BRITISH ASSOCIATION
FOR THE ADVANCEMENT OF SCIENCE

REPORT

OF THE

NINETY-FIRST MEETING

(NINETY-THIRD YEAR)

LIVERPOOL—1923

SEPTEMBER 12–19

LONDON
JOHN MURRAY, ALBEMARLE STREET

OFFICE OF THE ASSOCIATION
BURLINGTON HOUSE, LONDON, W.1

1924

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TABLE OF

Date of Meeting	Where held	Presidents	Old Life Members	New Life Members
1831, Sept. 27	York	Viscount Milton, D.C.L., F.R.S.	—	—
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., F.R.S.	—	—
1835, Aug. 10	Dublin	The Rev. Provost Lloyd, LL.D., F.R.S.	—	—
1836, Aug. 22	Bristol	The Marquis of Lansdowne, F.R.S.	—	—
1837, Sept. 11	Liverpool	The Earl of Burlington, F.R.S.	—	—
1838, Aug. 10	Newcastle-on-Tyne	The Duke of Northumberland, F.R.S.	—	—
1839, Aug. 26	Birmingham	The Rev. W. Vernon Harcourt, F.R.S.	—	—
1840, Sept. 17	Glasgow	The Marquis of Breadalbane, F.R.S.	—	—
1841, July 20	Plymouth	The Rev. W. Whewell, F.R.S.	169	65
1842, June 23	Manchester	The Lord Francis Egerton, F.G.S.	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., F.R.S.	226	150
1845, June 19	Cambridge	Sir John F. W. Herschel, Bart., F.R.S.	313	36
1846, Sept. 10	Southampton	Sir Roderick I. Murchison, Bart., F.R.S.	241	10
1847, June 23	Oxford	Sir Robert H. Inglis, Bart., F.R.S.	314	18
1848, Aug. 9	Swansea	The Marquis of Northampton, Pres. R.S.	149	3
1849, Sept. 12	Birmingham	The Rev. T. R. Robinson, D.D., F.R.S.	227	12
1850, July 21	Edinburgh	Sir David Brewster, K.H., F.R.S.	235	9
1851, July 2	Ipswich	G. B. Airy, Astronomer Royal, F.R.S.	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., F.R.S.	182	14
1857, Aug. 26	Dublin	The Rev. H. Lloyd, D.D., F.R.S.	236	15
1858, Sept. 22	Leeds	Richard Owen, M.D., D.C.L., F.R.S.	222	42
1859, Sept. 14	Aberdeen	H.R.H. The Prince Consort	184	27
1860, June 27	Oxford	The Lord Wrottesley, M.A., F.R.S.	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., F.R.S.	239	15
1863, Aug. 26	Newcastle-on-Tyne	Sir William G. Armstrong, C.B., F.R.S.	203	36
1864, Sept. 13	Bath	Sir Charles Lyell, Bart., M.A., F.R.S.	287	40
1865, Sept. 6	Birmingham	Prof. J. Phillips, M.A., LL.D., F.R.S.	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., F.R.S.	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., F.R.S.	204	21
1870, Sept. 14	Liverpool	Prof. T. H. Huxley, LL.D., F.R.S.	314	39
1871, Aug. 2	Edinburgh	Prof. Sir W. Thomson, LL.D., F.R.S.	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, 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
1887, Aug. 31	Manchester	Sir H. E. Roscoe, D.C.L., F.R.S.	428	86
1888, Sept. 5	Bath	Sir F. J. Bramwell, F.R.S.	266	36
1889, Sept. 11	Newcastle-on-Tyne	Prof. W. H. Flower, C.B., F.R.S.	277	20
1890, Sept. 3	Leeds	Sir F. A. Abel, C.B., F.R.S.	259	21
1891, Aug. 19	Cardiff	Dr. W. Huggins, F.R.S.	189	24
1892, Aug. 3	Edinburgh	Sir A. Geikie, LL.D., F.R.S.	280	14
1893, Sept. 13	Nottingham	Prof. J. S. Burdon Sanderson, F.R.S.	201	17
1894, Aug. 8	Oxford	The Marquis of Salisbury, K.G., F.R.S.	327	21
1895, Sept. 11	Ipswich	Sir Douglas Galton, K.C.B., F.R.S.	214	13
1896, Sept. 16	Liverpool	Sir Joseph Lister, Bart., Pres. R.S.	330	31
1897, Aug. 18	Toronto	Sir John Evans, K.C.B., F.R.S.	120	8
1898, Sept. 7	Bristol	Sir W. Crookes, F.R.S.	281	19
1899, Sept. 13	Dover	Sir Michael Foster, K.C.B., Sec. R.S.	296	20

* Ladies were not admitted by purchased tickets until 1843. † Tickets of Admission to Sections only.

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ANNUAL MEