehem, Pa., U.S.A.
1886. *Mackintosh, J. B. School of Mines, Fourth Avenue, New York, U.S.A.
1850. ‡Macknight, Alexander. 20 Albany-street, Edinburgh.
1867. ‡Mackson, H. G. 25 Cliff-road, Woodhouse, Leeds.
1872. *MCLACHLAN, ROBERT, F.R.S., F.L.S. West View, Clarendon-road, Lewisham, S.E.
1873. ‡McLandsborough, John, M.Inst.C.E., F.R.A.S., F.G.S. Manningham, Bradford, Yorkshire.
1885. *M'LAREN, The Right Hon. Lord, F.R.S.E. 46 Moray-place, Edinburgh.
1860. ‡Maclaren, Archibald. Summertown, Oxfordshire.
1873. ‡MacLaren, Walter S. B. Newington House, Edinburgh.
1882. ‡Maclean, Inspector-General, C.B. 1 Rockstone-terrace, Southampton.
1884. ‡McLennan, Frank. 317 Drummond-street, Montreal, Canada.
1884. ‡McLennan, Hugh. 317 Drummond-street, Montreal, Canada.
1884. ‡McLennan, John. Lancaster, Ontario, Canada.
1862. ‡Macleod, Henry Dunning. 17 Gloucester-terrace, Campden Hill-road, London, W.
1868. §M'LEOD, HERBERT, F.R.S., F.C.S., Professor of Chemistry in the Royal Indian Civil Engineering College, Cooper's Hill, Staines.
1875. ‡Macliver, D. 1 Broad-street, Bristol.
1875. ‡Macliver, P. S. 1 Broad-street, Bristol.
1861. *Maclure, John William, F.R.G.S., F.S.S. Whalley Range, Manchester.
1883. *McMahon, Colonel C. A. 20 Nevern-square, South Kensington, London, S.W.
1883. ‡MacMahon, Captain P. A., R.A., Instructor in Mathematics at the Royal Military Academy, Woolwich.
1878. *M'Master, George, M.A., J.P. Donnybrook, Ireland.
1862. ‡Macmillan, Alexander. Streatham-lane, Upper Tooting, Surrey, S.W.
1884. *Macmillan, Angus, M.D. Hull.
1874. ‡MacMordie, Hans, M.A. 8 Donegall-street, Belfast.
1884. ‡McMurrick, Playfair. Ontario Agricultural College, Guelph, Ontario, Canada.
1871. ‡M'NAB, WILLIAM RAMSAY, M.D., Professor of Botany in the Royal College of Science, Dublin. 4 Vernon-parade, Clontarf, Dublin.
1870. ‡*Macnaught, John, M.D. 74 Huskisson-street, Liverpool.*
1867. ‡M'Neill, John. Balhousie House, Perth.
1883. ‡McNicoll, Dr. E. D. 15 Manchester-road, Southport.
1878. ‡Macnie, George. 59 Bolton-street, Dublin.
1883. ‡Macpherson, J. 44 Frederick-street, Edinburgh.

Year of Election.

1886. §Macpherson, Major J. C., R.E. Ordnance Survey Office, Bedford.
*MACRORY, EDMUND, M.A. 2 Ilchester-gardens, Prince's-square, London, W.
1876. **Mactear, James. 16 Burnbank-gardens, Glasgow.*
1855. ‡MACVICAR, Rev. JOHN GIBSON, D.D., LL.D. Moffat, N.B.
1883. ‡McWhirter, William. 170 Kent-road, Glasgow.
1883. ‡Madden, W. H. Marlborough College, Wilts.
1883. ‡Maggs, Thomas Charles, F.G.S. Culver Lodge, Acton Vale, Middlesex, W.
1868. ‡Magnay, F. A. Drayton, near Norwich.
1875. *Magnus, Sir Philip, B.Sc. 48 Gloucester-place, Portman-square, London, W.
1878. ‡Mahony, W. A. 34 College-green, Dublin.
1869. ‡Main, Robert. Admiralty, Whitehall, London, S.W.
1885. *Maitland, Sir James R. G., Bart. Stirling, N.B.
1883. §Maitland, P. C. 233 East India-road, London, E.
*Malcolm, Frederick. Morden College, Blackheath, London, S.E.
1881. ‡Malcolm, Lieut.-Colonel, R.E. 72 Nunthorpe-road, York.
1874. ‡Malcolmson, A. B. Friends' Institute, Belfast.
1857. ‡Mallet, John William, Ph.D., M.D., F.R.S., F.C.S., Professor of Chemistry in the University of Virginia, U.S.A.
1870. ‡Manifold, W. H. 45 Rodney-street, Liverpool.
1884. *Mann, F. S. W. Linton Park, Maidstone.
1885. ‡Mann, George. 72 Bon Accord-street, Aberdeen.
Manning, His Eminence Cardinal. Archbishop's House, Westminster, S.W.
1878. §Manning, Robert. 4 Upper Ely-place, Dublin.
1864. ‡Mansel-Pleydell, J. C. Whatcombe, Blandford.
1870. ‡Marcoartu, Senor Don Arturo de. Madrid.
1883. ‡Marginson, James Fleetwood. The Mount, Fleetwood, Lancashire.
1864. ‡MARKHAM, CLEMENTS R., C.B., F.R.S., F.L.S., Sec.R.G.S., F.S.A. 21 Eccleston-square, London, S.W.
1863. ‡Marley, John. Mining Office, Darlington.
1881. *Marr, John Edward, M.A., F.G.S. St. John's College, Cambridge.
1871. ‡MARRECO, A. FRIERE-. College of Physical Science, Newcastle-on-Tyne.
1857. ‡Marriott, William, F.C.S. Grafton-street, Huddersfield.
1842. Marsden, Richard. Norfolk-street, Manchester.
1884. *Marsden, Samuel. St. Louis, Missouri, U.S.A.
1883. *Marsh, Henry. Cressy House, Woodsley-road, Leeds.
1870. ‡Marsh, John. Rann Lea, Rainhill, Liverpool.
1864. ‡Marsh, Thomas Edward Miller. 37 Grosvenor-place, Bath.
1882. *MARSHALL, A. MILNES, M.A., M.D., D.Sc., F.R.S., Professor of Zoology in Owens College, Manchester.
1881. ‡*Marshall, D. H. Greenhill Cottage, Rothesay.*
1881. *Marshall, John, F.R.A.S., F.G.S. Church Institute, Leeds.
1881. ‡Marshall, John Ingham Fearby. 28 St. Saviourgate, York.
1876. ‡Marshall, Peter. 6 Parkgrove-terrace, Glasgow.
1858. ‡Marshall, Reginald Dykes. Adel, near Leeds.
1886. *Marshall, W. Bayley. 15 Augustus-road, Edgbaston, Birmingham.
1849. *MARSHALL, WILLIAM P., M.Inst.C.E. 15 Augustus-road, Birmingham.
1865. §MARTEN, EDWARD BINDON. Pedmore, near Stourbridge.
1883. ‡Marten, Henry John. 4 Storey's-gate, London, S.W.
1848. ‡Martin, Henry D. 4 Imperial-circus, Cheltenham.
1878. ‡MARTIN, H. NEWELL, M.A., M.D., D.Sc., F.R.S., Professor of Biology in Johns Hopkins University, Baltimore, U.S.A.

Year of Election.

1883. *MARTIN, JOHN BIDDULPH, M.A., F.S.S. 17 Hyde Park-gate, London, S.W.
1884. §Martin, N. H., F.L.S. 29 Moseley-street, Newcastle-on-Tyne.
1836. Martin, Studley. Liverpool.
*Martineau, Rev. James, LL.D., D.D. 35 Gordon-square, London, W.C.
1865. ‡Martineau, R. F. Highfield-road, Edgbaston, Birmingham.
1886. §Martineau, R. F. 18 Highfield-road, Edgbaston, Birmingham.
1865. ‡Martineau, Thomas. 7 Cannon-street, Birmingham.
1886. §MARTINEAU, THOMAS, J.P. West Hill, Augustus-road, Edgbaston, Birmingham.
1875. ‡Martyn, Samuel, M.D. 8 Buckingham-villas, Clifton, Bristol.
1883. ‡Marwick, James, LL.D. Killermont, Maryhill, Glasgow.
1878. ‡Masaki, Taiso. Japanese Consulate, 84 Bishopsgate-street Within, London, E.C.
1847. ‡MASKELYNE, NEVIL STORY, M.A., M.P., F.R.S., F.G.S., Professor of Mineralogy in the University of Oxford. Salthrop, Wroughton, Wiltshire.
1886. §Mason, Hon. J. E. Fiji.
1879. ‡Mason, James, M.D. Montgomery House, Sheffield.
1868. ‡Mason, James Wood, F.G.S. The Indian Museum, Calcutta. (Care of Messrs. Henry S. King & Co., 65 Cornhill, London, E.C.)
1876. §Mason, Robert. 6 Albion-crescent, Dowanhill, Glasgow.
1876. ‡Mason, Stephen. 9 Rosslyn-terrace, Hillhead, Glasgow.
Massey, Hugh, Lord. Hermitage, Castleconnel, Co. Limerick.
1885. ‡Masson, Orme, D.Sc. 58 Great King-street, Edinburgh.
1883. ‡Mather, Robert V. Birkdale Lodge, Birkdale, Southport.
1865. *Mathews, G. S. 32 Augustus-road, Edgbaston, Birmingham.
1861. *MATHEWS, WILLIAM, M.A., F.G.S. 60 Harborne-road, Birmingham.
1881. ‡Mathwin, Henry, B.A. Bickerton House, Southport.
1883. ‡Mathwin, Mrs. 40 York-road, Birkdale, Southport.
1865. ‡Matthews, C. E. Waterloo-street, Birmingham.
1858. ‡Matthews, F. C. Mandre Works, Driffield, Yorkshire.
1885. ‡MATTHEWS, JAMES. Springhill, Aberdeen.
1885. ‡Matthews, J. Duncan. Springhill, Aberdeen.
1863. ‡Maughan, Rev. W. Benwell Parsonage, Newcastle-on-Tyne.
1865. *MAW, GEORGE, F.L.S., F.G.S., F.S.A. Kenley, Surrey.
1876. ‡Maxton, John. 6 Belgrave-terrace, Glasgow.
1864. *Maxwell, Francis. 4 Moray-place, Edinburgh.
*Maxwell, Robert Perceval. Finnebrogue, Downpatrick.
1883. §May, William, F.G.S., F.R.G.S. Northfield, St. Mary Cray, Kent.
1883. ‡Mayall, George. Clairville, Birkdale, Southport.
1868. ‡Mayall, J. E., F.C.S. Stork's Nest, Lancing, Sussex.
1884. *Maybury, A. C., D.Sc. 19 Bloomsbury-square, London, W.C.
1835. Mayne, Edward Ellis. Rocklands, Stillorgan, Ireland.
1878. *Mayne, Thomas. 33 Castle-street, Dublin.
1863. ‡Mease, George D. Lydney, Gloucestershire.
1878. §Meath, The Most Rev. C. P. Reichel, D.D., Bishop of. Meath.
1884. ‡Mecham, Arthur. 11 Newton-terrace, Glasgow.
1883. ‡*Medd, John Charles, M.A. 99 Park-street, Grosvenor-square, London, W.*
1881. ‡Meek, Sir James. Middlethorpe, York.
1871. ‡Meikie, James, F.S.S. 6 St. Andrew's-square, Edinburgh.
1879. §Meiklejohn, John W. S., M.D. 105 Holland-road, London, W.

Year of Election.

1881. *MELDOLA, RAPHAEL, F.R.S., F.R.A.S., F.C.S., F.I.C., Professor of Chemistry in the City and Guilds of London Institute, Finsbury Technical Institute. 6 Brunswick-square, London, W.C.
1867. ‡MELDRUM, CHARLES, C.M.G., M.A., F.R.S., F.R.A.S. Port Louis, Mauritius.
1883. ‡Mellis, Rev. James. 23 Park-street, Southport.
1879. *Mellish, Henry. Hodsock Priory, Worksop.
1866. ‡MELLO, Rev. J. M., M.A., F.G.S. St. Thomas's Rectory, Brampton, Chesterfield.
1883. §Mello, Mrs. J. M. St. Thomas's Rectory, Brampton, Chesterfield.
1854. ‡Melly, Charles Pierre. 11 Rumford-street, Liverpool.
1881. §Melrose, James. Clifton, York.
1847. ‡Melville, Professor Alexander Gordon, M.D. Queen's College, Galway.
1863. ‡Melvin, Alexander. 42 Buccleuch-place, Edinburgh.
1877. *Menabrea, General Count, LL.D. 14 Rue de l'Elysée, Paris.
1862. ‡MENNELL, HENRY T. St. Dunstan's-buildings, Great Tower-street, London, E.C.
1879. ‡Merivale, John Herman, Professor of Mining in the College of Science, Newcastle-on-Tyne.
1879. ‡Merivale, Walter. Engineers' Office, North-Eastern Railway, Newcastle-on-Tyne.
1877. ‡Merrifield, John, Ph.D., F.R.A.S. Gascoigne-place, Plymouth.
1880. ‡Merry, Alfred S. Bryn Heulog, Sketty, near Swansea.
1872. *Messent, John. 429 Strand, London, W.C.
1863. ‡Messent, P. T. 4 Northumberland-terrace, Tynemouth.
1869. ‡MIALL, LOUIS C., F.G.S., Professor of Biology in Yorkshire College, Leeds.
1886. §Middlemore, Thomas. Holloway Head, Birmingham.
1865. ‡Middlemore, William. Edgbaston, Birmingham.
1881. *Middlesbrough, The Right Rev. Richard Lacy, D.D., Bishop of. Middlesbrough.
1883. §Middleton, Henry. St. John's College, Cambridge.
1881. ‡Middleton, R. Morton, F.L.S., F.Z.S. Hudworth Cottage, Castle Eden, Co. Durham.
1876. *Middleton, Robert T. 197 West George-street, Glasgow.
1886. §Miles, Charles Albert. Buenos Ayres.
1881. §MILES, MORRIS. 44 Carlton-road, Southampton.
1885. §Mill, Hugh Robert, B.Sc., F.R.S.E., F.C.S. Scottish Marine Station, Granton, Edinburgh.
1859. ‡Millar, John, J.P. Lisburn, Ireland.
1863. ‡Millar, John, M.D., F.L.S., F.G.S. Bethnal House, Cambridge-road, London, E.
Millar, Thomas, M.A., LL.D., F.R.S.E. Perth.
1876. ‡Millar, William. Highfield House, Dennistoun, Glasgow.
1876. ‡Millar, W. J. 145 Hill-street, Garnethill, Glasgow.
1882. ‡Miller, A. J. High-street, Southampton.
1876. ‡Miller, Daniel. 258 St. George's-road, Glasgow.
1875. ‡Miller, George. Brentry, near Bristol.
1884. §Miller, Mrs. Hugh. 51 Lauriston-place, Edinburgh.
1885. ‡Miller, John. 9 Rubislaw-terrace, Aberdeen.
1886. §Miller, Rev. John. The College, Weymouth.
1861. *Miller, Robert. Cranage Hall, Holmes Chapel, Cheshire.
1876. *Miller, Robert. 1 Lily Bank-terrace, Hillhead, Glasgow.
1884. **Miller, Robert Kalley, M.A., Professor of Mathematics in the Royal Naval College, Greenwich, London, S.E.*
1884. ‡Miller, T. F., B.Ap.Sc. Napanee, Ontario, Canada.

Year of
Election.
1876. ‡Miller, Thomas Paterson. Cairns, Cambuslang, N.B.
1868. *MILLS, EDMUND J., D.Sc., F.R.S., F.C.S., Young Professor of Technical Chemistry in Anderson's College, Glasgow. 60 John-street, Glasgow.
1880. ‡Mills, Mansfeldt H. Tapton-grove, Chesterfield.
1834. Milne, Admiral Sir Alexander, Bart., G.C.B., F.R.S.E. 13 New-street, Spring-gardens, London, S.W.
1885. ‡Milne, Alexander D. 40 Albyn-place, Aberdeen.
1882. *Milne, John, F.G.S., Professor of Geology in the Imperial College of Engineering, Tokio, Japan. Ingleside, Birdhirst Rise, South Croydon, Surrey.
1885. ‡Milne, J. D. 14 Rubislaw-terrace, Aberdeen.
1885. ‡Milne, William. 40 Albyn-place, Aberdeen.
1867. *MILNE-HOME, DAVID, M.A., LL.D., F.R.S.E., F.G.S. 10 York-place, Edinburgh.
1882. §Milnes, Alfred, M.A., F.S.S. 30 Almeric-road, London, S.W.
1880. ‡Minchin, G. M., M.A. Royal Indian Engineering College, Cooper's Hill, Surrey.
1855. ‡Mirrlees, James Buchanan. 45 Scotland-street, Glasgow.
1859. ‡Mitchell, Alexander, M.D. Old Rain, Aberdeen.
1876. ‡Mitchell, Andrew. 20 Woodside-place, Glasgow.
1883. ‡Mitchell, Charles T., M.A. 41 Addison-gardens North, Kensington, London, W.
1883. ‡Mitchell, Mrs. Charles T. 41 Addison-gardens North, Kensington, London, W.
1863. ‡Mitchell, C. Walker. Newcastle-on-Tyne.
1873. ‡Mitchell, Henry. Parkfield House, Bradford, Yorkshire.
1885. ‡Mitchell, Rev. J. Mitford, B.A. 6 Queen's-terrace, Aberdeen.
1870. §Mitchell, John, J.P. York House, Clitheroe, Lancashire.
1868. ‡Mitchell, John, jun. Pole Park House, Dundee.
1885. §Mitchell, P. Chalmers. Christ Church, Oxford.
1862. **Mitchell, W. Stephen, M.A., LL.B.*
1879. ‡MIVART, ST. GEORGE, M.D., F.R.S., F.L.S., F.Z.S., Professor of Biology in University College, Kensington. 71 Seymour-street, London, W.
1884. §Moat, Robert. Spring Grove, Bewdley.
1885. §Moffat, William. 7 Union-place, Aberdeen.
1864. ‡Mogg, John Rees. High Littleton House, near Bristol.
1885. ‡Moir, James. 25 Carden-place, Aberdeen.
1861. ‡MOLESWORTH, Rev. W. NASSAU, M.A. Spotland, Rochdale.
1883. §Mollison, W. L., M.A. Clare College, Cambridge.
1878. §Molloy, Constantine, Q.C. 65 Lower Leeson-street, Dublin.
1877. *Molloy, Rev. Gerald, D.D. 86 Stephen's-green, Dublin.
1884. ‡Monaghan, Patrick. Halifax (Box 317), Nova Scotia, Canada.
1853. ‡Monroe, Henry, M.D. 10 North-street, Sculcoates, Hull.
1882. *Montagu, Samuel, M.P. 12 Kensington Palace-gardens, London, W.
1872. ‡Montgomery, R. Mortimer. 3 Porchester-place, Edgware-road, London, W.
1872. ‡Moon, W., LL.D. 104 Queen's-road, Brighton.
1884. §Moore, George Frederick. 25 Marlborough-road, Tue Brook, Liverpool.
1881. §Moore, Henry. Collingham, Maresfield-gardens, Fitzjohn's-avenue, London, N.W.
*MOORE, JOHN CARRICK, M.A., F.R.S., F.G.S. 113 Eaton-square, London, S.W.; and Corswall, Wigtonshire.
1854. ‡MOORE, THOMAS JOHN, Cor. M.Z.S. Free Public Museum, Liverpool.

Year of Election.
1877. ‡Moore, W. F. The Friary, Plymouth.
1857. *Moore, Rev. William Prior. The Royal School, Cavan, Ireland.
1877. ‡Moore, William Vanderkemp. 15 Princess-square, Plymouth.
1871. ‡MORE, ALEXANDER G., F.L.S., M.R.I.A. 3 Botanic View, Glasnevin, Dublin.
1881. ‡MORGAN, ALFRED. 50 West Bay-street, Jacksonville, Florida, U.S.A.
1873. ‡Morgan, Edward Delmar. 15 Rowland-gardens, London, W.
1885. ‡Morgan, John. 57 Thomson-street, Aberdeen.
1882. §Morgan, Thomas. Cross House, Southampton.
1878. ‡MORGAN, WILLIAM, Ph.D., F.C.S. Swansea.
1867. ‡Morison, William R. Dundee.
1883. §Morley, Henry Forster, M.A., B.Sc., F.C.S. University Hall, Gordon-square, London, W.C.
1881. ‡Morrell, W. W. York City and County Bank, York.
1880. ‡Morris, Alfred Arthur Vennor. Wernolau, Cross Inn R.S.O., Carmarthenshire.
1883. ‡Morris, C. S. Millbrook Iron Works, Landore, South Wales.
*Morris, Rev. Francis Orpen, B.A. Nunburnholme Rectory, Hayton, York.
1883. ‡Morris, George Lockwood. Millbrook Iron Works, Swansea.
1880. §Morris, James. 6 Windsor-street, Uplands, Swansea.
1883. ‡Morris, John. 40 Wellesley-road, Liverpool.
1880. ‡Morris, M. I. E. The Lodge, Penclawdd, near Swansea.
Morris, Samuel, M.R.D.S. Fortview, Clontarf, near Dublin.
1876. ‡Morris, Rev. S. S. O., M.A., R.N., F.C.S. H.M.S. 'Garnet,' S. Coast of America.
1874. ‡Morrison, G. J., M.Inst.C.E. 5 Victoria-street, Westminster, S.W.
1871. *Morrison, James Darsie. 27 Grange-road, Edinburgh.
1886. §Morrison, John T. Scottish Marine Station, Granton, N.B.
1865. §Mortimer, J. R. St. John's-villas, Driffield.
1869. ‡Mortimer, William. Bedford-circus, Exeter.
1857. §MORTON, GEORGE H., F.G.S. 122 London-road, Liverpool.
1858. *MORTON, HENRY JOSEPH. 2 Westbourne-villas, Scarborough.
1871. ‡Morton, Hugh. Belvedere House, Trinity, Edinburgh.
1886. *Morton, P. J. 10 The Grove, Highgate, London, N.
1868. ‡MOSELEY, H. N., M.A., LL.D., F.R.S., Linacre Professor of Human and Comparative Anatomy in the University of Oxford. 14 St. Giles's, Oxford.
1883. ‡Moseley, Mrs. 14 St. Giles's, Oxford.
Mosley, Sir Oswald, Bart., D.C.L. Rolleston Hall, Burton-upon-Trent, Staffordshire.
Moss, John. Otterspool, near Liverpool.
1878. *Moss, JOHN FRANCIS, F.R.G.S. Beechwood, Brincliffe, Sheffield.
1870. ‡Moss, John Miles, M.A. 2 Esplanade, Waterloo, Liverpool.
1876. §Moss, RICHARD JACKSON, F.C.S., M.R.I.A. St. Aubin's, Ballybrack, Co. Dublin.
1873. *Mosse, George Staley. 13 Scarsdale-villas, Kensington, London, W.
1864. *Mosse, J. R. Conservative Club, London, S.W.
1873. ‡*Mossman, William. Woodhall, Calverley, Leeds.*
1869. §MOTT, ALBERT J., F.G.S. Crickley Hill, Gloucester.
1865. ‡Mott, Charles Grey. The Park, Birkenhead.
1866. §MOTT, FREDERICK T., F.R.G.S. Birstall Hill, Leicester.
1862. *MOUAT, FREDERICK JOHN, M.D., Local Government Inspector. 12 Durham-villas, Campden Hill, London, W.
1856. ‡Mould, Rev. J. G., B.D. Fulmodeston Rectory, Dereham, Norfolk.

Year of Election.

1878. *Moulton, J. Fletcher, M.A., F.R.S. 74 Onslow-gardens, London, S.W.
1863. ‡Mounsey, Edward. Sunderland.
Mounsey, John. Sunderland.
1861. *Mountcastle, William Robert. Bridge Farm, Ellenbrook, near Manchester.
1877. ‡MOUNT-EDGCUMBE, The Right Hon. the Earl of, D.C.L. Mount-Edgcumbe, Devonport.
1882. ‡MOUNT-TEMPLE, The Right Hon. Lord. Broadlands, Romsey, Hants.
Mowbray, James. Combus, Clackmannan, Scotland.
1850. ‡Mowbray, John T. 15 Albany-street, Edinburgh.
1886. *Moyles, Mrs. Thomas. The Beeches, Ladywood-road, Edgbaston, Birmingham.
1884. ‡Moyse, C. E., B.A., Professor of English Language and Literature in McGill College, Montreal. 802 Sherbrooke-street, Montreal, Canada.
1884. ‡Moyse, Charles E. 802 Sherbrooke-street, Montreal, Canada.
1876. *Muir, John. 6 Park-gardens, Glasgow.
1874. ‡Muir, M. M. Pattison, M.A. F.R.S.E. Caius College, Cambridge.
1876. ‡Muir, Thomas, M.A., LL.D., F.R.S.E. Beechcroft, Bishopton, Renfrewshire.
1884. *Muir, William Ker. Detroit, Michigan, U.S.A.
1872. ‡Muirhead, Alexander, D.Sc., F.C.S. Cowley-street, Westminster, S.W.
1871. *MUIRHEAD, HENRY, M.D., LL.D. Bushy Hill, Cambuslang, Lanarkshire.
1876. *Muirhead, Robert Franklin, M.A., B.Sc. Meikle Cloak, Lochwinnoch, Renfrewshire.
1884. §Muirhead-Paterson, Miss Mary. Laurieville, Queen's Drive, Crosshill, Glasgow.
1883. §MULHALL, MICHAEL G. 19 Albion-street, Hyde-park, London, W.
1883. ‡Mulhall, Mrs. Marion. 19 Albion-street, Hyde-park, London, W.
1884. *MÜLLER, HUGO, Ph.D., F.R.S., F.C.S. 13 Park-square East, Regent's Park, London, N.W.
1880. ‡Muller, Hugo M. 1 Grünanger-gasse, Vienna.
Munby, Arthur Joseph. 6 Fig-tree-court, Temple, London, E.C.
1866. ‡MUNDELLA, The Right Hon. A. J., M.P., F.R.S., F.R.G.S. The Park, Nottingham.
1876. ‡Munro, Donald, F.C.S. The University, Glasgow.
1885. §Munro, J. E. Crawford, LL.D., Professor of Political Economy in Owens College, Manchester.
1883. *Munro, Robert. Braehead House, Kilmarnock, N.B.
1872. *Munster, H. Sillwood Lodge, Brighton.
1864. ‡MURCH, JEROM. Cranwells, Bath.
1864. *Murchison, K. R. Brockhurst, East Grinstead.
1855. ‡Murdoch, James B. Hamilton-place, Langside, Glasgow.
1852. ‡Murney, Henry, M.D. 10 Chichester-street, Belfast.
1852. ‡Murphy, Joseph John. Old Forge, Dunmurry, Co. Antrim.
1884. §Murphy, Patrick. Newry, Ireland.
1869. ‡Murray, Adam. Westbourne Sussex-gardens, Hyde-park, London, W.
Murray, John, F.G.S., F.R.G.S. 50 Albemarle-street, London, W.; and Newsted, Wimbledon, Surrey.
1859. ‡Murray, John, M.D. Forres, Scotland.
*Murray, John, M.Inst.C.E. Downlands, Sutton, Surrey.
1884. §MURRAY, JOHN, F.R.S.E. *Challenger* Expedition Office, Edinburgh.
1884. ‡Murray, J. Clark, LL.D., Professor of Logic and Mental and Moral Philosophy in McGill College, Montreal, 111 McKay-street, Montreal, Canada.

Year of Election.
1872. ‡Murray, J. Jardine, F.R.C.S.E. 99 Montpellier-road, Brighton.
1863. ‡Murray, William. 34 Clayton-street, Newcastle-on-Tyne.
1883. ‡Murray, W. Vaughan. 4 Westbourne-crescent, Hyde Park, London, W.
1874. §Musgrave, James, J.P. Drumglass House, Belfast.
1861. ‡Musgrove, John, jun. Bolton.
1870. *Muspratt, Edward Knowles. Seaforth Hall, near Liverpool.
1859. §MYLNE, ROBERT WILLIAM, F.R.S., F.G.S., F.S.A. 7 Whitehall-place, London, S.W.

1842. Nadin, Joseph. Manchester.
1886. §Nagel, D. H. Trinity College, Oxford.
1876. ‡Napier, James S. 9 Woodside-place, Glasgow.
1876. ‡*Napier, John. Saughfield House, Hillhead, Glasgow.*
1876. *Napier, Captain Johnstone. Laverstock House, Salisbury.
1872. ‡Nares, Captain Sir G. S., K.C.B., R.N., F.R.S., F.R.G.S. Maple-road, Surbiton.
1850. *NASMYTH, JAMES. Penshurst, Tunbridge.
1886. §Neale, E. Vansittart. 14 City-buildings, Corporation-street, Manchester.
1883. *Neild, Theodore. Dalton Hall, Manchester.
Neilson, Robert, J.P., D.L. Halewood, Liverpool.
1855. ‡Neilson, Walter. 172 West George-street, Glasgow.
1876. ‡Nelson, D. M. 11 Bothwell-street, Glasgow.
1886. §Nettlefold, Edward. 51 Carpenter-road, Edgbaston, Birmingham.
1868. ‡Nevill, Rev. H. R. The Close, Norwich.
1866. *Nevill, The Right Rev. Samuel Tarratt, D.D., F.L.S., Bishop of Dunedin, New Zealand.
1857. ‡Neville, John, M.R.I.A. Roden-place, Dundalk, Ireland.
1852. ‡NEVILLE, PARKE, M.Inst.C.E., M.R.I.A. 58 Pembroke-road, Dublin.
1869. ‡Nevins, John Birkbeck, M.D. 3 Abercromby-square, Liverpool.
1842. New, Herbert. Evesham, Worcestershire.
Newall, Henry. Hare Hill, Littleborough, Lancashire.
*Newall, Robert Stirling, F.R.S., F.R.A.S. Ferndene, Gateshead-upon-Tyne.
1886. §Newbolt, F. G. Cowley Grange, Oxford.
1879. ‡Newbould, John. Sharrow Bank, Sheffield.
1866. *Newdigate, Albert L. Engineer's Office, The Harbour, Dover.
1876. ‡*Newhaus, Albert. 1 Prince's-terrace, Glasgow.*
1883. ‡*Newman, Albert Robert. 33 Lisson-grove, Marylebone-road, London, N.W.*
1842. *NEWMAN, Professor FRANCIS WILLIAM. 15 Arundel-crescent, Weston-super-Mare.
1860. *NEWTON, ALFRED, M.A., F.R.S., F.L.S., Professor of Zoology and Comparative Anatomy in the University of Cambridge. Magdalene College, Cambridge.
1883. ‡Newton, A. W. 7A Westcliffe-road, Birkdale, Southport.
1872. ‡Newton, Rev. J. 125 Eastern-road, Brighton.
1865. ‡*Newton, Thomas Henry Goodwin. Clopton House, near Stratford-on-Avon.*
1886. §Newton, William. 18 Fenchurch-street, London, E.C.
1883. ‡Nias, Miss Isabel. 56 Montagu-square, London, W.
1882. ‡Nias, J. B., B.A. 56 Montagu-square, London, W.
1867. ‡Nicholl, Thomas. Dundee.
1875. ‡Nicholls, J. F. City Library, Bristol.
1866. ‡NICHOLSON, Sir CHARLES, Bart., M.D., D.C.L., LL.D., F.G.S., F.R.G.S. The Grange, Totteridge, Herts.

Year of Election.

1838. *Nicholson, Cornelius, F.G.S., F.S.A. Ashleigh, Ventnor, Isle of Wight.

1871. §Nicholson, E. Chambers. Herne Hill, London, S.E.

1867. ‡NICHOLSON, HENRY ALLEYNE, M.D., D.Sc., F.G.S., Professor of Natural History in the University of Aberdeen.

1884. §Nicholson, Joseph S., M.A., Professor of Political Economy in the University of Edinburgh. 15 Jordan-lane, Edinburgh.

1883. ‡Nicholson, Richard, J.P. Whinfield, Hesketh Park, Southport.

1881. ‡Nicholson, William R. Clifton, York.

1885. §Nicol, W. W. J., M.A., D.Sc., F.R.S.E. Mason Science College, Birmingham.

1878. ‡Niven, Charles, M.A., F.R.S., F.R.A.S., Professor of Natural Philosophy in the University of Aberdeen. Aberdeen.

1886. §Niven George. Erkingholme, Coolhurst-road, London, N.

1877. ‡Niven, James, M.A. King's College, Aberdeen.

1874. ‡Nixon, Randal C. J., M.A. Royal Academical Institution, Belfast.

1884. ‡Nixon, T. Alcock. 33 Harcourt-street, Dublin.

1863. *NOBLE, Captain ANDREW, C.B., F.R.S., F.R.A.S., F.C.S. Elswick Works, Newcastle-on-Tyne.

1880. ‡Noble, John. Rossenstein, Thornhill-road, Croydon, Surrey.

1879. ‡Noble, T. S., F.G.S. Lendal, York.

1886. §Nock, J. B. 8 Vicarage-road, Edgbaston, Birmingham.

1870. ‡Nolan, Joseph, M.R.I.A. 14 Hume-street, Dublin.

1882. §Norfolk, F. Elm Villa, Ordnance-road, Southampton.

1859. ‡Norfolk, Richard. Ladygate, Beverley.

1868. ‡Norgate, William. Newmarket-road, Norwich.

1863. §NORMAN, Rev. ALFRED MERLE, M.A., D.C.L., F.L.S. Burnmoor Rectory, Fence House, Co. Durham.

Norreys, Sir Denham Jephson, Bart. Mallow Castle, Co. Cork.

1865. ‡NORRIS, RICHARD, M.D. 2 Walsall-road, Birchfield, Birmingham.

1872. ‡Norris, Thomas George. Gorphwysfa, Llanrwst, North Wales.

1883. *Norris, William G. Coalbrookdale, Shropshire.

1881. §North, Samuel William, M.R.C.S., F.G.S. 84 Micklegate, York.

1881. ‡North, William, B.A., F.C.S. 28 Regent's Park-road, London, N.W.

*NORTHWICK, The Right Hon. Lord, M.A. 7 Park-street, Grosvenor-square, London, W.

NORTON, The Right Hon. Lord, K.C.M.G. 35 Eaton-place, London, S.W.; and Hamshall, Birmingham.

1886. §Norton, Lady. 35 Eaton-place, London, S.W.; and Hamshall, Birmingham.

1868. ‡Norwich, The Hon. and Right Rev. J. T. Pelham, D.D., Lord Bishop of. Norwich.

1861. ‡Noton, Thomas. Priory House, Oldham.

Nowell, John. Farnley Wood, near Huddersfield.

1878. ‡*Nugent, Edward. Seel's-buildings, Liverpool.*

1883. ‡Nunnerley, John. 46 Alexandra-road, Southport.

1883. ‡Nutt, Alfred. Rosendale Hall, West Dulwich, London, S.E.

1883. §Nutt, Miss Lilian. Rosendale Hall, West Dulwich, London, S.E.

1883. ‡Nutt, Miss Mabel. Rosendale Hall, West Dulwich, London, S.E.

1882. §Obach, Eugene, Ph.D. 2 Victoria-road, Old Charlton, Kent.

1878. ‡O'Brien, Murrough. 1 Willow-terrace, Blackrock, Co. Dublin.

O'Callaghan, George. Tallas, Co. Clare.

1878. ‡*O'Carroll, Joseph F. 78 Rathgar-road, Dublin.*

1878. ‡O'Conor Don, The. Clonalis, Castlerea, Ireland.

1883. ‡Odgers, William Blake, M.A., LL.D. 4 Elm-court, Temple, London, E.C.

Year of Election.

1858. *ODLING, WILLIAM, M.B., F.R.S., F.C.S., Waynflete Professor of Chemistry in the University of Oxford. 15 Norham-gardens, Oxford.

1884. ‡Odlum, Edward, M.A. Pembroke, Ontario, Canada.

1857. ‡O'Donnavan, William John. 54 Kenilworth-square, Rathgar, Dublin.

1877. §Ogden, Joseph. 21 Station-road, South Norwood, London, S.E.

1885. ‡Ogilvie, Alexander, LL.D. Gordon's College, Aberdeen.

1876. ‡Ogilvie, Campbell P. Sizewell House, Leiston, Suffolk.

1885. ‡Ogilvie, F. Grant, M.A., B.Sc. Gordon's College, Aberdeen.

1874. ‡*Ogilvie, Thomas Robertson. Bank Top, 3 Lyle-street, Greenock, N.B.*

1859. ‡Ogilvy, Rev. C. W. Norman. Baldovan House, Dundee.

1863. ‡OGILVY, Sir JOHN, Bart. Inverquharity, N.B.

*Ogle, William, M.D., M.A. The Elms, Derby.

1837. ‡O'Hagan, John, M.A., Q.C. 22 Upper Fitzwilliam-street, Dublin.

1884. §O'Halloran, J. S., F.R.G.S. Royal Colonial Institute, Northumberland-avenue, London, W.C.

1881. ‡Oldfield, Joseph. Lendal, York.

1853. ‡OLDHAM, JAMES, M.Inst.C.E. Cottingham, near Hull.

1885. §Oldham, John. River Plate Telegraph Company, Monte Video.

1863. ‡Oliver, Daniel, F.R.S., F.L.S., Professor of Botany in University College, London. Royal Gardens, Kew, Surrey.

1883. ‡Oliver, J. A. Westwood. Braehead House, Lochwinnoch, Scotland.

1883. §Oliver, Samuel A. Bellingham House, Wigan, Lancashire.

1882. §Olsen, O. T., F.R.A.S., F.R.G.S. 3 St. Andrew's-terrace, Grimsby.

*OMMANNEY, Admiral Sir ERASMUS, C.B., F.R.S., F.R.A.S., F.R.G.S. The Towers, Yarmouth, Isle of Wight.

1880. *Ommanney, Rev. E. A. 123 Vassal-road, Brixton, London, S.W.

1872. ‡Onslow, D. Robert. New University Club, St. James's, London, S.W.

1883. ‡Oppert, Gustav, Professor of Sanskrit. Madras.

1867. ‡Orchar, James G. 9 William-street, Forebank, Dundee.

1883. §Ord, Miss Maria. Fern Lea, Park-crescent, Southport.

1883. §Ord, Miss Sarah. Fern Lea, Park-crescent, Southport.

1880. ‡O'Reilly, J. P., Professor of Mining and Mineralogy in the Royal College of Science, Dublin.

1842. ORMEROD, GEORGE WAREING, M.A., F.G.S. Woodway, Teignmouth.

1861. ‡Ormerod, Henry Mere. Clarence-street, Manchester; and 11 Woodland-terrace, Cheetham Hill, Manchester.

1858. ‡Ormerod, T. T. Brighouse, near Halifax.

1835. ORPEN, JOHN H., LL.D., M.R.I.A. 58 Stephen's-green, Dublin.

1883. ‡Orpen, Miss. 58 Stephen's-green, Dublin.

1884. *Orpen, Captain R. T., R.E. 58 Stephen's-green, Dublin.

1884. *Orpen, Rev. T. H., M.A. Plas Dinas, Newnham, Cambridge.

1838. Orr, Alexander Smith. 57 Upper Sackville-street, Dublin.

1873. ‡Osborn, George. 47 Kingscross-street, Halifax.

1865. ‡Osborne, E. C. Carpenter-road, Edgbaston, Birmingham.

*OSLER, A. FOLLETT, F.R.S. South Bank, Edgbaston, Birmingham.

1865. *Osler, Henry F. Coppy Hill, Linthurst, near Bromsgrove, Birmingham.

1869. *Osler, Sidney F. Chesham Lodge, Lower Norwood, Surrey, S.E.

1884. ‡Osler, William, M.D., Professor of the Institutes of Medicine in McGill University, Montreal, Canada.

Year of Election.
1884. ‡O'Sullivan, James, F.C.S. 71 Spring Terrace-road, Burton-on-Trent.
1882. *Oswald, T. R. New Place House, Southampton.
1881. *Ottewell, Alfred D. 83 Siddals-road, Derby.
1882. ‡Owen, Rev. C. M., M.A. St. George's, Edgbaston, Birmingham.
1870. ‡Owen, Harold. Tue Brook Villa, Liverpool.
OWEN, Sir RICHARD, K.C.B., M.D., D.C.L., LL.D., F.R.S., F.L.S., F.G.S., Hon. F.R.S.E. Sheen Lodge, Mortlake, Surrey, S.W.
1884. §Owen, Professor Richard, M.D., LL.D. New Harmony, Indiana, U.S.A.
1877. ‡Oxland, Dr. Robert, F.C.S. 8 Portland-square, Plymouth.

1883. ‡Page, George W. Fakenham, Norfolk.
1883. ‡Page, Joseph Edward. 12 Saunders-street, Southport.
1872. *Paget, Joseph. Stuffynwood Hall, Mansfield, Nottingham.
1884. ‡Paine, Cyrus F. Rochester, New York, U.S.A.
1875. ‡Paine, William Henry, M.D., F.G.S. Stroud, Gloucestershire.
1870. *PALGRAVE, R. H. INGLIS, F.R.S., F.S.S. Belton, Great Yarmouth.
1883. ‡Palgrave, Mrs. R. H. Inglis. Belton, Great Yarmouth.
1873. ‡Palmer, George, M.P. The Acacias, Reading, Berks.
1878. *Palmer, Joseph Edward. Lyons Mills, Straffan Station, Dublin.
1866. §Palmer, William. Kilbourne House, Cavendish Hill, Sherwood, Notts.
1872. *Palmer, W. R. 1 The Cloisters, Temple, E.C.
Palmes, Rev. William Lindsay, M.A. Naburn Hall, York.
1883. §Pant, F. J. van der. Clifton Lodge, Kingston-on-Thames.
1886. §Panton, George A., F.R.S.E. 47 Wheeley's-road, Edgbaston, Birmingham.
1884. §Panton, Professor J. Hoyes, M.D. Ontario Agricultural College, Guelph, Ontario, Canada.
1883. ‡Park, Henry. Wigan.
1883. ‡Park, Mrs. Wigan.
1880. *Parke, George Henry, F.L.S., F.G.S. Barrow-in-Furness, Lancashire.
1863. ‡Parker, Henry. Low Elswick, Newcastle-on-Tyne.
1863. ‡Parker, Rev. Henry. Idlerton Rectory, Low Elswick, Newcastle-on-Tyne.
1874. ‡Parker, Henry R., LL.D. Methodist College, Belfast.
Parker, Richard. Dunscombe, Cork.
1886. §Parker, Lawley. Chad Lodge, Edgbaston, Birmingham.
1865. **Parker, Walter Mantel. High-street, Alton, Hants.*
1853. ‡Parker, William. Thornton-le-Moor, Lincolnshire.
1865. *Parkes, Samuel Hickling, F.L.S. 6 St. Mary's-row, Birmingham.
1864. ‡PARKES, WILLIAM. 23 Abingdon-street, Westminster, S.W.
1879. §Parkin, William, F.S.S. The Mount, Sheffield.
1859. ‡Parkinson, Robert, Ph.D. West View, Toller-lane, Bradford, Yorkshire.
1841. Parnell, Edward A., F.C.S. Ashley Villa, Swansea.
1862. *Parnell, John, M.A. 1 The Common, Upper Clapton, London, E.
Parnell, Richard, M.D., F.R.S.E. Gattonside Villa, Melrose, N.B.
1883. ‡Parson, T. Cooke, M.R.C.S. Atherston House, Clifton, Bristol.
1877. ‡Parson, T. Edgcumbe. 36 Torrington-place, Plymouth.
1865. *Parsons, Charles Thomas. Norfolk-road, Edgbaston, Birmingham.
1878. ‡Parsons, Hon. C. A. 10 Connaught-place, London, W.
1878. ‡Parsons, Hon. and Rev. R. C. 10 Connaught-place, London, W.

Year of Election.

1883. ‡*Part, C. T. 5 King's Bench-walk, Temple, London, E.C.*
1883. ‡Part, Isabella. Rudleth, Watford, Herts.
1875. ‡Pass, Alfred C. Rushmere House, Durdham Down, Bristol.
1881. §Patchitt, Edward Cheshire. 128 Derby-road, Nottingham.
1884. *Paton, David. Johnstone, Scotland.
1883. §Paton, Henry, M.A. 15 Myrtle-terrace, Edinburgh.
1884. *Paton, Hugh. 992 Sherbrooke-street, Montreal, Canada.
1883. ‡Paton, Rev. William. Mossfield House, New Ferry, Chester.
1861. ‡Patterson, Andrew. Deaf and Dumb School, Old Trafford, Manchester.
1871. *Patterson, A. Henry. 3 New-square, Lincoln's Inn, London, W.C.
1884. ‡Patterson, Edward Mortimer. Fredericton, New Brunswick, Canada.
1863. ‡Patterson, H. L. Scott's House, near Newcastle-on-Tyne.
1867. ‡Patterson, James. Kinnettles, Dundee.
1876. ‡Patterson, T. L. Belmont, Margaret-street, Greenock.
1874. ‡Patterson, W. H., M.R.I.A. 26 High-street, Belfast.
1863. ‡Pattinson, John, F.C.S. 75 The Side, Newcastle-on-Tyne.
1863. ‡Pattinson, William. Felling, near Newcastle-upon-Tyne.
1867. §Pattison, Samuel Rowles, F.G.S. 11 Queen Victoria-street, London, E.C.
1864. ‡Pattison, Dr. T. H. London-street, Edinburgh.
1879. *Patzer, F. R. Stoke-on-Trent.
1863. ‡PAUL, BENJAMIN H., Ph.D. 1 Victoria-street, Westminster, S.W.
1883. ‡Paul, G., F.G.S. Moortown, Leeds.
1863. ‡PAVY, FREDERICK WILLIAM, M.D., F.R.S. 35 Grosvenor-street, London, W.
1864. ‡Payne, Edward Turner. 3 Sydney-place, Bath.
1881. ‡Payne, J. Buxton. 15 Mosley-street, Newcastle-on-Tyne.
1877. *Payne, J. C. Charles. Botanic-avenue, The Plains, Belfast.
1881. ‡Payne, Mrs. Botanic-avenue, The Plains, Belfast.
1866. ‡Payne, Dr. Joseph F. 78 Wimpole-street, London, W.
1886. §Payton, Henry. Eversleigh, Somerset-road, Birmingham.
1876. ‡Peace, G. H. Monton Grange, Eccles, near Manchester.
1879. ‡Peace, William K. Western Bank, Sheffield.
1885. ‡Peach, B. N., F.R.S.E., F.G.S. Geological Survey Office, Edinburgh.
1883. ‡Peacock, Ebenezer. 8 Mandeville-place, Manchester-square, London, W.
1875. ‡Peacock, Thomas Francis. 12 South-square, Gray's Inn, London, W.C.
1881. *PEARCE, HORACE, F.L.S., F.G.S. The Limes, Stourbridge.
1886. *Pearce, Mrs. Horace. The Limes, Stourbridge.
1882. §Pearce, Walter, M.B., B.Sc., F.C.S. St. Mary's Hospital, Paddington, London, W.; and Craufurd, Ray Mead, Maidenhead.
1884. ‡Pearce, William. Winnipeg, Canada.
1876. ‡Pearce, W. Elmpark House, Govan, Glasgow.
1886. §Pearsall, Howard D. 3 Cursitor-street, London, E.C.
1881. ‡Pearse, Richard Seward. Southampton.
1883. ‡Pearson, Arthur A. Colonial Office, London, S.W.
1883. ‡Pearson, Miss Helen E. 69 Alexandra-road, Southport.
1881. ‡Pearson, John. Glentworth House, The Mount, York.
1883. ‡Pearson, Mrs. Glentworth House, The Mount, York.
1872. *Pearson, Joseph. Grove Farm, Merlin, Raleigh, Ontario, Canada.
1881. ‡Pearson, Richard. 23 Bootham, York.
1870. ‡Pearson, Rev. Samuel. 48 Prince's-road, Liverpool.
1883. *Pearson, Thomas H. Golborne Park, near Newton-le-Willows, Lancashire.

Year of Election.

1863. §Pease, H. F. Brinkburn, Darlington.
1863. ‡Pease, Sir Joseph W., Bart., M.P. Hutton Hall, near Guisborough.
1863. ‡Pease, J. W. Newcastle-on-Tyne.
1883. ‡Peck, John Henry. 52 Hoghton-street, Southport.
Peckitt, Henry. Carlton Husthwaite, Thirsk, Yorkshire.
1855. *Peckover, Alexander, F.S.A., F.L.S., F.R.G.S. Bank House, Wisbech, Cambridgeshire.
*Peckover, Algernon, F.L.S. Sibald's Holme, Wisbech, Cambridgeshire.
1885. ‡Peddie, W. Spring Valley Villa, Morningside-road, Edinburgh.
1884. ‡Peebles, W. E. 9 North Frederick-street, Dublin.
1883. ‡Peek, C. E. Conservative Club, London, S.W.
1878. *Peek, William. 54 Woodstock-road, Bedford Park, Chiswick, London, W.
*Peel, George. Soho Iron Works, Manchester.
1873. ‡Peel, Thomas. 9 Hampton-place, Bradford, Yorkshire.
1881. ‡Peggs, J. Wallace. 21 Queen Anne's-gate, London, S.W.
1884. §Pegler, Alfred. Maybush Lodge, Old Shirley, Southampton.
1861. *Peile, George, jun. Shotley Bridge, Co. Durham.
1878. ‡Pemberton, Charles Seaton. 44 Lincoln's Inn-fields, London, W.C.
1865. ‡Pemberton, Oliver. 18 Temple-row, Birmingham.
1861. *Pender, John, M.P. 18 Arlington-street, London, S.W.
1856. §PENGELLY, WILLIAM, F.R.S., F.G.S. Lamorna, Torquay.
1881. ‡Penty, W. G. Melbourne-street, York.
1875. ‡Perceval, Rev. Canon John, M.A., LL.D. Rugby.
1845. ‡PERCY, JOHN, M.D., F.R.S., F.G.S. 1 Gloucester-crescent, Hyde Park, London, W.
*Perigal, Frederick. Thatched House Club, St. James's-street, London, S.W.
1886. §Perkin, T. Dix. Greenford Green, Harrow, Middlesex.
1868. *PERKIN, WILLIAM HENRY, Ph.D., F.R.S., F.C.S. The Chestnuts, Sudbury, Harrow, Middlesex.
1884. ‡Perkin, William Henry, jun., Ph.D. The Chestnuts, Sudbury, Harrow, Middlesex.
1877. ‡Perkins, Loftus. Seaford-street, Regent-square, London, W.C.
1864. *Perkins, V. R. Wotton-under-Edge, Gloucestershire.
1886. §Perrin, Miss Ellen. 31 St. John's Wood Park, London, N.W.
1885. §Perrin, Miss Emily. Girton College, Cambridge.
1886. §Perrin, Henry S. 31 St. John's Wood Park, London, N.W.
1886. §Perrin, Mrs. 23 Holland Villas-road, Kensington, London, W.
Perry, The Right Rev. Charles, M.A., D.D. 32 Avenue-road, Regent's Park, London, N.W.
1879. ‡Perry, James. Roscommon.
1874. *PERRY, JOHN, LL.D., F.R.S., Professor of Engineering and Applied Mathematics in the Technical College, Finsbury. 10 Penywern-road, South Kensington, London, S.W.
1883. ‡Perry, Ottley L., F.R.G.S. Bolton-le-Moors, Lancashire.
1883. ‡Perry, Russell R. 34 Duke-street, Brighton.
1870. *PERRY, Rev. S. J., LL.D., F.R.S., F.R.A.S., F.R.M.S. Stonyhurst College Observatory, Whalley, Blackburn.
1886. §Perry, William. Hanbury Villa, Stourbridge.
1885. ‡Peter, Rev. James. Manse of Deer, Mintlaw, N.B.
1883. §Petrie, Miss Anne S. Stone Hill, Rochdale.
1883. ‡Petrie, Miss Isabella. Stone Hill, Rochdale.
Peyton, Abel. Oakhurst, Edgbaston, Birmingham.

Year of Election.

1871. *Peyton, John E. H., F.R.A.S., F.G.S. 108 Marina, St. Leonard's-on-Sea.
1882. ‡Pfoundes, Charles, F.R.G.S. Spring Gardens, London, S.W.
1886. §Phelps, Colonel A. 23 Augustus-road, Edgbaston, Birmingham.
1884. ‡Phelps, Charles Edgar. Carisbrooke House, The Park, Nottingham.
1884. ‡Phelps, Mrs. Carisbrooke House, The Park, Nottingham.
1886. §Phelps, Hon. E. J. American Legation, Members' Mansions, Victoria-street, London, S.W.
1886. §Phelps, Mrs. Hamshall, Birmingham.
1863. *PHENÉ, JOHN SAMUEL, LL.D., F.S.A., F.G.S., F.R.G.S. 5 Carlton-terrace, Oakley-street, London, S.W.
1870. ‡Philip, T. D. 51 South Castle-street, Liverpool.
1853. *Philips, Rev. Edward. Hollington, Uttoxeter, Staffordshire.
1853. *Philips, Herbert. The Oak House, Macclesfield.
Philips, Robert N., M.P. The Park, Manchester.
1877. §Philips, T. Wishart. 53 Tredegar-square, Bow, London, E.
1863. ‡Philipson, Dr. 1 Savile-row, Newcastle-on-Tyne.
1883. ‡Phillips, Arthur G. 20 Canning-street, Liverpool.
1862. ‡Phillips, Rev. George, D.D. Queen's College, Cambridge.
1880. §Phillips, John H., Hon. Sec. Philosophical and Archæological Society, Scarborough.
1883. ‡Phillips, Mrs. Leah R. 1 East Park-terrace, Southampton.
1883. ‡Phillips, S. Rees. Wanford House, Exeter.
1881. ‡Phillips, William. 9 Bootham-terrace, York.
1868. ‡PHIPSON, T. L., Ph.D., F.C.S. 4 The Cedars, Putney, Surrey, S.W.
1884. *Pickard, Rev. H. Adair, M.A. 5 Canterbury-road, Oxford.
1883. *Pickard, Joseph William. Lindow-square, Lancaster.
1885. *Pickering, Spencer U. 48 Bryanston-square, London, W.
1864. ‡Pickering, William. Oak View, Clevedon.
1884. *Pickett, Thomas E., M.D. Maysville, Mason County, Kentucky, U.S.A.
1870. ‡Picton, J. Allanson, F.S.A. Sandyknowe, Wavertree, Liverpool.
1871. ‡Pigot, Thomas F., M.R.I.A. Royal College of Science, Dublin.
*Pike, Ebenezer. Besborough, Cork.
1884. ‡Pike, L. G., M.A., F.Z.S. 4 The Grove, Highgate, London, N.
1865. ‡PIKE, L. OWEN. 201 Maida-vale, London, W.
1873. ‡Pike, W. H. University College, Toronto, Canada.
1857. ‡Pilkington, Henry M., LL.D., Q.C. 45 Upper Mount-street, Dublin.
1883. ‡Pilling, R. C. The Robin's Nest, Blackburn.
Pim, George, M.R.I.A. Brenanstown, Cabinteely, Co. Dublin.
1877. ‡Pim, Joseph T. Greenbank, Monkstown, Co. Dublin.
1884. ‡Pinart, A. G. N. L. 74 Market-street, San Francisco, U.S.A.
1868. ‡Pinder, T. R. St. Andrew's, Norwich.
1876. ‡PIRIE, Rev. G., M.A., Professor of Mathematics in the University of Aberdeen. 33 College Bounds, Old Aberdeen.
1884. ‡Pirz, Anthony. Long Island, New York, U.S.A.
1875. ‡Pitman, John. Redcliff Hill, Bristol.
1883. ‡Pitt, George Newton, M.A., M.D. 34 Ashburn-place, South Kensington, London, S.W.
1864. ‡Pitt, R. 5 Widcomb-terrace, Bath.
1883. ‡Pitt, Sydney. 34 Ashburn-place, South Kensington, London, S.W.
1868. ‡PITT-RIVERS, Lieut.-General A. H. L., F.R.S., F.G.S., F.S.A. 4 Grosvenor-gardens, London, S.W.
1872. ‡Plant, Mrs. H. W. 28 Evington-street, Leicester.
1869. §PLANT, JAMES, F.G.S. 40 West-terrace, West-street, Leicester.

Year of Election.

1886. §Player, J. H. 5 Prince of Wales-terrace, Kensington, London, W.

1842. PLAYFAIR, The Right Hon. Sir LYON, K.C.B., Ph.D., LL.D., M.P., F.R.S. L. & E., F.C.S. 68 Onslow-gardens, South Kensington, London, S.W.

1867. ‡PLAYFAIR, Lieut.-Colonel Sir R. L., K.C.M.G., H.M. Consul, Algeria. (Messrs. King & Co., Pall Mall, London, S.W.)

1884. *Playfair, W. S., M.D., LL.D., Professor of Midwifery in King's College, London. 31 George-street, Hanover-square, London, W.

1883. *Plimpton, R. T., M.D. 23 Lansdowne-road, Clapham-road, London, S.W.

1857. ‡Plunkett, Thomas. Ballybrophy House, Borris-in-Ossory, Ireland.

1861. *POCHIN, HENRY DAVIS, F.C.S. Bodnant Hall, near Conway.

1881. §Pocklington, Henry. 20 Park-row, Leeds.

1846. ‡POLE, WILLIAM, Mus.Doc., F.R.S., M.Inst.C.E. Athenæum Club, Pall Mall, London, S.W.

*Pollexfen, Rev. John Hutton, M.A. Middleton Tyas Vicarage, Richmond, Yorkshire.

Pollock, A. 52 Upper Sackville-street, Dublin.

1862. *Polwhele, Thomas Roxburgh, M.A., F.G.S. Polwhele, Truro, Cornwall.

1854. ‡Poole, Braithwaite. Birkenhead.

1868. ‡PORTAL, WYNDHAM S. Malshanger, Basingstoke.

1883. *Porter, Rev. C. T., LL.D. Kensington House, Southport.

1874. ‡Porter, Rev. J. Leslie, D.D., LL.D., President of Queen's College, Belfast.

1886. §Porter, Paxton. Birmingham and Midland Institute, Birmingham.

1866. §Porter, Robert. Montpelier Cottage, Beeston, Nottingham.

1883. ‡Postgate, Professor J. P., M.A. Trinity College, Cambridge.

1863. ‡Potter, D. M. Cramlington, near Newcastle-on-Tyne.

1883. ‡Potter, M. C., B.A. St. Peter's College, Cambridge.

Potter, Richard, M.A. 10 Brookside, Cambridge.

1883. §Potts, John. 33 Chester-road, Macclesfield.

1886. *Poulton, Edward B., M.A. Wykeham House, Oxford.

1857. *POUNDEN, Captain LONSDALE, F.R.G.S. Junior United Service Club, St. James's-square, London, S.W.; and Brownswood House, Enniscorthy, Co. Wexford.

1873. *Powell, Francis S., M.P., F.R.G.S. Horton Old Hall, Yorkshire; and 1 Cambridge-square, London, W.

1883. §Powell, John. Wannarlwydd House, near Swansea.

1875. ‡Powell, William Augustus Frederick. Norland House, Clifton, Bristol.

1867. ‡Powrie, James. Reswallie, Forfar.

1855. *Poynter, John E. Clyde Neuk, Uddingston, Scotland.

1883. ‡POYNTING, J. H., M.A., Professor of Physics in the Mason College, Birmingham. 385 Hagley-road, Edgbaston, Birmingham.

1884. §Prance, Courtenay C. Hatherley Court, Cheltenham.

1884. *Prankerd, A. A., M.A., B.C.L., Law Lecturer in the University of Oxford. Trinity College, Oxford.

1869. *PREECE, WILLIAM HENRY, F.R.S., M.Inst.C.E. Gothic Lodge, Wimbledon Common, Surrey.

1884. *Premio-Real, His Excellency the Count of. Quebec, Canada.

*PRESTWICH, JOSEPH, M.A., F.R.S., F.G.S., F.C.S., Professor of Geology in the University of Oxford. 35 St. Giles's, Oxford; and Shoreham, near Sevenoaks.

1884. *Prevost, Major L. de T. 2nd Battalion Argyll and Sutherland Highlanders.

1871. ‡Price, Astley Paston. 47 Lincoln's-Inn-fields, London, W.C

Year of Election.

1856. *PRICE, Rev. BARTHOLOMEW, M.A., F.R.S., F.R.A.S., Sedleian Professor of Natural Philosophy in the University of Oxford, 11 St. Giles's, Oxford.
1872. ‡Price, David S., Ph.D. 26 Great George-street, Westminster, S.W.
1882. ‡*Price, John E., F.S.A.* 60 *Albion-road, Stoke Newington, London, N.*
Price, J. T. Neath Abbey, Glamorganshire.
1881. §Price, Peter. Crockherbtown, Cardiff.
1875. *Price, Rees. 1 Montague-place, Glasgow.
1875. *Price, William Philip. Tibberton Court, Gloucester.
1876. ‡Priestley, John. 174 Lloyd-street, Greenheys, Manchester.
1875. ‡Prince, Thomas. 6 Marlborough-road, Bradford, Yorkshire.
1883. §Prince, Thomas. Horsham-road, Dorking.
1864. *Prior, R. C. A., M.D. 48 York-terrace, Regent's Park, London, N.W.
1846. *PRITCHARD, Rev. CHARLES, D.D., F.R.S., F.G.S., F.R.A.S., Professor of Astronomy in the University of Oxford. 8 Keble-terrace, Oxford.
1876. *PRITCHARD, URBAN, M.D., F.R.C.S. 3 George-street, Hanover-square, London, W.
1881. §Procter, John William. Ashcroft, Nunthorpe, York.
1863. ‡Proctor, R. S. Summerhill-terrace, Newcastle-on-Tyne.
Proctor, William. Elmhurst, Higher Erith-road, Torquay.
1885. ‡Profeit, Dr. Balmoral, N.B.
1863. **Prosser, Thomas.* 25 *Harrison-place, Newcastle-on-Tyne.*
1863. ‡Proud, Joseph. South Hetton, Newcastle-on-Tyne.
1884. *Proudfoot, Alexander. 2 Phillips-place, Montreal, Canada.
1879. *Prouse, Oswald Milton, F.G.S., F.R.G.S. 4 Cambridge-villas, Richmond Park-road, Kingston-on-Thames.
1865. ‡Prowse, Albert P. Whitchurch Villa, Mannamead, Plymouth.
1872. *Pryor, M. Robert. Weston Manor, Stevenage, Herts.
1871. *Puckle, Thomas John. Woodcote-grove, Carshalton, Surrey.
1873. ‡Pullan, Lawrence. Bridge of Allan, N.B.
1867. *Pullar, Robert, F.R.S.E. Tayside, Perth.
1883. *Pullar, Rufus D., F.C.S. Tayside, Perth.
1842. *Pumphrey, Charles. Southfield, King's Norton, near Birmingham.
Punnet, Rev. John, M.A., F.C.P.S. St. Earth, Cornwall.
1885. §Purdie, Professor Thomas. St. Andrews, N.B.
1852. ‡Purdon, Thomas Henry, M.D. Belfast.
1860. ‡PURDY, FREDERICK, F.S.S., Principal of the Statistical Department of the Poor Law Board, Whitehall, London. Victoria-road, Kensington, London, W.
1881. ‡Purey-Cust, Very Rev. Arthur Percival, M.A., Dean of York. The Deanery, York.
1882. ‡Purrott, Charles. West End, near Southampton.
1874. ‡PURSER, FREDERICK, M.A. Rathmines, Dublin.
1866. ‡PURSER, Professor JOHN, M.A., M.R.I.A. Queen's College, Belfast.
1878. ‡Purser, John Mallet. 3 Wilton-terrace, Dublin.
1884. *Purves, W. Laidlaw. 20 Stafford-place, Oxford-street, London, W.
1860. *Pusey, S. E. B. Bouverie. Pusey House, Faringdon.
1883. §Pye-Smith, Arnold. 16 Fairfield-road, Croydon.
1883. §Pye-Smith, Mrs. 16 Fairfield-road, Croydon.
1868. §PYE-SMITH, P. H., M.D., F.R.S. 54 Harley-street, W.; and Guy's Hospital, London, S.E.
1879. §Pye-Smith, R. J. 6 Surrey-street, Sheffield.
1861. *Pyne, Joseph John. The Willows, Albert-road, Southport.

Year of Election.

1870. ‡Rabbits, W. T. Forest Hill, London, S.E.
1860. ‡RADCLIFFE, CHARLES BLAND, M.D. 25 Cavendish-square, London, W.
1870. ‡Radcliffe, Sir D. R. Phœnix Safe Works, Windsor, Liverpool.
1877. ‡Radford, George D. Mannamead, Plymouth.
1879. ‡Radford, R. Heber. Wood Bank, Pitsmoor, Sheffield.
*Radford, William, M.D. Sidmount, Sidmouth.
1855. *Radstock, The Right Hon. Lord. 70 Portland-place, London, W.
1878. ‡RAE, JOHN, M.D., LL.D., F.R.S., F.R.G.S. 4 Addison-gardens, Kensington, London, W.
1854. ‡Raffles, Thomas Stamford. 13 Abercromby-square, Liverpool.
1864. ‡Rainey, James T. St. George's Lodge, Bath.
Rake, Joseph. Charlotte-street, Bristol.
1863. ‡RAMSAY, ALEXANDER, F.G.S. 2 Cowper-road, Acton, Middlesex, W.
1845. ‡RAMSAY, Sir ANDREW CROMBIE, LL.D., F.R.S., F.G.S. 15 Cromwell-crescent, South Kensington, London, S.W.
1884. ‡Ramsay, George G., LL.D., Professor of Humanity in the University of Glasgow. 6 The College, Glasgow.
1884. ‡Ramsay, Mrs. G. G. 6 The College, Glasgow.
1861. ‡Ramsay, John. Kildalton, Argyleshire.
1884. ‡RAMSAY, R. A. 1134 Sherbrooke-street, Montreal, Canada.
1867. **Ramsay, W. F., M.D. 39 Hammersmith-road, West Kensington, London, W.*
1876. *RAMSAY, WILLIAM, Ph.D., Professor of Chemistry in University College, Bristol.
1883. ‡Ramsay, Mrs. 10 Osborne-road, Clifton, Bristol.
1885. ‡Ramsay, Major. Straloch, N.B.
1873. *Ramsden, William. Bracken Hall, Great Horton, Bradford, Yorkshire.
1835. *Rance, Henry. St. Andrew's-street, Cambridge.
1869. *Rance, H. W. Henniker, LL.D. 10 Castletown-road, West Kensington, London, S.W.
1865. ‡Randel, J. 50 Vittoria-street, Birmingham.
1868. *Ransom, Edwin, F.R.G.S. Ashburnham-road, Bedford.
1863. §Ransom, William Henry, M.D., F.R.S. The Pavement, Nottingham.
1861. ‡Ransome, Arthur, M.A., M.D., F.R.S. Devisdale, Bowdon, Manchester.
Ransome, Thomas. 34 Princess-street, Manchester.
1872. *Ranyard, Arthur Cowper, F.R.A.S. 25 Old-square, Lincoln's Inn, London, W.C.
Rashleigh, Jonathan. 3 Cumberland-terrace, Regent's Park, London, N.W.
1864. ‡Rate, Rev. John, M.A. Lapley Vicarage, Penkridge, Staffordshire.
1870. ‡Rathbone, Benson. Exchange-buildings, Liverpool.
1870. ‡Rathbone, Philip H. Greenbank Cottage, Wavertree, Liverpool.
1870. §Rathbone, R. R. Beechwood House, Liverpool.
1874. ‡RAVENSTEIN, E. G., F.R.G.S. 29 Lambert-road, Brixton, London, S.W.
Rawdon, William Frederick, M.D. Bootham, York.
1870. ‡Rawlins, G. W. The Hollies, Rainhill, Liverpool.
1866. *RAWLINSON, Rev. Canon GEORGE, M.A., Camden Professor of Ancient History in the University of Oxford. The Oaks, Precincts, Canterbury.
1855. *RAWLINSON, Major-General Sir HENRY C., K.C.B., LL.D., F.R.S., F.R.G.S. 21 Charles-street, Berkeley-square, London, W.
1875. §RAWSON, Sir RAWSON W., K.C.M.G., C.B., F.R.G.S. 68 Cornwall-gardens, Queen's-gate, London, S.W.

Year of
Election.
1886. §Rawson, W. Stepney, M.A., F.C.S. 68 Cornwall-gardens, Queen's-gate, London, S.W.
1883. ‡Ray, Miss Catherine. Mount Cottage, Flask-walk, Hampstead, London, N.W.
1868. *RAYLEIGH, The Right Hon. Lord, M.A., D.C.L., LL.D., Sec.R.S., F.R.A.S., F.R.G.S. Terling Place, Witham, Essex.
1883. *Rayne, Charles A., M.B., B.Sc., M.R.C.S. 3 Queen-street, Lancaster.
1865. ‡Read, William. Albion House, Epworth, Rawtry.
*Read, W. H. Rudston, M.A., F.L.S. 12 Blake-street, York.
1870. ‡READE, THOMAS MELLARD, F.G.S. Blundellsands, Liverpool.
1884. §Readman, J. B., F.R.S.E. 9 Moray-place, Edinburgh.
1862. *Readwin, Thomas Allison, M.R.I.A., F.G.S. 5 Crowhurst-road, Brixton, London, S.W.
1852. *REDFERN, Professor PETER, M.D. 4 Lower-crescent, Belfast.
1863. ‡Redmayne, Giles. 20 New Bond-street, London, W.
Redwood, Isaac. Cae Wern, near Neath, South Wales.
1861. ‡REED, Sir EDWARD J., K.C.B., M.P., F.R.S. 74 Gloucester-road, South Kensington, London, W.
1875. ‡Rees-Mogg, W. Wooldridge. Cholwell House, near Bristol.
1881. §Reid, Arthur S., B.A., F.G.S. Trinity College, Glenalmond, N.B.
1883. *REID, CLEMENT, F.G.S. 28 Jermyn-street, London, S.W.
1876. ‡Reid, James. 10 Woodside-terrace, Glasgow.
1884. ‡Reid, Rev. James, B.A. Bay City, Michigan, U.S.A.
1850. ‡Reid, William, M.D. Cruivie, Cupar, Fife.
1881. ‡Reid, William. 19½ Blake-street, York.
1875. §REINOLD, A. W., M.A., F.R.S., Professor of Physical Science in the Royal Naval College, Greenwich, S.E.
1863. §RENALS, E. 'Nottingham Express' Office, Nottingham.
1863. ‡*Rendel, G. Benwell, Newcastle-on-Tyne.*
1885. ‡Rennett, Dr. 12 Golden-square, Aberdeen.
1867. ‡Renny, W. W. 8 Douglas-terrace, Broughty Ferry, Dundee.
1884. ‡Retallack, Captain Francis. 6 Beauchamp-avenue, Leamington.
1883. *Reynolds, A. H. Manchester and Salford Bank, Southport.
1871. ‡REYNOLDS, JAMES EMERSON, M.A., F.R.S., F.C.S., M.R.I.A., Professor of Chemistry in the University of Dublin. The Laboratory, Trinity College, Dublin.
1870. *REYNOLDS, OSBORNE, M.A., LL.D., F.R.S., M.Inst.C.E., Professor of Engineering in Owens College, Manchester. Fallowfield, Manchester.
1858. §REYNOLDS, RICHARD, F.C.S. 13 Briggate, Leeds.
1883. ‡Rhodes, Dr. James. 25 Victoria-street, Glossop.
1858. *Rhodes, John. 18 Albion-street, Leeds.
1877. *Rhodes, John. 360 Blackburn-road, Accrington, Lancashire.
1884. ‡Rhodes, Lieut.-Colonel William. Quebec, Canada.
1877. *Riccardi, Dr. Paul, Secretary of the Society of Naturalists. Via Stimmate, 15, Modena, Italy.
1863. ‡RICHARDSON, BENJAMIN WARD, M.A., M.D., LL.D., F.R.S. 25 Manchester-square, London, W.
1861. ‡Richardson, Charles. 10 Berkeley-square, Bristol.
1869. *Richardson, Charles. 4 Northumberland-avenue, Putney, S.W.
1863. *Richardson, Edward. Warkworth, Northumberland.
1882. §Richardson, Rev. George, M.A. The College, Winchester.
1868. *Richardson, George. 4 Edward-street, Werneth, Oldham.
1884. *Richardson, George Straker. Heathfield House, Swansea.
1884. *Richardson, J. Clarke. Derwen Fawr, Swansea.
1870. ‡Richardson, Ralph, F.R.S.E. 10 Magdala-place, Edinburgh.

Year of Election.

1881. ‡Richardson, W. B. Elm Bank, York.
1861. ‡Richardson, William. 4 Edward-street, Werneth, Oldham.
1876. §Richardson, William Haden. City Glass Works, Glasgow.
1886. §Richmond Robert. Leighton Buzzard.
1863. ‡Richter, Otto, Ph.D. 407 St. Vincent-street, Glasgow.
1868. ‡RICKETTS, CHARLES, M.D., F.G.S. 18 Hamilton-square, Birkenhead.
1877. ‡Ricketts, James, M.D. St. Helen's, Lancashire.
*RIDDELL, Major-General CHARLES J. BUCHANAN, C.B., R.A., F.R.S. Oaklands, Chudleigh, Devon.
1861. *Riddell, Henry B. Whitefield House, Rothbury, Morpeth.
1883. *Rideal, Samuel. Mayow-road, Forest Hill, Kent, S.E.
1872. ‡Ridge, James. 98 Queen's-road, Brighton.
1862. ‡Ridgway, Henry Ackroyd, B.A. Bank Field, Halifax.
1861. ‡Ridley, John. 19 Belsize-park, Hampstead, London, N.W.
1884. ‡Ridout, Thomas. Ottawa, Canada.
1863. *Rigby, Samuel. Fern Bank, Liverpool-road, Chester.
1881. *Rigg, Arthur. 71 Warrington-crescent, London, W.
1883. *Rigg, Edward, M.A. Royal Mint, London, E.
1883. ‡Rigg, F. F., M.A. 32 Queen's-road, Southport.
1883. *Rigge, Samuel Taylor. Halifax.
1873. ‡Ripley, Sir Edward, Bart. Acacia, Apperley, near Leeds.
*RIPON, The Most Hon. the Marquis of, K.G., G.C.S.I., C.I.E., D.C.L., F.R.S., F.L.S., F.R.G.S. 1 Carlton-gardens, London, S.W.
1867. ‡Ritchie, John. Fleuchar Craig, Dundee.
1855. ‡Ritchie, Robert. 14 Hill-street, Edinburgh.
1867. ‡Ritchie, William. Emslea, Dundee.
1869. *Rivington, John. Babbicombe, near Torquay.
1854. ‡Robberds, Rev. John, B.A. Battledown Tower, Cheltenham.
1869. *ROBBINS, JOHN, F.C.S. 57 Warrington-crescent, Maida Vale, London, W.
1878. ‡Roberts, Charles, F.R.C.S. 2 Bolton-row, London, W.
1859. ‡Roberts, George Christopher. Hull.
1870. *ROBERTS, ISAAC, F.G.S. Kennessee, Maghull, Lancashire.
1883. ‡ROBERTS, RALPH A. 23 Clyde-road, Dublin.
1881. §Roberts, R. D., M.A., D.Sc., F.G.S. Clare College, Cambridge.
1879. ‡Roberts, Samuel. The Towers, Sheffield.
1879. ‡Roberts, Samuel, jun. The Towers, Sheffield.
1883. ‡ROBERTS, Sir WILLIAM, M.D., F.R.S. 89 Mosley-street, Manchester.
1868. *ROBERTS-AUSTEN, W. CHANDLER, F.R.S., F.C.S., Chemist to the Royal Mint, and Professor of Metallurgy in the Royal School of Mines. Royal Mint, London, E.
1883. §Robertson, Alexander. Montreal, Canada.
1884. *Robertson, Andrew. Elmbank, Dorchester-street, Montreal, Canada.
1859. ‡Robertson, Dr. Andrew. Indego, Aberdeen.
1884. ‡Robertson, E. Stanley, M.A. 43 Waterloo-road, Dublin.
1871. ‡Robertson, George, M.Inst.C.E., F.R.S.E. 47 Albany-street, Edinburgh.
1883. ‡Robertson, George H. The Nook, Gateacre, near Liverpool.
1883. ‡Robertson, Mrs. George H. The Nook, Gateacre, near Liverpool.
1870. *Robertson, John. 4 Albert-road, Southport.
1876. ‡Robertson, R. A. Newthorn, Ayton-road, Pollokshields, Glasgow.
1866. ‡*Robertson, William Tindal, M.D. Nottingham.*
1886. *Robinson, C. R. 27 Elvetham-road, Birmingham.
1886. §Robinson, Edward E. 56 Dovey-street, Liverpool.
1861. ‡Robinson, Enoch. Dukinfield, Ashton-under-Lyne.
1852. ‡Robinson, Rev. George. Beech Hill, Armagh.

Year of Election.

Robinson, H. Oliver. 34 Bishopsgate-street, London, E.C.

1873. §Robinson, Hugh. 82 Donegall-street, Belfast.

1861. ‡ROBINSON, JOHN, M.Inst.C.E. Atlas Works, Manchester.

1863. ‡Robinson, J. H. Cumberland-row, Newcastle-on-Tyne.

1878. ‡Robinson, John L. 198 Great Brunswick-street, Dublin.

1876. ‡Robinson, M. E. 6 Park-circus, Glasgow.

1881. §Robinson, Richard Atkinson. 195 Brompton-road, London, S.W.

1875. *Robinson, Robert, M.Inst.C.E., F.G.S. 2 West-terrace, Darlington.

1860. ‡Robinson, Admiral Sir Robert Spencer, K.C.B., F.R.S. 61 Eaton-place, London, S.W.

1884. ‡Robinson, Stillman. Columbus, Ohio, U.S.A.

1863. ‡Robinson, T. W. U. Houghton-le-Spring, Durham.

1870. ‡Robinson, William. 40 Smithdown-road, Liverpool.

1882. §Robinson, W. Braham. Rosenheim, Westwood Park, Southampton.

1870. *Robson, E. R. Palace Chambers, 9 Bridge-street Westminster, S.W.

1876. ‡Robson, Hazleton R. 14 Royal-crescent West, Glasgow.

1855. ‡Robson, Neil. 127 St. Vincent-street, Glasgow.

1872. *Robson, William. Marchholm, Gillsland-road, Merchiston, Edinburgh.

1885. §Rodger, Edward. 1 Claremont-gardens, Glasgow.

1885. *Rodriguez, Epifanio. 12 John-street, Adelphi, London, W.C.

1872. ‡RODWELL, GEORGE F., F.R.A.S., F.C.S. Marlborough College, Wiltshire.

1866. ‡Roe, Thomas. Grove-villas, Sitchurch.

1860. ‡ROGERS, JAMES E. THOROLD, Professor of Economic Science and Statistics in King's College, London. Beaumont-street, Oxford.

1867. ‡Rogers, James S. Rosemill, by Dundee.

1883. §Rogers, Major R. Alma House, Cheltenham.

1882. §Rogers, Rev. Saltren, M.A. Gwennap, Redruth, Cornwall.

1870. ‡Rogers, T. L., M.D. Rainhill, Liverpool.

1883. ‡Rogers, Thomas Stanley, LL.B. 77 Albert-road, Southport.

1884. *Rogers, Walter M. Lamowa, Falmouth.

1886. §Rogers, W. Woodbourne. Wheeley's-road, Edgbaston, Birmingham.

1876. ‡ROLLIT, Sir A. K., M.P., B.A., LL.D., D.C.L., F.R.A.S., Hon. Fellow K.C.L. Thwaite House, Cottingham, East Yorkshire.

1866. ‡*Rolph, G. F.*

1876. ‡ROMANES, GEORGE JOHN, M.A., LL.D., F.R.S., F.L.S. 18 Cornwall-terrace, Regent's Park, London, N.W.

1846. ‡Ronalds, Edmund, Ph.D. Stewartfield, Bonnington, Edinburgh.

1869. ‡Roper, C. H. Magdalen-street, Exeter.

1872. ‡Roper, Freeman Clarke Samuel, F.L.S., F.G.S. Palgrave House, Eastbourne.

1881. *Roper, W. O. Eadenbreck, Lancaster.

1855. *ROSCOE, Sir HENRY ENFIELD, B.A., Ph.D., LL.D., M.P., F.R.S., F.C.S. (PRESIDENT ELECT). Victoria Park, Manchester.

1883. *Rose, J. Holland, M.A. Ventnor College, Ventnor, Isle of Wight.

1885. ‡Ross, Alexander. Riverfield, Inverness.

1874. ‡Ross, Alexander Milton, M.A., M.D., F.G.S. Toronto, Canada.

1857. ‡Ross, David, LL.D. 32 Nelson-street, Dublin.

1880. §Ross, Captain G. E. A., F.R.G.S. Forfar House, Cromwell-road, London, S.W.

1872. ‡Ross, James, M.D. Tenterfield House, Waterfoot, near Manchester.

1859. *Ross, Rev. James Coulman. Baldon Vicarage, Oxford.

1874. ‡Ross, Rev. William. Chapelhill Manse, Rothesay, Scotland.

1880. ‡Ross, Colonel William Alexander. Acton House, Acton, London, W.

Year of
Election.

1869. *Rosse, The Right Hon. the Earl of, B.A., D.C.L., LL.D., F.R.S., F.R.A.S., M.R.I.A. Birr Castle, Parsonstown, Ireland.
1865. *Rothera, George Bell. 17 Waverley-street, Nottingham.
1876. ‡Rottenburgh, Paul. 13 Albion-crescent, Glasgow.
1884. *Rouse, M. L. 343 Church-street, Toronto, Canada.
1861. ‡Routh, Edward J., M.A., D.Sc., F.R.S., F.R.A.S., F.G.S. St. Peter's College, Cambridge.
1881. ‡Routh, Rev. William, M.A. Clifton Green, York.
1872. **Row, A. V. Nursing Observatory, Daba-gardens, Vizagapatam, India. (Care of Messrs. King & Co., 45 Pall Mall, London, S.W.)*
1861. ‡Rowan, David. Elliot-street, Glasgow.
1883. ‡Rowan, Frederick John. 134 St. Vincent-street, Glasgow.
1881. ‡Rowe, Rev. G. Lord Mayor's Walk, York.
1865. §Rowe, Rev. John. Load Vicarage, Langport, Somerset.
1877. ‡Rowe, J. Brooking, F.L.S., F.S.A. 16 Lockyer-street, Plymouth.
1855. *Rowney, Thomas H., Ph.D., F.C.S., Professor of Chemistry in Queen's College, Galway. Salerno, Salthill, Galway.
1881. *Rowntree, Joseph. 37 St. Mary's, York.
1881. *Rowntree, J. S. The Mount, York.
1862. ‡Rowsell, Rev. Evan Edward, M.A. Hambledon Rectory, Godalming.
1876. ‡Roxburgh, John. 7 Royal Bank-terrace, Glasgow.
1883. ‡Roy, Charles S., M.D., F.R.S., Professor of Pathology in the University of Cambridge. Trinity College, Cambridge.
1885. ‡Roy, John. 33 Belvidere-street, Aberdeen.
1861. *Royle, Peter, M.D., L.R.C.P., M.R.C.S. 27 Lever-street, Manchester.
1875. ‡Rücker, A. W., M.A., F.R.S., Professor of Physics in the Royal School of Mines. Errington, Clapham Park, London, S.W.
1869. §Rudler, F. W., F.G.S. The Museum, Jermyn-street, London, S.W.
1882. ‡Rumball, Thomas, M.Inst.C.E. 8 Queen Anne's-gate, London, S.W.
1884. §Runtz, John. Linton Lodge, Lordship-road, Stoke Newington, London, N.
1847. ‡Ruskin, John, M.A., F.G.S. Brantwood, Coniston, Ambleside.
1875. *Russell, The Hon. F. A. R. Pembroke Lodge, Richmond Park, Surrey.
1884. §Russell, George. Hoe Park House, Plymouth.
1883. *Russell, J. W. Merton College, Oxford.
1865. ‡Russell, James, M.D. 91 Newhall-street, Birmingham.
Russell, John. 39 Mountjoy-square, Dublin.
1852. *Russell, Norman Scott. Arts Club, Hanover-square, London, W.
1876. §Russell, R., F.G.S. 1 Sea View, St. Bees, Carnforth.
1886. §Russell, Thomas H. 3 Newhall-street, Birmingham.
1862. ‡Russell, W. H. L., B.A., F.R.S. 3 Ridgmount-terrace, Highgate, London, N.
1852. *Russell, William J., Ph.D., F.R.S., F.C.S., Lecturer on Chemistry in St. Bartholomew's Medical College. 34 Upper Hamilton-terrace, St. John's Wood, London, N.W.
1886. §Rust, Arthur. Eversleigh, Leicester.
1883. *Ruston, Joseph, M.P. Monk's Manor, Lincoln.
1871. §Rutherford, William, M.D., F.R.S., F.R.S.E., Professor of the Institutes of Medicine in the University of Edinburgh.
1881. ‡Rutson, Albert. Newby Wiske, Thirsk.
Rutson, William. Newby Wiske, Northallerton, Yorkshire.
1879. ‡Ruxton, Rear-Admiral Fitzherbert, R.N., F.R.G.S. 41 Cromwell-gardens, London, S.W.

Year of Election.

1875. ‡Ryalls, Charles Wager, LL.D. 3 Brick-court, Temple, London, E.C.
1886. §Ryland, F. Augustus-road, Edgbaston, Birmingham.
1865. ‡Ryland, Thomas. The Redlands, Erdington, Birmingham.
1861. *RYLANDS, THOMAS GLAZEBROOK, F.L.S., F.G.S. Highfields, Thelwall, near Warrington.

1883. *Sabine, Robert. 3 Great Winchester-street-buildings, London, E.C.
1883. ‡Sadler, Robert. 7 Lulworth-road, Birkdale, Southport.
1871. ‡Sadler, Samuel Champernowne. Purton Court, Purton, near Swindon, Wiltshire.
1885. §Saint, W. Johnstone. Woodhill, Braemar, N.B.
1866. *St. Albans, His Grace the Duke of. Bestwood Lodge, Arnold, near Nottingham.
1886. §St. Clair, George, F.G.S. 127 Bristol-road, Birmingham.
1881. ‡Salkeld, William. 4 Paradise-terrace, Darlington.
1857. ‡SALMON, Rev. GEORGE, D.D., D.C.L., LL.D., F.R.S., Regius Professor of Divinity in the University of Dublin. Trinity College, Dublin.
1883. ‡Salmond, Robert G. The Nook, Kingswood-road, Upper Norwood, S.E.
1873. *Salomons, Sir David, Bart. Broomhill, Tunbridge Wells.
1883. §Salt, Shirley H., M.A. 73 Queensborough-terrace, London, W.
1872. ‡SALVIN, OSBERT, M.A., F.R.S., F.L.S. Hawksfold, Haslemere.
1861. *Samson, Henry. 6 St. Peter's-square, Manchester.
1861. *Sandeman, Archibald, M.A. Garry Cottage, Perth.
1876. ‡Sandeman, David. Woodlands, Lenzie, Glasgow.
1883. ‡Sandeman, E. 53 Newton-street, Greenock.
1878. ‡Sanders, Alfred, F.L.S. 2 Clarence-place, Gravesend, Kent.
1883. *Sanders, Charles J. B. Pennsylvania, Exeter.
1884. ‡Sanders, Henry. 185 James-street, Montreal, Canada.
1872. ‡Sanders, Mrs. 8 Powis-square, Brighton.
1883. ‡Sanderson, Surgeon Alfred. East India United Service Club, St. James's-square, London, S.W.
1872. ‡SANDERSON, J. S. BURDON, M.D., LL.D., F.R.S., Professor of Physiology in the University of Oxford. 50 Banbury-road, Oxford.
1883. ‡Sanderson, Mrs. Burdon. 50 Banbury-road, Oxford.
Sandes, Thomas, A.B. Sallow Glin, Tarbert, Co. Kerry.
1864. ‡Sandford, William. 9 Springfield-place, Bath.
1873. ‡Sands, T. C. 24 Spring-gardens, Bradford, Yorkshire.
1886. §Sankey, Percy E. Lyndhurst, St. Peter's, Kent.
1886. §Sauborn, John Wentworth. Albion, New York, U.S.A.
1886. §Saundby, Robert, M.D. 83A Edmund-street, Birmingham.
1868. ‡Saunders, A., M.Inst.C.E. King's Lynn.
1886. §Saunders, C. T. Temple-row, Birmingham.
1881. ‡SAUNDERS, HOWARD, F.L.S., F.Z.S. 7 Radnor-place, London, W.
1883. ‡Saunders, Rev. J. C. Cambridge.
1846. ‡SAUNDERS, TRELAWNEY W. India Office, London, S.W.
1864. ‡Saunders, T. W., Recorder of Bath. 1 Priory-place, Bath.
1884. ‡Saunders, William. London, Ontario, Canada.
1884. ‡Saunderson, C. E. 26 St. Famille-street, Montreal, Canada.
1871. §Savage, W. D. Ellerslie House, Brighton.
1883. ‡Savage, W. W. 109 St. James's-street, Brighton.
1883. §Savery, G. M., M.A. Cotlake House, Taunton.
1872. *Sawyer, George David, F.R.M.S. 55 Buckingham-place, Brighton.
1868. ‡*Sawyer, John Robert. Grove-terrace, Thorpe Hamlet, Norwich.*

Year of Election.

1884. ‡Sayre, Robert H. Bethlehem, Pennsylvania, U.S.A.
1883. *Scarborough, George. Holly Bank, Halifax, Yorkshire.
1883. ‡Scarisbrick, Charles. 5 Palace-gate, Kensington, London, W.
1884. ‡Scarth, William Bain. Winnipeg, Manitoba, Canada.
1868. §Schacht, G. F. 1 Windsor-terrace, Clifton, Bristol.
1879. *SCHÄFER, E. A., F.R.S., M.R.C.S., Professor of Physiology in University College, London. Boreham Wood, Elstree, Herts.
1883. ‡Schäfer, Mrs. Boreham Wood, Elstree, Herts.
1880. *Schemmann, Louis Carl. Hamburg. (Care of Messrs. Allen Everitt & Sons, Birmingham.)
1842. Schofield, Joseph. Stubley Hall, Littleborough, Lancashire.
1883. ‡Schofield, William. Alma-road, Birkdale, Southport.
1885. §Scholes, L. The Limes, Cleveland-road, Manchester.
1876. ‡Schuman, Sigismond. 7 Royal Bank-place, Glasgow.
SCHUNCK, EDWARD, F.R.S., F.C.S. Oaklands, Kersall Moor, Manchester.
1873. *SCHUSTER, ARTHUR, Ph.D., F.R.S., F.R.A.S., Professor of Applied Mathematics in Owens College, Manchester.
1861. *Schwabe, Edmund Salis. Ryecroft House, Cheetham Hill, Manchester.
1847. *SCLATER, PHILIP LUTLEY, M.A., Ph.D., F.R.S., F.L.S., F.G.S., F.R.G.S., Sec.Z.S. 3 Hanover-square, London, W.
1883. *SCLATER, WILLIAM LUTLEY, B.A., F.Z.S. 3 Hanover-square, London, W.
1882. *SCLATER-BOOTH, The Right Hon. G., M.P., F.R.S. 74 St. George's-square, London, S.W.
1867. ‡SCOTT, ALEXANDER. Clydesdale Bank, Dundee.
1881. *Scott, Alexander, M.A., D.Sc. 4 North Bailey, Durham.
1882. ‡Scott, Colonel A. de C., R.E. Ordnance Survey Office, Southampton.
1878. ‡Scott, Arthur William, M A., Professor of Mathematics and Natural Science in St. David's College, Lampeter.
1881. §Scott, Miss Charlotte Angus. Lancashire College, Whalley Range, Manchester.
1876. ‡Scott, Mr. Bailie. Glasgow.
1871. ‡Scott, Rev. C. G. 12 Pilrig-street, Edinburgh.
1885. ‡Scott, George Jamieson. Bayview House, Aberdeen.
1886. §Scott, Robert. 161 Queen Victoria-street, London, E.C.
1857. *SCOTT, ROBERT H., M.A., F.R.S., F.G.S., F.R.M.S., Secretary to the Council of the Meteorological Office. 6 Elm Park-gardens, London, S.W.
1861. §Scott, Rev. Robert Selkirk, D.D. 16 Victoria-crescent, Dowanhill, Glasgow.
1884. *Scott, Sydney C. 39 King-street, Cheapside, London, E.C.
1858. ‡Scott, William. Holbeck, near Leeds.
1869. ‡Scott, William Bower. Chudleigh, Devon.
1885. ‡Scott-Moncrieff, W. G. The Castle, Banff.
1881. *Scrivener, A. P. Haglis House, Wendover.
1883. ‡Scrivener, Mrs. Haglis House, Wendover.
1859. ‡Seaton, John Love. The Park, Hull.
1880. ‡Sedgwick, Adam, M.A., F.R.S. Trinity College, Cambridge.
1880. ‡SEEBOHM, HENRY, F.L.S., F.Z.S. 6 Tenterden-street, Hanover-square, London, W.
1861. *SEELEY, HARRY GOVIER, F.R.S., F.L.S., F.G.S., F.R.G.S., F.Z.S., Professor of Geography in King's College, London. The Vine, Sevenoaks.
1855. ‡Seligman, H. L. 27 St. Vincent-place, Glasgow.
1879. §Selim, Adolphus. 21 Mincing-lane, London, E.C.

Year of Election.

1885. §Semple, Dr. United Service Club, Edinburgh.
1873. ‡Semple, R. H., M.D. 8 Torrington-square, London, W.C.
1858. *Senior, George, F.S.S. Old Whittington, Chesterfield.
1870. *Sephton, Rev. J. 90 Huskisson-street, Liverpool
1883. §Seville, Miss M. A. Blythe House, Southport.
1875. §Seville, Thomas. Blythe House, Southport.
1868. ‡Sewell, Philip E. Catton, Norwich.
1883. ‡Shadwell, John Lancelot. 21 Nottingham-place, London, W.
*Shaen, William. 15 Upper Phillimore-gardens, Kensington, London, W.
1871. *Shand, James. Fullbrooks, Worcester Park, Surrey.
1867. §Shanks, James. Dens Iron Works, Arbroath, N.B.
1881. ‡Shann, George, M.D. Petergate, York.
1869. *Shapter, Dr. Lewis, LL.D. 1 Barnfield-crescent, Exeter.
1878. ‡SHARP, DAVID, M.B. Bleckley, Shirley Warren, Southampton.
Sharp, Rev. John, B.A. Horbury, Wakefield.
1886. §Sharp, T. B. French Walls, Birmingham.
*Sharp, William, M.D., F.R.S., F.G.S. Horton House, Rugby.
Sharp, Rev. William, B.A. Mareham Rectory, near Boston, Lincolnshire.
1883. ‡Sharples, Charles H., F.C.S. 7 Fishergate, Preston.
1854. *Shaw, Charles Wright. 3 Windsor-terrace, Douglas, Isle of Man.
1870. ‡Shaw, Duncan. Cordova, Spain.
1865. ‡Shaw, George. Cannon-street, Birmingham.
1881. *SHAW, H. S. HELE, Professor of Engineering in University College, Liverpool.
1870. ‡Shaw, John. 21 St. James's-road, Liverpool.
1845. ‡Shaw, John, M.D., F.L.S., F.G.S. Hop House, Boston, Lincolnshire.
1883. *Shaw, W. N., M.A. Emmanuel College, Cambridge.
1884. ‡*Sheafer, Peter W.*
1883. ‡Sheard, J. 42 Hoghton-street, Southport.
1883. *Shearer, Miss A. M. Bushy Hill, Cambuslang, Lanark.
1883. ‡*Sheild, Robert. Wing House, near Oldham.*
1884. §Sheldon, Professor J. P. Downton College, near Salisbury.
1878. §Shelford, William, M.Inst.C.E. 35A Great George-street, Westminster, S.W.
1881. ‡Shenstone, W. A. Clifton College, Bristol.
1863. ‡Shepherd, A. B. 17 Great Cumberland-place, Hyde Park, London, W.
1885. ‡Shepherd, Rev. Alexander. Ecclesmechen, Uphall, Edinburgh.
1885. ‡Shepherd, Charles. 1 Wellington-street, Aberdeen.
1883. ‡Shepherd, James. Birkdale, Southport.
1870. §Shepherd, Joseph. 29 Everton-crescent, Liverpool.
Sheppard, Rev. Henry W., B.A. The Parsonage, Emsworth, Hants.
1883. §Sherlock, David. Lower Leeson-street, Dublin.
1883. §Sherlock, Mrs. David. Lower Leeson-street, Dublin.
1883. ‡Sherlock, Rev. Edgar. Bentham Rectory, *viâ* Lancaster.
1886. §Shield, Arthur H. 35A Great George-street, London, S.W.
1883. *Shillitoe, Buxton, F.R.C.S. 2 Frederick-place, Old Jewry, London, E.C.
1866. ‡Shilton, Samuel Richard Parr. Sneinton House, Nottingham.
1867. ‡Shinn, William C. 4 Varden's-road, Clapham Junction, Surrey, S.W.
1885. §Shirras, G. F. 16 Carden-place, Aberdeen.
1883. ‡Shone, Isaac. Pentrefelin House, Wrexham.
1870. *SHOOLBRED, JAMES N., M.Inst.C.E., F.G.S. 3 Westminster-chambers, London, S.W.

Year of Election.

1875. ‡Shore, Thomas W., F.C.S., F.G.S. Hartley Institution, Southampton.
1882. ‡Shore, T. W., jun., B.Sc. Uplands, Woolston, Southampton.
1881. ‡Shuter, James L. 9 Steele's-road, Haverstock Hill, London, N.W.
1883. §Sibly, Miss Martha Agnes. Flook House, Taunton.
1883. *Sidebotham, Edward John. Erlesdene, Bowdon, Cheshire.
1883. *Sidebotham, James Nasmyth. Erlesdene, Bowdon, Cheshire.
1877. *Sidebotham, Joseph Watson. Erlesdene, Bowdon, Cheshire.
1885. *SIDGWICK, HENRY, M.A., Litt.D., Professor of Moral Philosophy in the University of Cambridge. Hillside, Chesterton-road, Cambridge.
Sidney, M. J. F. Cowpen, Newcastle-upon-Tyne.
1873. *Siemens, Alexander. 12 Queen Anne's-gate, Westminster, S.W.
1878. ‡Sigerson, Professor George, M.D., F.L.S., M.R.I.A. 3 Clare-street, Dublin.
1859. ‡Sim, John. Hardgate, Aberdeen.
1871. ‡Sime, James. Craigmount House, Grange, Edinburgh.
1862. ‡Simms, James. 138 Fleet-street, London, E.C.
1874. ‡Simms, William. The Linen Hall, Belfast.
1876. ‡Simon, Frederick. 24 Sutherland-gardens, London, W.
1847. ‡Simon, John, C.B., D.C.L., F.R.S., F.R.C.S., Consulting Surgeon to St. Thomas's Hospital. 40 Kensington-square, London, W.
1866. ‡Simons, George. The Park, Nottingham.
1871. *SIMPSON, ALEXANDER R., M.D., Professor of Midwifery in the University of Edinburgh. 52 Queen-street, Edinburgh.
1883. §Simpson, Byron R. 7 York-road, Birkdale, Southport.
1867. ‡Simpson, G. B. Seafield, Broughty Ferry, by Dundee.
1859. ‡Simpson, John. Maykirk, Kincardineshire.
1863. ‡Simpson, J. B., F.G.S. Hedgefield House, Blaydon-on-Tyne.
1857. ‡SIMPSON, MAXWELL, M.D., LL.D., F.R.S., F.C.S., Professor of Chemistry in Queen's College, Cork.
1883. ‡Simpson, Walter M. 7 York-road, Birkdale, Southport.
Simpson, William. Bradmore House, Hammersmith, London, W.
1884. *Simpson, W. J. R., M.D. Town House, Aberdeen.
1874. ‡Sinclair, Thomas. Dunedin, Belfast.
1884. ‡*Sinclair, Vetch, M.D.* 48 *Albany-street, Edinburgh.*
1870. *Sinclair, W. P. 19 Devonshire-road, Prince's Park, Liverpool.
1864. *Sircar, Mahendra Lal, M.D. 51 Sankaritola, Calcutta. (Care of Messrs. S. Harraden & Co., 3 Hill's-place, Oxford-street, London, W.)
1865. ‡Sissons, William. 92 Park-street, Hull.
1879. ‡Skertchly, Sydney B. J., F.G.S. 3 Loughborough-terrace, Carshalton, Surrey.
1883. ‡Skillicorne, W. N. 9 Queen's-parade, Cheltenham.
1885. §Skinner, Provost. Inverurie, N.B.
1870. §SLADEN, WALTER PERCY, F.G.S., F.L.S. Orsett House, Ewell, Surrey.
1873. ‡Slater, Clayton. Barnoldswick, near Leeds.
1842. *Slater, William. Park-lane, Higher Broughton, Manchester.
1884. ‡Slattery, James W. 9 Stephen's-green, Dublin.
1877. ‡Sleeman, Rev. Philip, L.Th., F.R.A.S., F.G.S. Clifton, Bristol.
1884. ‡Slooten, William Venn. Nova Scotia, Canada.
1849. ‡Sloper, George Elgar. Devizes.
1849. ‡Sloper, Samuel W. Devizes.
1860. ‡Sloper, S. Elgar. Winterton, near Hythe, Southampton.
1867. ‡Small, David. Gray House, Dundee.
1881. ‡Smallshan, John. 81 Manchester-road, Southport.

Year of Election.

1885. §Smart, James. Valley Works, Brechin, N.B.
1858. ‡Smeeton, G. H. Commercial-street, Leeds.
1876. ‡Smellie, Thomas D. 213 St. Vincent-street, Glasgow.
1877. ‡Smelt, Rev. Maurice Allen, M.A., F.R.A.S. Heath Lodge, Cheltenham.
1876. ‡Smieton, James. Panmure Villa, Broughty Ferry, Dundee.
1876. ‡Smieton, John G. 3 Polworth-road, Coventry Park, Streatham, London, S.W.
1867. ‡Smieton, Thomas A. Panmure Villa, Broughty Ferry, Dundee.
1857. ‡Smith, Aquilla, M.D., M.R.I.A. 121 Lower Baggot-street, Dublin.
1872. *Smith, Basil Woodd, F.R.A.S. Branch Hill Lodge, Hampstead Heath, London, N.W.
1874. *Smith, Benjamin Leigh, F.R.G.S. Oxford and Cambridge Club, Pall Mall, London, S.W.
1873. ‡Smith, C. Sidney College, Cambridge.
1865. ‡SMITH, DAVID, F.R.A.S. 40 Bennett's-hill, Birmingham.
1886. §Smith, E. Fisher, J.P. The Priory, Dudley.
1886. §Smith, E. O. Council House, Birmingham.
1886. §Smith, Edwin. 33 Wheeley's-road, Edgbaston, Birmingham.
1865. ‡Smith, Frederick. The Priory, Dudley.
1866. *Smith, F. C. Bank, Nottingham.
1855. ‡Smith, George. Port Dundas, Glasgow.
1885. ‡Smith, Rev. G. A., M.A. 91 Fountainhall-road, Aberdeen.
1860. *Smith, Heywood, M.A., M.D. 18 Harley-street, Cavendish-square, London, W.
1870. ‡Smith, H. L. Crabwall Hall, Cheshire.
1885. ‡Smith, Rev. James, B.D. Manse of Newhills, N.B.
1876. *Smith, J. Guthrie. 54 West Nile-street, Glasgow.
1874. ‡Smith, John Haigh. 77 Southbank-road, Southport.
Smith, John Peter George. Netherall, Largs, Ayrshire.
1871. ‡Smith, J. William Robertson, M.A., Lord Almoner's Professor of Arabic in the University of Cambridge.
1883. ‡Smith, M. Holroyd. Fern Hill, Halifax.
1886. *Smith, Mrs. Hencotes House, Hexham.
1860. *SMITH, PROTHEROE, M.D. 42 Park-street, Grosvenor-square, London, W.
1837. Smith, Richard Bryan. Villa Nova, Shrewsbury.
1885. §SMITH, ROBERT H., M.Inst.C.E., Professor of Engineering in the Mason Science College, Birmingham.
1840. *Smith, Robert Mackay. 4 Bellevue-crescent, Edinburgh.
1870. ‡Smith, Samuel. Bank of Liverpool, Liverpool.
1866. ‡Smith, Samuel. 33 Compton-street, Goswell-road, London, E.C.
1873. ‡Smith, Swire. Lowfield, Keighley, Yorkshire.
1867. ‡Smith, Thomas. Dundee.
1867. ‡Smith, Thomas. Poole Park Works, Dundee.
1859. ‡Smith, Thomas James, F.G.S., F.C.S. Hornsea Burton, East Yorkshire.
1884. ‡Smith, Vernon. 127 Metcalfe-street, Ottawa, Canada.
1885. *Smith, Watson. Owens College, Manchester.
1852. ‡Smith, William. Eglinton Engine Works, Glasgow.
1875. *Smith, William. Sundon House, Clifton, Bristol.
1876. ‡Smith, William. 12 Woodside-place, Glasgow.
1883. ‡Smithells, Arthur, B.Sc., Professor of Chemistry in the Yorkshire College, Leeds.
1883. ‡Smithson, Edward Walter. 13 Lendal, York.
1883. ‡Smithson, Mrs. 13 Lendal, York.
1878. ‡Smithson, Joseph S. Balnagowan, Rathmines, Co. Dublin.

Year of Election.

1882. §Smithson, T. Spencer. Facit, Rochdale.
1874. ‡Smoothy, Frederick. Bocking, Essex.
1850. *SMYTH, CHARLES PIAZZI, F.R.S.E., F.R.A.S., Astronomer Royal for Scotland, Professor of Astronomy in the University of Edinburgh. 15 Royal-terrace, Edinburgh.
1883. ‡Smyth, Rev. Christopher. Woodford Rectory, Thrapston.
1874. ‡Smyth, Henry. Downpatrick, Ireland.
1878. §Smyth, Mrs. Isabella. Wigmore Lodge, Cullenswood-avenue, Dublin.
1857. *SMYTH, JOHN, jun., M.A., F.R.M.S. Milltown, Banbridge, Ireland.
1864. ‡SMYTH, WARINGTON W., M.A., F.R.S., F.G.S., F.R.G.S., Lecturer on Mining and Mineralogy at the Royal School of Mines, and Inspector of the Mineral Property of the Crown. 5 Inverness-terrace, Bayswater, London, W.
1854. ‡Smythe, General W. J., R.A., F.R.S. Athenæum Club, Pall Mall, London, S.W.
1883. ‡*Snape, Joseph. 13 Scarisbrick-street, Southport.*
1878. §Snell, H. Saxon. 22 Southampton-buildings, London, W.C.
1879. *SOLLAS, W. J., M.A., D.Sc., F.R.S.E., F.G.S., Professor of Geology in the University of Dublin. Trinity College, Dublin.
Sorbey, Alfred. The Rookery, Ashford, Bakewell.
1859. *SORBY, H. CLIFTON, LL.D., F.R.S., F.G.S. Broomfield, Sheffield.
1879. *Sorby, Thomas W. Storthfield, Sheffield.
1886. §Southall, Alfred. Carrick House, Richmond Hill-road, Birmingham.
1865. *Southall, John Tertius. Parkfields, Ross, Herefordshire.
1859. ‡Southall, Norman. 44 Cannon-street West, London, E.C.
1863. ‡Sowerby, John. Shipcote House, Gateshead, Durham.
1883. §Spanton, William Dunnett, F.R.C.S. Chatterley House, Hanley, Staffordshire.
1863. *Spark, H. King. Starforth House, Barnard Castle.
1879. ‡*Spence, David. Brookfield House, Freyinghall, Yorkshire.*
1869. *Spence, J. Berger. 31 Lombard-street, London, E.C.
1881. ‡Spencer, Herbert E. Lord Mayor's Walk, York.
1884. §Spencer, John, M.Inst.M.E. Globe Tube Works, Wednesbury.
1861. ‡Spencer, John Frederick. 28 Great George-street, London, S.W.
1861. *Spencer, Joseph. Springbank, Old Trafford, Manchester.
1863. *Spencer, Thomas. The Grove, Ryton, Blaydon-on-Tyne, Co. Durham.
1875. ‡Spencer, W. H. Richmond Hill, Clifton, Bristol.
1884. *Spice, Robert Paulson, M.Inst.C.E. 21 Parliament-street, Westminster, S.W.
1864. *Spicer, Henry, B.A., M.P., F.L.S., F.G.S. 14 Aberdeen Park, Highbury, London, N.
1864. *SPILLER, JOHN, F.C.S. 2 St. Mary's-road, Canonbury, London, N.
1878. §Spottiswoode, George Andrew. 3 Cadogan-square, London, S.W.
1864. *Spottiswoode, W. Hugh, F.C.S. 41 Grosvenor-place, London, S.W.
1854. *SPRAGUE, THOMAS BOND, M.A., F.R.S.E. 29 Buckingham-terrace, Edinburgh.
1883. §Spratling, W. J., B.Sc., F.G.S. Maythorpe, 72 Wickham-road, Brockley, S.E.
1853. ‡Spratt, Joseph James. West Parade, Hull.
1884. *Spruce, Samuel. Beech House, Tamworth.
Square, Joseph Elliot. 147 Maida Vale, London, W.
1877. ‡SQUARE, WILLIAM, F.R.C.S., F.R.G.S. 4 Portland-square, Plymouth.
*Squire, Lovell. 6 Heathfield-terrace, Chiswick, Middlesex.
1879. ‡Stacye, Rev. John. Shrewsbury Hospital, Sheffield.

Year of Election.

1858. *STAINTON, HENRY T., F.R.S., F.L.S., F.G.S. Mountsfield, Lewisham, S.E.
1884. ‡Stancoffe, Frederick. Dorchester-street, Montreal, Canada.
1883. *Stanford, Edward, jun., F.R.G.S. 17 Spring-gardens, London, S.W.
1865. ‡STANFORD, EDWARD C. C., F.C.S. Glenwood, Dalmuir, N.B.
1837. Staniforth, Rev. Thomas. Storrs, Windermere.
1881. *Stanley, William Ford, F.G.S. Cumberlow, South Norwood, Surrey, S.E.
1883. ‡Stanley, Mrs. Cumberlow, South Norwood, Surrey, S.E.
Stapleton, M. H., M.B., M.R.I.A. 1 Mountjoy-place, Dublin.
1883. ‡Stapley, Alfred M. Marion-terrace, Crewe.
1866. ‡Starey, Thomas R. Daybrook House, Nottingham.
1876. §Starling, John Henry, F.C.S. The Avenue, Erith, Kent.
Staveley, T. K. Ripon, Yorkshire.
1873. *Stead, Charles. Saltaire, Bradford, Yorkshire.
1881. §Stead, W. H. Hexham House, Southport, Lancashire.
1881. ‡Stead, Mrs. W. H. Hexham House, Southport, Lancashire.
1884. ‡Stearns, Sergeant P. U.S. Consul-General, Montreal, Canada.
1873. ‡Steinthal, G. A. 15 Hallfield-road, Bradford, Yorkshire.
1861. ‡Steinthal, H. M. Hollywood, Fallowfield, near Manchester.
1884. ‡Stephen, George. 140 Drummond-street, Montreal, Canada.
1884. ‡Stephen, Mrs. George. 140 Drummond-street, Montreal, Canada.
1884. *Stephens, W. Hudson. Lowville (P.O.), State of New York, U.S.A.
1879. *STEPHENSON, HENRY, J.P. Endcliffe Vale, Sheffield.
1881. ‡Stephenson, J. F. 3 Mount-parade, York.
1861. *Stern, S. J. Littlegrove, East Barnet, Herts.
1876. ‡Steuart, Walter. City Bank, Pollockshaws, near Glasgow.
1870. *Stevens, Miss Anna Maria. Oak Villa, George-street, Ryde, Isle of Wight.
1880. *Stevens, J. Edward. 6 Carlton-terrace, Swansea.
1886. §Stevens, M. Highfield House, Urmstone, near Manchester.
1868. ‡Stevenson, Henry, F.L.S. Newmarket-road, Norwich.
1878. ‡Stevenson, Rev. James, M.A. 21 Garville-avenue, Rathgar, Dublin.
1863. *STEVENSON, JAMES C., M.P., F.C.S. Westoe, South Shields.
1882. ‡Steward, Rev. C. E., M.A. The Polygon, Southampton.
1885. ‡Stewart, Rev. Alexander. Heathcot, Aberdeen.
1855. ‡STEWART, BALFOUR, M.A., LL.D., F.R.S., Professor of Natural Philosophy in Owens College, Manchester.
1864. ‡STEWART, CHARLES, M.A., F.L.S. St. Thomas's Hospital, London, S.E.
1885. ‡Stewart, David. 293 Union-street, Aberdeen.
1886. *Stewart, Duncan. London Iron Works, Glasgow.
1875. *Stewart, James, B.A., M.R.C.P.Ed. Dunmurry, Sneyd Park, Clifton, Gloucestershire.
1876. ‡Stewart, William. Violet Grove House, St. George's-road, Glasgow.
1867. ‡Stirling, Dr. D. Perth.
1876. ‡Stirling, William, M.D., D.Sc., F.R.S.E., Professor of Physiology in the University of Aberdeen.
1867. *Stirrup, Mark, F.G.S. Richmond Hill, Bowdon, Cheshire.
1865. *Stock, Joseph S. St. Mildred's, Walmer.
1883. *STOCKER, W. R. Cooper's Hill, Staines.
1854. ‡Stoess, Le Chevalier Ch. de W. (Bavarian Consul). Liverpool.
1845. *STOKES, GEORGE GABRIEL, M.A., D.C.L., LL.D., Pres. R.S., Lucasian Professor of Mathematics in the University of Cambridge. Lensfield Cottage, Cambridge.

Year of Election.

1862. ‡Stone, Edward James, M.A., F.R.S., F.R.A.S., Director of the Radcliffe Observatory, Oxford.
1886. §Stone, J. B. The Grange, Erdington, Birmingham.
1886. §Stone, J. H. Grosvenor-road, Handsworth, Birmingham.
1874. ‡Stone, J. Harris, M.A., F.L.S., F.C.S. 11 Sheffield-gardens, Kensington, London, W.
1876. ‡Stone, Octavius C., F.R.G.S. Springfield, Nuneaton.
1883. ‡Stone, Thomas William. 189 Goldhawk-road, Shepherd's Bush, London, W.
1859. ‡Stone, Dr. William H. 14 Dean's-yard, Westminster, S.W.
1857. ‡Stoney, Bindon B., LL.D., F.R.S., M.Inst.C.E., M.R.I.A., Engineer of the Port of Dublin. 14 Elgin-road, Dublin.
1878. *Stoney, G. Gerald. 9 Palmerston Park, Dublin.
1861. *Stoney, George Johnstone, M.A., F.R.S., M.R.I.A. 9 Palmerston Park, Dublin.
1876. §Stopes, Henry, F.G.S. Kenwyn, Cintra Park, Upper Norwood, S.E.
1883. §Stopes, Mrs. Kenwyn, Cintra Park, Upper Norwood, S.E.
1854. ‡Store, George. Prospect House, Fairfield, Liverpool.
1873. ‡Storr, William. The 'Times' Office, Printing-house-square, London, E.C.
1884. §Storrs, George H. Fern Bank, Stalybridge.
1859. §Story, Captain James Hamilton. 17 Bryanston-square, London, W.
1874. ‡Stott, William. Scar Bottom, Greetland, near Halifax, Yorkshire.
1871. *Strachey, Lieut.-General Richard, R.E., C.S.I., F.R.S., F.R.G.S., F.L.S., F.G.S. 69 Lancaster-gate, Hyde Park, London, W.
1881. ‡Strahan, Aubrey, M.A., F.G.S. Geological Museum, Jermyn-street, London, S.W.
1876. ‡Strain, John. 143 West Regent-street, Glasgow.
1863. ‡Straker, John. Wellington House, Durham.
1882. ‡Strange, Rev. Cresswell, M.A. Edgbaston Vicarage, Birmingham.
1881. ‡Strangways, C. Fox, F.G.S. Geological Museum, Jermyn-street, London, S.W.
*Strickland, Charles. 21 Fitzwilliam-place, Dublin.
1879. ‡Strickland, Sir Charles W., K.C.B. Hildenley-road, Malton.
Strickland, William. French Park, Roscommon, Ireland.
1884. ‡Stringham, Irving. The University, Berkeley, California, U.S.A.
1859. ‡Stronach, William, R.E. Ardmellie, Banff.
1883. §Strong, Henry J., M.D. Whitgift House, Croydon.
1867. ‡Stronner, D. 14 Princess-street, Dundee.
1876. *Struthers, John, M.D., LL.D., Professor of Anatomy in the University of Aberdeen.
1878. ‡Strype, W. G. Wicklow.
1876. *Stuart, Charles Maddock. High School, Newcastle, Staffordshire.
1872. *Stuart, Rev. Edward A., M.A. 116 Grosvenor-road, Highbury New Park, London, N.
1886. §Stuart, G. Morton, M.A. Ferndale, Carpenter-road, Edgbaston, Birmingham.
1884. ‡Stuart, Dr. W. Theophilus. 183 Spadina-avenue, Toronto, Canada.
1885. §Stump, Edward C. Belgrave-road, Oldham.
1879. *Styring, Robert. 3 Hartshead, Sheffield.
1857. ‡Sullivan, William K., Ph.D., M.R.I.A. Queen's College, Cork.
1883. §Summers, Alfred. Sunnyside, Ashton-under-Lyne.
1883. ‡Summers, William, M.P. Sunnyside, Ashton-under-Lyne.
1884. ‡Sumner, George. 107 Stanley-street, Montreal, Canada.
1883. ‡Sutcliffe, J. S., J.P. Beech House, Bacup.

Year of Election.
1873. ‡Sutcliffe, J. W. Sprink Bank, Bradford, Yorkshire.
1873. ‡Sutcliffe, Robert. Idle, near Leeds.
1863. ‡Sutherland, Benjamin John. 10 Oxford-street, Newcastle-on-Tyne.
1862. *SUTHERLAND, GEORGE GRANVILLE WILLIAM, Duke of, K.G., F.R.S., F.R.G.S. Stafford House, London, S.W.
1886. §Sutherland, Hugh. Winnipeg, Manitoba, Canada.
1884. ‡Sutherland, J. C. Richmond, Quebec, Canada.
1863. ‡SUTTON, FRANCIS, F.C.S. Bank Plain, Norwich.
1881. ‡Sutton, William. Town Hall, Southport.
1881. ‡Swales, William. Ashville, Holgate-road, York.
1876. ‡Swan, David, jun. Braeside, Maryhill, Glasgow.
1881. §Swan, Joseph Wilson, M.A. Mosley-street, Newcastle-on-Tyne.
1861. *Swan, Patrick Don S. Kirkcaldy, N.B.
1862. *SWAN, WILLIAM, LL.D., F.R.S.E., Professor of Natural Philosophy in the University of St. Andrews, N.B.
1862. *Swann, Rev. S. Kirke, F.R.A.S. Forest Hill Lodge, Warsop, Mansfield, Nottinghamshire.
1879. ‡Swanwick, Frederick. Whittington, Chesterfield.
1883. ‡Sweeting, Rev. T. E. 50 Roe-lane, Southport.
1870. *Swinburne, Sir John, Bart., M.P. Capheaton, Newcastle-on-Tyne.
1863. ‡*Swindell, J. S. E. Summerhill, Kingswinford, Dudley.*
1885. ‡Swindells, Miss. Springfield House, Ilkley, Yorkshire.
1873. *Swinglehurst, Henry. Hincaster House, near Milnthorpe.
1858. ‡SYDNEY, The Right Rev. ALFRED BARRY, Bishop of, D.D., D.C.L. Sydney.
1883. ‡Sykes, Alfred. Highfield, Huddersfield.
1873. §Sykes, Benjamin Clifford, M.D. Cleckheaton.
1847. ‡*Sykes, H. P. 47 Albion-street, Hyde Park, London, W.*
1862. ‡Sykes, Thomas. Cleckheaton.
1847. ‡*Sykes, Captain W. H. F. 47 Albion-street, Hyde Park, London, W.*
SYLVESTER, JAMES JOSEPH, M.A., D.C.L., LL.D., F.R.S., Savilian Professor of Geometry in the University of Oxford. Oxford.
1870. ‡SYMES, RICHARD GLASCOTT, B.A., F.G.S. Geological Survey of Ireland, 14 Hume-street, Dublin.
1885. §Symington, Johnson, M.D. 10 Warrender Park-crescent, Edinburgh.
1881. *Symington, Thomas. 13 Dundas-street, Edinburgh.
1856. *Symonds, Frederick, M.A., F.R.C.S. 35 Beaumont-street, Oxford.
1859. ‡Symonds, Captain Thomas Edward, R.N. 10 Adam-street, Adelphi, London, W.C.
1860. ‡SYMONDS, Rev. W. S., M.A., F.G.S. Pendock Rectory, Worcestershire.
1859. §SYMONS, G. J., F.R.S., Sec.R.Met.Soc. 62 Camden-square, London, N.W.
1883. ‡Symons, Simon. Belfast House, Farquhar-road, Norwood, S.E.
1855. *SYMONS, WILLIAM, F.C.S. 26 Joy-street, Barnstaple.
1886. §Symons, W. H. 130 Fellows-road, Hampstead, London, N.W.
Synge, Francis. Glanmore, Ashford, Co. Wicklow.
1872. ‡Synge, Major-General Millington, R.E., F.S.A., F.R.G.S. United Service Club, Pall Mall, London, S.W.

1865. ‡Tailyour, Colonel Renny, R.E. Newmanswalls, Montrose, N.B.
1877. *TAIT, LAWSON, F.R.C.S. The Crescent, Birmingham.
1871. ‡TAIT, PETER GUTHRIE, F.R.S.E., Professor of Natural Philosophy in the University of Edinburgh. George-square, Edinburgh.
1867. ‡*Tait, P. M., F.R.G.S., F.S.S. Oriental Club, Hanover-square, London, W.*
1883. §Tapscott, R. L. 41 Parkfield-road, Prince's Park, Liverpool.

Year of
Election.

1866. ‡Tarbotton, Marriott Ogle, M.Inst.C.E., F.G.S. The Park, Nottingham.
1878. ‡TARPEY, HUGH. Dublin.
1861. *Tarratt, Henry W. Ferniebrae, Dean Park, Bournemouth.
1857. *Tate, Alexander. Longwood, Whitehouse, Belfast.
1870. ‡Tate, Norman A. 7 Nivell-chambers, Fazackerley-street, Liverpool.
1858. *Tatham, George, J.P. Springfield Mount, Leeds.
1876. ‡*Tatlock, Robert R. 26 Burnbank-gardens, Glasgow.*
1879. ‡Tattershall, William Edward. 15 North Church-street, Sheffield.
1886. §Taunton, Richard. Brook Vale, Witton.
1878. *Taylor, A. Claude. Clinton-terrace, Derby-road, Nottingham.
1884. *Taylor, Rev. Charles, D.D. St. John's Lodge, Cambridge.
Taylor, Frederick. Laurel Cottage, Rainhill, near Prescot, Lancashire.
1874. ‡Taylor, G. P. Students' Chambers, Belfast.
1881. *Taylor, H. A. 25 Collingham-road, South Kensington, London, S.W.
1884. *Taylor, H. M., M.A. Trinity College, Cambridge.
1882. *Taylor, Herbert Owen, M.D. 17 Castlegate, Nottingham.
1879. ‡Taylor, John. Broomhall-place, Sheffield.
1861. *Taylor, John, M.Inst.C.E., F.G.S. 6 Queen-street-place, Upper Thames-street, London, E.C.
1873. ‡TAYLOR, JOHN ELLOR, Ph.D., F.L.S., F.G.S. The Mount, Ipswich.
1881. *Taylor, John Francis. Holly Bank House, York.
1865. ‡Taylor, Joseph. 99 Constitution-hill, Birmingham.
1883. ‡Taylor, Michael W., M.D. Hatton Hall, Penrith.
1876. ‡Taylor, Robert. 70 Bath-street, Glasgow.
1878. ‡Taylor, Robert, J.P., LL.D. Corballis, Drogheda.
1884. *Taylor, Miss S. Oak House, Shaw, near Oldham.
1881. ‡Taylor, Rev. S. B., M.A., Chaplain of Lower Assam, Gauhatti, Assam. (Care of Messrs. Grindlay & Co., 55 Parliament-street, London, S.W.)
1883. ‡Taylor, S. Leigh. Birklands, Westcliffe-road, Birkdale, Southport.
1870. ‡Taylor, Thomas. Aston Rowant, Tetsworth, Oxon.
1883. ‡*Taylor, William. Park-road, Southport.*
1883. ‡Taylor, William, M.D. 21 Crockherbtown, Cardiff.
1884. ‡Taylor-Whitehead, Samuel, J.P. Burton Closes, Bakewell.
1858. ‡Teale, Thomas Pridgin, jun. 20 Park-row, Leeds.
1885. §Teall, J. J. H., M.A., F.G.S. 12 Cumberland-road, Kew, Surrey.
1880. ‡Tebb, Miss. 7 Albert-road, Regent's Park, London, N.W.
1869. ‡Teesdale, C. S. M. Whyke House, Chichester.
1876. *Temperley, Ernest, M.A. Queen's College, Cambridge.
1879. ‡Temple, Lieutenant George T., R.N., F.R.G.S. The Nash, near Worcester.
1880. §TEMPLE, Sir RICHARD, Bart., G.C.S.I., C.I.E., D.C.L., LL.D., M.P., F.R.G.S. Athenæum Club, London, S.W.
1863. ‡Tennant, Henry. Saltwell, Newcastle-on-Tyne.
1882. §Terrill, William. 3 Hanover-street, Swansea.
1881. ‡Terry, Mr. Alderman. Mount-villas, York.
1883. ‡Tetley, C. F. The Brewery, Leeds.
1883. ‡Tetley, Mrs. C. F. The Brewery, Leeds.
1866. ‡Thackeray, J. L. Arno Vale, Nottingham.
1882. *Thane, George Dancer, Professor of Anatomy in University College, Gower-street, London, W.C.
1885. ‡Thin, Dr. George, 22 Queen Anne-street, London, W.
1871. ‡Thin, James. 7 Rillbank-terrace, Edinburgh.

Year of Election.

1871. ‡THISELTON-DYER, W. T., C.M.G., M.A., B.Sc., F.R.S., F.L.S. 11 Brunswick-villas, Kew Gardens-road, Kew.
1835. Thom, John. Lark-hill, Chorley, Lancashire.
1870. ‡Thom, Robert Wilson. Lark-hill, Chorley, Lancashire.
1871. ‡Thomas, Ascanius William Nevill. Chudleigh, Devon.
1875. *THOMAS, CHRISTOPHER JAMES. Drayton Lodge, Redland, Bristol.
1883. ‡Thomas, Ernest C., B.A. 13 South-square, Gray's Inn, London, W.C.
1884. ‡THOMAS, F. WOLFERSTAN. Molson's Bank, Montreal, Canada.
Thomas, George. Brislington, Bristol.
1875. ‡Thomas, Herbert. Ivor House, Redlands, Bristol.
1869. ‡Thomas, H. D. Fore-street, Exeter.
1881. §THOMAS, J. BLOUNT. Southampton.
1869. ‡Thomas, J. Henwood, F.R.G.S. Custom House, London, E.C.
1880. *Thomas, Joseph William, F.C.S. The Laboratory, West Wharf, Cardiff.
1883. ‡Thomas, P. Bossley. 4 Bold-street, Southport.
1883. §Thomas, Thomas H. 45 The Walk, Cardiff.
1883. ‡Thomas, William. Lan, Swansea.
1886. §Thomas, William. 109 Tettenhall-road, Wolverhampton.
1886. §Thomasson, Yeoville. 9 Observatory-gardens, Kensington, London, W.
1875. ‡Thompson, Arthur. 12 St. Nicholas-street, Hereford.
1883. ‡Thompson, Miss C. E. Heald Bank, Bowdon, Manchester.
1885. §Thompson, D'Arcy W., B.A., Professor of Physiology in University College, Dundee. University College, Dundee.
1882. ‡Thompson, Charles O. Terre Haute, Indiana, U.S.A.
1883. *Thompson, Francis. 1 Avenue-villas, St. Peter's-road, Croydon.
1859. ‡Thompson, George, jun. Pitmedden, Aberdeen.
Thompson, Harry Stephen. Kirby Hall, Great Ouseburn, Yorkshire.
1870. ‡THOMPSON, Sir HENRY. 35 Wimpole-street, London, W.
1883. *Thompson, Henry G., M.D. 8 Addiscombe-villas, Croydon.
Thompson, Henry Stafford. Fairfield, near York.
1883. *Thompson, Isaac Cooke, F.R.M.S. Woodstock, Waverley-road, Liverpool.
1861. *THOMPSON, JOSEPH. Riversdale, Wilmslow, Manchester.
1864. ‡THOMPSON, Rev. JOSEPH HESSELGRAVE, B.A. Cradley, near Brierley Hill.
1873. ‡Thompson, M. W. Guiseley, Yorkshire.
1876. *Thompson, Richard. Park-street, The Mount, York.
1883. ‡Thompson, Richard. Bramley Mead, Whalley, Lancashire.
1874. ‡Thompson, Robert. Walton, Fortwilliam Park, Belfast.
1876. ‡THOMPSON, SILVANUS PHILLIPS, B.A., D.Sc., F.R.A.S., Professor of Physics in the City and Guilds of London Institute, Finsbury Technical Institute, E.C.
1884. ‡Thompson, Sydney de Courcy. 16 Canonbury-park South, London, N.
1883. *Thompson, T. H. Heald Bank, Bowdon, Manchester.
1863. ‡Thompson, William. 11 North-terrace, Newcastle-on-Tyne.
1867. ‡Thoms, William. Magdalen-yard-road, Dundee.
Thomson, Guy. Oxford.
1850. *THOMSON, Professor JAMES, M.A., LL.D., D.Sc., F.R.S. L. & E. 2 Florentine-gardens, Hillhead-street, Glasgow.
1868. §THOMSON, JAMES, F.G.S. 3 Abbotsford-place, Glasgow.
*Thomson, James Gibson. 14 York-place, Edinburgh.
1876. ‡Thomson, James R. Mount Blow, Dalmuir, Glasgow.
1883. ‡THOMSON, J. J., M.A., F.R.S., Professor of Experimental Physics in the University of Cambridge. Trinity College, Cambridge.

Year of
Election.

1871. *THOMSON, JOHN MILLAR, F.C.S. King's College, London, W.C.
1886. §Thomson, Joseph. Thornhill, Dumfriesshire.
1871. ‡*Thomson, Robert, LL.B.* 12 *Rutland-square, Edinburgh.*
1847. *THOMSON, Sir WILLIAM, M.A., LL.D., D.C.L., F.R.S. L. & E., F.R.A.S., Professor of Natural Philosophy in the University of Glasgow. The University, Glasgow.
1877. *Thomson, Lady. The University, Glasgow.
1874. §THOMSON, WILLIAM, F.R.S.E., F.C.S. Royal Institution, Manchester.
1880. §Thomson, William J. Ghyllbank, St. Helen's.
1871. ‡Thornburn, Rev. David, M.A. 1 John's-place, Leith.
1852. ‡Thornburn, Rev. William Reid, M.A. Starkies, Bury, Lancashire.
1886. §Thornley, J. E. Lyndon, Bickenhill, near Birmingham.
1867. ‡Thornton, Thomas. Dundee.
1883. §Thorowgood, Samuel. Castle-square, Brighton.
1845. ‡Thorp, Dr. Disney. Lyppiatt Lodge, Suffolk Lawn, Cheltenham.
1881. ‡Thorp, Fielden. Blossom-street, York.
1871. ‡Thorp, Henry. Briarleigh, Sale, near Manchester.
1881. *Thorp, Josiah. 8 Gladstone-road, Liverpool.
1864. *THORP, WILLIAM, B.Sc., F.C.S. 39 Sandringham-road, Kingsland, London, E.
1871. ‡THORPE, T. E., Ph.D., F.R.S. L. & E., F.C.S., Professor of Chemistry in the Normal School of Science. Science Schools, South Kensington, London, S.W.
1883. §Threlfall, Henry Singleton. 5 Prince's-street, Southport.
1883. ‡Thresh, John C., D.Sc. The Willows, Buxton.
1868. ‡THUILLIER, General Sir H. E. L., R.A., C.S.I., F.R.S., F.R.G.S. 11 Sussex-gardens, Hyde Park, London, W.
1870. ‡Tichborne, Charles R. C., LL.D., F.C.S., M.R.I.A. Apothecaries' Hall of Ireland, Dublin.
1873. *TIDDEMAN, R. H., M.A., F.G.S. 28 Jermyn-street, London, S.W.
1884. §TIDY, CHARLES MEYMOTT, M.D. 3 Mandeville-place, Cavendish-square, London, W.
1874. ‡TILDEN, WILLIAM A., D.Sc., F.R.S., F.C.S., Professor of Chemistry and Metallurgy in the Mason Science College, Birmingham. 36 Frederick-road, Birmingham.
1873. ‡Tilghman, B. C. Philadelphia, U.S.A.
1883. §Tillyard, A. I., M.A. Fordfield, Cambridge.
1883. ‡Tillyard, Mrs. Fordfield, Cambridge.
Tinker, Ebenezer. Mealhill, near Huddersfield.
1865. ‡Timmins, Samuel, J.P., F.S.A. Hill Cottage, Fillongley, Coventry.
1876. ‡Todd, Rev. Dr. Tudor Hall, Forest Hill, London, S.E.
1857. ‡Tombe, Rev. Canon. Glenealy, Co. Wicklow.
1856. ‡Tomes, Robert Fisher. Littleton, Worcestershire.
1864. *TOMLINSON, CHARLES, F.R.S., F.C.S. 7 North-road, Highgate, London, N.
1865. ‡Tonks, Edmund, B.C.L. Packwood Grange, Knowle, Warwickshire.
1865. *Tonks, William Henry. The Rookery, Sutton Coldfield.
1873. *Tookey, Charles, F.C.S. Royal School of Mines, Jermyn-street, London, S.W.
1861. *Topham, John, A.I.C.E. High Elms, 265 Mare-street, Hackney, London, E.
1872. *TOPLEY, WILLIAM, F.G.S., A.I.C.E. Geological Survey Office, Jermyn-street, London, S.W.
1886. §Topley, Mrs. W. Hurstbourne, Elgin-road, Croydon.
1875. §Torr, Charles Hawley. 7 Regent-street, Nottingham.
1886. §Torr, Charles Walker. Cambridge-street Works, Birmingham.
1884. ‡Torrance, John F. Folly Lake, Nova Scotia, Canada.

Year of Election.
1884. *Torrance, Rev. Robert, D.D. Guelph, Ontario, Canada.
1859. ‡Torry, Very Rev. John, Dean of St. Andrews. Coupar Angus, N.B.
Towgood, Edward. St. Neot's, Huntingdonshire.
1873. ‡Townend, W. H. Heaton Hall, Bradford, Yorkshire.
1875. ‡Townsend, Charles. Avenue House, Cotham Park, Bristol.
1883. ‡Townsend, Francis Edward. 19 Aughton-road, Birkdale, Southport.
1861. ‡Townsend, William. Attleborough Hall, near Nuneaton.
1877. ‡Tozer, Henry. Ashburton.
1876. *TRAIL, Professor J. W. H., M.A., M.D., F.L.S. University of Aberdeen, Old Aberdeen.
1883. ‡TRAILL, Dr. Ballylough, Bushmills, Ireland.
1870. ‡TRAILL, WILLIAM A. Giant's Causeway Electric Tramway, Portrush, Ireland.
1883. ‡Traill, Mrs. Portrush, Ireland.
1875. ‡Trapnell, Caleb. Severnleigh, Stoke Bishop.
1868. ‡TRAQUAIR, RAMSAY H., M.D., F.R.S., F.G.S., Keeper of the Natural History Collections, Museum of Science and Art, Edinburgh.
1884. ‡Trechmann, Charles O., Ph.D., F.G.S. Hartlepool.
Tregelles, Nathaniel. Liskeard, Cornwall.
1868. ‡Trehane, John. Exe View Lawn, Exeter.
1869. ‡Trehane, John, jun. Bedford-circus, Exeter.
1870. ‡Trench, Dr. Municipal Offices, Dale-street, Liverpool.
Trench, F. A. Newlands House, Clondalkin, Ireland.
1883. ‡Trendell, Edwin James, J.P. Abbey House, Abingdon, Berks.
1884. ‡Trenham, Norman W. 18 St. Alexis-street, Montreal, Canada.
1884. §Tribe, Paul C. M. 44 West Oneida-street, Oswego, New York, U.S.A.
1879. ‡Trickett, F. W. 12 Old Haymarket, Sheffield.
1877. ‡TRIMEN, HENRY, M.B., F.L.S. British Museum, London, S.W.
1871. ‡TRIMEN, ROLAND, F.R.S., F.L.S., F.Z.S. Colonial Secretary's Office, Cape Town, Cape of Good Hope.
1860. §TRISTRAM, Rev. HENRY BAKER, D.D., LL.D., F.R.S., F.L.S., Canon of Durham. The College, Durham.
1884. **Trotter, Alexander Pelham.* 7 *Furnival's Inn, London, W.C.*
1882. *TROTTER, Rev. COUTTS, M.A. Trinity College, Cambridge.
1885. §Trotter, Coutts. 17 Charlotte-square, Edinburgh.
1869. ‡Troyte, C. A. W. Huntsham Court, Bampton, Devon.
1885. *Tubby, A. H. Guy's Hospital, London, S.E.
1869. ‡Tucker, Charles. Marlands, Exeter.
1847. *Tuckett, Francis Fox. Frenchay, Bristol.
Tuke, James H. Bancroft, Hitchin.
1871. ‡Tuke, J. Batty, M.D. Cupar, Fifeshire.
1881. ‡*Tully, G. T.* 10 *West Cliff-terrace, Preston.*
1883. ‡TUPPER, The Hon. Sir CHARLES, G.C.M.G., C.B., High Commissioner for Canada. 9 Victoria-chambers, London, S.W.
1854. ‡*Turnbull, James, M.D.* 86 *Rodney-street, Liverpool.*
1855. ‡Turnbull, John. 37 West George-street, Glasgow.
1871. ‡Turnbull, William, F.R.S.E. Menslaws, Jedburgh, N.B.
1873. *Turner, George. Horton Grange, Bradford, Yorkshire.
1882. §Turner, G. S. 9 Carlton-crescent, Southampton.
1883. ‡Turner, Mrs. G. S. 9 Carlton-crescent, Southampton.
1875. ‡*Turner, Thomas, F.S.S. Ashley House, Kingsdown, Bristol.*
1886. §Turner, Thomas. Mason Science College, Birmingham.
1863. *TURNER, Sir WILLIAM, M.B., F.R.S. L. & E., Professor of Anatomy in the University of Edinburgh. 6 Eton-terrace, Edinburgh.
1883. §Turrell, Miss S. S. High School, Redland-grove, Bristol.

Year of Election.

1884. *Tutin, Thomas. Weston-on-Trent, Derby.
1842. Twamley, Charles, F.G.S. Ryton-on-Dunsmore, Coventry.
1884. *Tweddell, Ralph Hart. Provender, Faversham, Kent.
1886. *Twigg, G. H. Church-road, Moseley, Birmingham.
1847. ‡TWISS, Sir TRAVERS, Q.C., D.C.L., F.R.S., F.R.G.S. 3 Paper-buildings, Temple, London, E.C.
1882. §Tyer, Edward. Horneck, Fitzjohn's-avenue, Hampstead, London, N.W.
1865. ‡TYLOR, EDWARD BURNETT, D.C.L., LL.D., F.R.S., Keeper of the University Museum, Oxford.
1858. *TYNDALL, JOHN, D.C.L., LL.D., Ph.D., F.R.S., F.G.S., Professor of Natural Philosophy in the Royal Institution. Royal Institution, Albemarle-street, London, W.
1883. §Tyrer, Thomas, F.C.S. Garden-wharf, Battersea, London, S.W.
1861. *Tysoe, John. 28 Heald-road, Bowdon, near Manchester.

1884. *Underhill, G. E., M.A. Magdalen College, Oxford.
1886. §Underhill, Thomas, M.D. West Bromwich.
1885. §Unwin, Howard. Newton-grove, Bedford Park, Chiswick, London.
1883. §Unwin, John. Park-crescent, Southport.
1883. §Unwin, William Andrews. The Briars, Freshfield, near Liverpool.
1876. *UNWIN, W. C., F.R.S., M.Inst.C.E., Professor of Engineering at the Central Institute, City and Guilds of London. 7 Palace-gate Mansions, Kensington, London, W.
1872. ‡Upward, Alfred. 11 Great Queen-street, Westminster, London, S.W.
1876. ‡Ure, John F. 6 Claremont-terrace, Glasgow.
1859. ‡Urquhart, W. Pollard. Craigston Castle, N.B.; and Castlepollard, Ireland.
1866. ‡Urquhart, William W. Rosebay, Broughty Ferry, by Dundee.
1880. ‡USSHER, W. A. E., F.G.S. 28 Jermyn-street, London, S.W.

1885. ‡Vachell, Charles Tanfield, M.D. Cardiff.
1863. ‡Vandoni, le Commandeur Comte de, Chargé d'Affaires de S. M. Tunisienne, Geneva.
1884. ‡Van Horne, W. C. Dorchester-street West, Montreal, Canada.
1883. *VanSittart, The Hon. Mrs. A. A. 11 Lypiatt-terrace, Cheltenham.
1886. §VARDY, Rev A. R., M.A. King Edward's School, Birmingham.
1868. ‡Varley, Frederick H., F.R.A.S. Mildmay Park Works, Mildmay-avenue, Stoke Newington, London, N.
1865. *VARLEY, S. ALFRED. 2 Hamilton-road, Highbury Park, London, N.
1870. ‡Varley, Mrs. S. A. 2 Hamilton-road, Highbury Park, London, N.
1869. ‡Varwell, P. Alphington-street, Exeter.
1884. §Vasey, Charles. 112 Cambridge-gardens, London, W.
1875. ‡Vaughan, Miss. Burlton Hall, Shrewsbury.
1883. ‡Vaughan, William. 42 Sussex-road, Southport.
1881. §VELEY, V. H., M.A., F.C.S. University College, Oxford.
1873. *VERNEY, Captain EDMUND H., R.N., F.R.G.S. Rhianva, Bangor, North Wales.
1883. *Verney, Mrs. Rhianva, Bangor, North Wales.
Verney, Sir Harry, Bart., M.P. Lower Claydon, Buckinghamshire.
Vernon, George John, Lord. Sudbury Hall, Derbyshire.
1883. ‡VERNON, H. H., M.D. York-road, Birkdale, Southport.
1864. *VICARY, WILLIAM, F.G.S. The Priory, Colleton-crescent, Exeter.
1868. ‡Vincent, Rev. William. Postwick Rectory, near Norwich.
1883. ‡Vines, Sydney Howard, M.A., D.Sc., F.R.S., F.L.S. 66 Hills-road, Cambridge.

Year of Election.

1856. ‡VIVIAN, EDWARD, M.A. Woodfield, Torquay.
*VIVIAN, Sir H. HUSSEY, Bart., M.P., F.G.S. Park Wern, Swansea; and 27 Belgrave-square, London, S.W.
1884. ‡*Von Linden, François Hermann. Amsterdam, Holland.*
1869. ‡Vose, Dr. James. Gambier-terrace, Liverpool.

1886. *Wackrill, Samuel Thomas, J.P. Leamington.
1860. §Waddingham, John. Guiting Grange, Winchcombe, Gloucestershire.
1884. ‡Wait, Charles E. Rolla, Missouri, U.S.A.
1886. §Waite, J. W. The Cedars, Bestcot, Walsall.
1879. *Wake, Bernard. Abbeyfield, Sheffield.
1870. §WAKE, CHARLES STANILAND. Welton, near Brough, East Yorkshire.
1884. ‡Waldstein, Charles, M.A., Ph.D., Director of the Fitzwilliam Museum, Cambridge. Cambridge.
1873. ‡Wales, James. 4 Mount Royd, Manningham, Bradford, Yorkshire.
1882. *Walkden, Samuel. (Care of Messrs. Guillaume & Sons, 9 Salisbury-square, Fleet-street, London, E.C.)
1885. ‡Walker, Baillie. 52 Victoria-street, Aberdeen.
1885. §Walker, Charles Clement, F.R.A.S. Lillieshall Old Hall, Newport, Shropshire.
1883. ‡Walker, E. R. Pagefield Ironworks, Wigan.
Walker, Frederick John. The Priory, Bathwick, Bath.
1883. ‡Walker, George. 11 Hamilton-square, Birkenhead, Liverpool.
1866. ‡Walker, H. Westwood, Newport, by Dundee.
1885. §WALKER, General J. T., C.B., R.E., LL.D., F.R.S., F.R.G.S. 13 Cromwell-road, London, S.W.
1866. *WALKER, JOHN FRANCIS, M.A., F.C.S., F.G.S., F.L.S. 16 Gillygate, York.
1881. ‡Walker, John Sydenham. 83 Bootham, York.
1867. *Walker, Peter G. 2 Airlie-place, Dundee.
1886. *Walker, Major Philip Billingsley. Sydney, New South Wales.
1866. ‡Walker, S. D. 38 Hampden-street, Nottingham.
1884. ‡Walker, Samuel. Woodbury, Sydenham Hill, London, S.E.
1883. ‡Walker, Thomas A. 4 Saunders-street, Southport.
Walker, William. 47 Northumberland-street, Edinburgh.
1881. *Walker, William. 14 Bootham-terrace, York.
1883. §Walker, Mrs. 14 Bootham-terrace, York.
1883. ‡Wall, Henry. 14 Park-road, Southport.
1863. ‡WALLACE, ALFRED RUSSEL, F.L.S., F.R.G.S. Nutwood Cottage, Frith Hill, Godalming.
1883. §Wallace, George J. Hawthornbank, Dunfermline.
1859. ‡WALLACE, WILLIAM, Ph.D., F.C.S. Chemical Laboratory, 138 Bath-street, Glasgow.
1862. ‡Wallich, George Charles, M.D., F.L.S., F.R.G.S. 26 Addison-road North, Notting Hill, London, W.
1886. §Walliker, Samuel. Grandale, Westfield-road, Edgbaston, Birmingham.
1883. ‡Wallis, Rev. Frederick. Caius College, Cambridge.
1884. ‡Wallis, Herbert. Redpath-street, Montreal, Canada.
1886. §Wallis, Whitworth. Westfield, Westfield-road, Edgbaston, Birmingham.
1883. ‡Walmesley, Oswald. Shevington Hall, near Wigan.
1883. ‡Walmsley, T. M. Clevelands, Chorley-road, Heaton, Bolton.
1862. ‡WALPOLE, The Right Hon. SPENCER HORATIO, M.A., D.C.L., F.R.S. Ealing, Middlesex, W.

Year of Election.

1863. ‡Walters, Robert. Eldon-square, Newcastle-on-Tyne.
1881. †Walton, Thomas, M.A. Oliver's Mount School, Scarborough.
Walton, Thomas Todd. Mortimer House, Clifton, Bristol.
1863. ‡Wanklyn, James Alfred. 7 Westminster-chambers, London, S.W.
1884. ‡Wanless, John, M.D. 88 Union-avenue, Montreal, Canada.
1872. ‡Warburton, Benjamin. Leicester.
1874. §Ward, F. D., J.P., M.R.I.A. Clonaver, Strandtown, Co. Down.
1881. §Ward, George, F.C.S. Buckingham-terrace, Headingley, Leeds.
1879. ‡Ward, H. Marshall, M.A., Professor of Botany in the Royal Indian Civil Engineering College, Cooper's Hill, Egham.
1874. ‡Ward, John, F.S.A., F.G.S., F.R.G.S. Lenoxvale, Belfast.
1857. ‡Ward, John S. Prospect Hill, Lisburn, Ireland.
1880. *Ward, J. Wesney. 5 Holtham-road, St. John's Wood, London, N.W.
1884. *Ward, John William. Newstead, Halifax.
1883. ‡Ward, Thomas, F.C.S. Arnold House, Blackpool.
1882. ‡Ward, William. Cleveland Cottage, Hill-lane Southampton.
1867. ‡Warden, Alexander J. 23 Panmure-street, Dundee.
1858. ‡Wardle, Thomas. Leek Brook, Leek, Staffordshire.
1884. §Wardwell, George J. Rutland, Vermont, U.S.A.
1865. ‡Waring, Edward John, M.D., F.L.S. 49 Clifton-gardens, Maida Vale, London, W.
1878. §WARINGTON, ROBERT, F.R.S., F.C.S. Harpenden, St. Albans, Herts.
1882. ‡Warner, F. W., F.L.S. 20 Hyde-street, Winchester.
1884. *Warner, James D. 199 Baltic-street, Brooklyn, U.S.A.
1875. ‡Warren, Algernon. Naseby House, Pembroke-road, Clifton, Bristol.
1883. *Warren, Dr. Samuel. Abberley Villa, Hoylake.
1856. ‡Washbourne, Buchanan, M.D. Gloucester.
1876. ‡*Waterhouse, A. Willenhall House, Barnet, Herts.*
1875. *Waterhouse, Lieut.-Colonel J. 40 Hamilton-terrace, London, N.W.
1854. ‡Waterhouse, Nicholas. 5 Rake-lane, Liverpool.
1870. ‡Waters, A. T. H., M.D. 29 Hope-street, Liverpool.
1875. ‡Watherston, Rev. Alexander Law, M.A., F.R.A.S. The Grammar School, Hinckley, Leicestershire.
1881. §Watherston, E. J. 12 Pall Mall East, London, S.W.
1884. ‡Watson, A. G., D.C.L. The School, Harrow, Middlesex.
1867. ‡Watson, Rev. Archibald, D.D. The Manse, Dundee.
1886. *Watson, C. J. 34 Smallbrook-street, Birmingham.
1883. ‡Watson, C. Knight, M.A. Society of Antiquaries, Burlington House, London, W.
1855. ‡Watson, Ebenezer. 1 Woodside-terrace, Glasgow.
1867. ‡*Watson, Frederick Edwin. Thickthorne House, Cringleford, Norwich.*
1885. §Watson, Deputy Surgeon-General G. A. 4 St. Margaret's-terrace, Cheltenham.
1882. §WATSON, Rev. H. W., D.Sc., F.R.S. Berkeswell Rectory, Coventry.
1873. *Watson, Sir James. 9 Woodside-terrace, Glasgow.
1884. ‡Watson, John. Queen's University, Kingston, Ontario, Canada.
1859. ‡WATSON, JOHN FORBES, M.A., M.D., F.L.S. India Museum, London, S.W.
1863. ‡Watson, Joseph. Bensham-grove, near Gateshead-on-Tyne.
1863. ‡Watson, R. S. 101 Pilgrim-street, Newcastle-on-Tyne.
1867. ‡Watson, Thomas Donald. 41 Cross-street, Finsbury, London, E.C.
1879. *WATSON, WILLIAM HENRY, F.C.S., F.G.S. Analytical Laboratory, The Folds, Bolton-le-Moors.

Year of Election.

1882. ‡Watt, Alexander. 89 Hartington-road, Sefton Park, Liverpool.
1884. ‡Watt, D. A. P. 284 Upper Stanley-street, Montreal, Canada.
1869. ‡Watt, Robert B. E., F.R.G.S. Ashley-avenue, Belfast.
1861. ‡Watts, Sir James. Abney Hall, Cheadle, near Manchester.
1875. *WATTS, JOHN, B.A., D.Sc. Merton College, Oxford.
1884. *Watts, Rev. Robert R. Stourpaine Vicarage, Blandford.
1870. §Watts, William, F.G.S. Oldham Corporation Waterworks, Piethorn, near Rochdale.
1873. *WATTS, W. MARSHALL, D.Sc. Giggleswick Grammar School, near Settle.
1883. §Watts, W. W., B.A., F.G.S. Broseley, Shropshire.
Waud, Rev. S. W., M.A., F.R.A.S., F.C.P.S. Rettenden, near Wickford, Essex.
1859. ‡ *Waugh, Edwin. Sager-street, Manchester.*
1869. ‡Way, Samuel James. Adelaide, South Australia.
1883. ‡Webb, George. 5 Tenterden-street, Bury, Lancashire.
1871. ‡Webb, Richard M. 72 Grand-parade, Brighton.
1866. *WEBB, WILLIAM FREDERICK, F.G.S., F.R.G.S. Newstead Abbey, near Nottingham.
1886. §Webber, Major-General C. E., C.B. 112 Belvedere-road, London, S.E.
1859. ‡Webster, John. Edgehill, Aberdeen.
1834. ‡Webster, Richard, F.R.A.S. 6 Queen Victoria-street, London, E.C.
1882. *Webster, Sir Richard Everard, Q.C., M.P. Hornton Lodge, Hornton-street, Kensington, London, S.W.
1884. *Wedekind, Dr. Ludwig, Professor of Mathematics at Karlsruhe. Karlsruhe.
1854. ‡Weightman, William Henry. Fern Lea, Seaforth, Liverpool.
1886. §Weiss, Henry. Westbourne-road, Birmingham.
1865. ‡Welch, Christopher, M.A. United University Club, Pall Mall East, London, S.W.
1876. ‡Weldon, W. F. R., B.A. St. John's College, Cambridge.
1881. ‡Wellcome, Henry S. First Avenue Hotel, Holborn, London, W.C.
1879. §WELLS, CHARLES A. Lewes; and 45 Springfield-road, Brighton.
1881. §Wells, Rev. Edward, B.A. West Dean Rectory, Salisbury.
1883. ‡Wells, G. I. J. Cressington Park, Liverpool.
1883. ‡Welsh, Miss. Girton College, Cambridge.
1850. ‡Wemyss, Alexander Watson, M.D. St. Andrews, N.B.
1881. *Wenlock, The Right Hon. Lord. 8 Great Cumberland-place, London, W.; and Escrick Park, Yorkshire.
Wentworth, Frederick W. T. Vernon. Wentworth Castle, near Barnsley, Yorkshire.
1864. *Were, Anthony Berwick. Hensingham, Whitehaven, Cumberland.
1886. §Wertheimer, J., B.A., B.Sc., F.C.S. 32 Lyddon-terrace, Leeds.
1865. ‡Wesley, William Henry. Royal Astronomical Society, Burlington House, London, W.
1853. ‡West, Alfred. Holderness-road, Hull.
1870. ‡West, Captain E. W. Bombay.
1853. ‡West, Leonard. Summergangs Cottage, Hull.
1853. ‡West, Stephen. Hessle Grange, near Hull.
1870. *Westgarth, William. 10 Bolton-gardens, South Kensington, London, S.W.
1842. Westhead, Edward. Chorlton-on-Medlock, near Manchester.
1882. §Westlake, Ernest, F.G.S. Fordingbridge, Hants.
1882. ‡Westlake, Richard. Portswood, Southampton.
1882. ‡Westlake, W. C. Grosvenor House, Southampton.

Year of
Election.

1863. ‡Westmacott, Percy. Whickham, Gateshead, Durham.
1875. *Weston, Joseph D. Dorset House, Clifton Down, Bristol.
1864. ‡WESTROPP, W. H. S., M.R.I.A. Lisdoonvarna, Co. Clare.
1860. ‡WESTWOOD, JOHN O., M.A., F.L.S., Professor of Zoology in the University of Oxford. Oxford.
1882. §WETHERED, EDWARD, F.G.S. 5 Berkeley-place, Cheltenham.
1884. ‡Wharton, E. R., M.A. 4 Broad-street, Oxford.
1885. *Wharton, Captain W. J. L., R.N., F.R.S., F.R.G.S. Florys, Prince's-road, Wimbledon Park, Surrey.
1853. ‡Wheatley, E. B. Cote Wall, Mirfield, Yorkshire.
1866. ‡Wheatstone, Charles C. 19 Park-crescent, Regent's Park, London, N.W.
1884. §Wheeler, Claude L. 123 Metcalfe-street, Montreal, Canada.
1847. ‡Wheeler, Edmund, F.R.A.S. 48 Tollington-road, Holloway, London, N.
1883. *Wheeler, George Brash. Elm Lodge, Wickham-road, Beckenham, Kent.
1878. *Wheeler, W. H., M.Inst.C.E. Boston, Lincolnshire.
1883. ‡Whelpton, Miss K. Newnham College, Cambridge.
1879. *WHIDBORNE, Rev. GEORGE FERRIS, M.A., F.G.S. Charante, Torquay.
1873. ‡Whipple, George Matthew, B.Sc., F.R.A.S. Kew Observatory, Richmond, Surrey.
1884. ‡Whischer, Arthur Henry. Dominion Lands Office, Winnipeg, Canada.
1874. ‡Whitaker, Henry, M.D. 33 High-street, Belfast.
1883. ‡Whitaker, T. Helm View, Halifax.
1859. *WHITAKER, WILLIAM, B.A., F.G.S. Geological Survey Office, Jermyn-street, London, S.W.; and 33 East Park-terrace, Southampton.
1886. §Whitcombe, E. B. Borough Asylum, Winson Green, Birmingham.
1886. §White, Alderman, J.P. Sir Harry's-road, Edgbaston, Birmingham.
1876. ‡White, Angus. Easdale, Argyleshire.
1886. §White, A. Silva, Secretary to the Scottish Geographical Society, Edinburgh.
1883. ‡White, Charles. 23 Alexandra-road, Southport.
1882. §White, Rev. George Cecil, M.A. St. Paul's Vicarage, Southampton.
1885. *White, J. Martin. Spring Grove, Dundee.
1873. ‡White, John. Medina Docks, Cowes, Isle of Wight.
1859. ‡WHITE, JOHN FORBES. 311 Union-street, Aberdeen.
1883. ‡White, John Reed. Rossall School, near Fleetwood.
1865. ‡White, Joseph. Regent's-street, Nottingham.
1869. ‡White, Laban. Blandford, Dorset.
1884. ‡White, R. 'Gazette' Office, Montreal, Canada.
1859. ‡White, Thomas Henry. Tandragee, Ireland.
1877. *White, William. 365 Euston-road, London, N.W.
1883. *White, Mrs. 365 Euston-road, London, N.W.
1886. §White, William. 55 Highbury-hill, London, N.
1861. ‡Whitehead, James, M.D. 87 Mosley-street, Manchester.
1861. *Whitehead, John B. Ashday Lea, Rawtenstall, Manchester.
1861. *Whitehead, Peter Ormerod. 25 Peel-avenue, Ardwick, Manchester.
1883. ‡Whitehead, P. J. 6 Cross-street, Southport.
1855. *Whitehouse, Wildeman W. O. 18 Salisbury-road, West Brighton.
1871. ‡Whitelaw, Alexander. 1 Oakley-terrace, Glasgow.
1884. ‡Whiteley, Joseph. Huddersfield.

Year of Election.

1881. §Whitfield, John, F.C.S. 113 Westborough, Scarborough.

1866. ‡Whitfield, Samuel. Eversfield, Eastnor-grove, Leamington.

1852. ‡Whitla, Valentine. Beneden, Belfast.

Whitley, Rev. Charles Thomas, M.A., F.R.A.S. Bedlington, Morpeth.

1870. ‡Whittem, James Sibley. Walgrave, near Coventry.

1857. *WHITTY, Rev. JOHN IRWINE, M.A., D.C.L., LL.D. 92 Mortimer-street, Herne Bay, Kent.

1874. *Whitwill, Mark. Redland House, Bristol.

1883. ‡Whitworth, James. 88 Portland-street, Southport.

1870. ‡WHITWORTH, Rev. W. ALLEN, M.A. Glenthorne-road, Hammersmith, London, W.

1865. ‡Wiggin, Henry, M.P. Metchley Grange, Harborne, Birmingham.

1886. §Wiggin, Henry A. The Lea, Harborne, Birmingham.

1885. ‡Wigglesworth, Alfred. Gordondale House, Aberdeen.

1881. *Wigglesworth, James. New Parks House, Falsgrave, Scarborough.

1883. ‡Wigglesworth, Mrs. New Parks House, Falsgrave, Scarborough.

1881. *Wigglesworth, Robert. Harrogate Club, Harrogate.

1878. ‡Wigham, John R. Albany House, Monkstown, Dublin.

1883. ‡Wigner, G. W., F.C.S. Plough-court, 37 Lombard-street, London, E.C.

1884. ‡Wilber, Charles Dana, LL.D. Grand Pacific Hotel, Chicago, U.S.A.

1881. ‡WILBERFORCE, W. W. Fishergate, York.

1857. ‡Wilkinson, George. Temple Hill, Killiney, Co. Dublin.

1886. *Wilkinson, J. H. Corporation-street, Birmingham.

1879. ‡Wilkinson, Joseph. York.

1859. ‡WILKINSON, ROBERT. Lincoln Lodge, Totteridge, Hertfordshire.

1872. ‡Wilkinson, William. 168 North-street, Brighton.

1869. §Wilks, George Augustus Frederick, M.D. Stanbury, Torquay.

1859. ‡Willet, John, M.Inst.C.E. 35 Albyn-place, Aberdeen.

1872. ‡WILLETT, HENRY, F.G.S. Arnold House, Brighton.

WILLIAMS, CHARLES JAMES B., M.D., F.R.S. 47 Upper Brook-street, Grosvenor-square, London, W.

1861. *Williams, Charles Theodore, M.A., M.B. 47 Upper Brook-street, Grosvenor-square, London, W.

1883. *Williams, Edward Starbuck. Ty-ar-y-graig, Swansea.

1886. §Williams, Francis. 24 Augustus-road, Edgbaston, Birmingham.

1861. *Williams, Harry Samuel, M.A., F.R.A.S. 1 Gorse-lane, Swansea.

1875. *Williams, Herbert A., M.A. 91 Pembroke-road, Clifton, Bristol.

1883. ‡Williams, Rev. H. A. The Ridgeway, Wimbledon, Surrey.

1857. ‡Williams, Rev. James. Llanfairinghornwy, Holyhead.

1870. §WILLIAMS, JOHN, F.C.S. 63 Warwick-gardens, Kensington, London, W.

1875. *Williams, M. B. Killay House, near Swansea.

1879. ‡WILLIAMS, MATTHEW W., F.C.S. Queenwood College, Stockbridge, Hants.

1886. §Williams, Richard, J.P. Brunswick House, Wednesbury.

Williams, Robert, M.A. Bridehead, Dorset.

1883. ‡Williams, R. Price. North Brow, Primrose Hill, London, N.W.

1869. ‡WILLIAMS, Rev. STEPHEN. Stonyhurst College, Whalley, Blackburn.

1883. §Williams, T. H. 2 Chapel-walk, South Castle-street, Liverpool.

1883. §Williams, T. Howell. 125 Fortess-road, London, N.W.

1877. *Williams, W. Carleton, F.C.S. Firth College, Sheffield.

1865. ‡Williams, W. M. Stonebridge Park, Willesden.

1883. ‡Williamson, Miss. Sunnybank, Ripon, Yorkshire.

Year of Election.

1850. *WILLIAMSON, ALEXANDER WILLIAM, Ph.D., LL.D., For. Sec. R.S., F.C.S., Corresponding Member of the French Academy, Professor of Chemistry and of Practical Chemistry, University College, London. (GENERAL TREASURER.) University College, London, W.C.

1857. ‡WILLIAMSON, BENJAMIN, M.A., F.R.S., Professor of Natural Philosophy in the University of Dublin. Trinity College, Dublin.

1876. ‡Williamson, Rev. F. J. Ballantrae, Girvan, N.B.

1863. ‡Williamson, John. South Shields.

1876. ‡Williamson, Stephen. 19 James-street, Liverpool.

WILLIAMSON, WILLIAM C., LL.D., F.R.S., Professor of Botany in Owens College, Manchester. 4 Egerton-road, Fallowfield, Manchester.

1883. ‡WILLIS, T. W. 51 Stanley-street, Southport.

1882. ‡Willmore, Charles. Queenwood College, near Stockbridge, Hants.

1865. *Willmott, Henry. Hatherley Lawn, Cheltenham.

1859. *Wills, The Hon. Sir Alfred. 12 King's Bench-walk, Inner Temple, London, E.C.

1886. §Wills, A. W. Wylde Green, Erdington, Birmingham.

1886. §Wilson, Alexander B. Holywood, Belfast.

1885. ‡Wilson, Alexander H. 2 Albyn-place, Aberdeen.

1878. ‡Wilson, Professor Alexander S., M.A., B.Sc. 124 Bothwell-street, Glasgow.

1859. ‡Wilson, Alexander Stephen, C.E. North Kinmundy, Summerhill, by Aberdeen.

1876. ‡Wilson, Dr. Andrew. 118 Gilmore-place, Edinburgh.

1874. ‡WILSON, Colonel Sir C. W., R.E., K.C.B., K.C.M.G., D.C.L., F.R.S., F.R.G.S. Mountjoy Barracks, Phœnix Park, Dublin.

1850. ‡Wilson, Dr. Daniel. Toronto, Upper Canada.

1876. ‡Wilson, David. 124 Bothwell-street, Glasgow.

1863. ‡Wilson, Frederic R. Alnwick, Northumberland.

1847. *Wilson, Frederick. 73 Newman-street, Oxford-street, London, W.

1885. ‡Wilson, Brigade-Surgeon G. A. East India United Service Club, St. James's-square, London, S.W.

1875. ‡Wilson, George Fergusson, F.R.S., F.C.S., F.L.S. Heatherbank, Weybridge Heath, Surrey.

1874. *Wilson, George Orr. Dunardagh, Blackrock, Co. Dublin.

1863. ‡Wilson, George W. Heron Hill, Hawick, N.B.

1883. *Wilson, Henry, M.A. Eastnor, Malvern Link, Worcestershire.

1879. ‡Wilson, Henry J. 255 Pitsmoor-road, Sheffield.

1885. ‡Wilson, J. Dove, LL.D. 17 Rubislaw-terrace, Aberdeen.

1886. §Wilson, J. E. B. Woodslee, Wimbledon, Surrey.

1857. ‡Wilson, James Moncrieff. Queen Insurance Company, Liverpool.

1865. ‡WILSON, Rev. JAMES M., M.A., F.G.S. The College, Clifton, Bristol.

1884. ‡Wilson, James S. Grant. H.M. Geological Survey, Sheriff Court-buildings, Edinburgh.

1858. *Wilson, John. Seacroft Hall, near Leeds.

WILSON, JOHN, F.R.S.E., F.G.S., Professor of Agriculture in the University of Edinburgh. The University, Edinburgh.

1879. ‡Wilson, John Wycliffe. Eastbourne, East Bank-road, Sheffield.

1876. ‡Wilson, R. W. R. St. Stephen's Club, Westminster, S.W.

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1861. *WILTSHIRE, Rev. THOMAS, M.A., F.G.S., F.L.S., F.R.A.S., Assistant Professor of Geology and Mineralogy in King's College, London. 25 Granville-park, Lewisham, London, S.E.
1877. ‡Windeatt, T. W. Dart View, Totnes.
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Year of
Election.

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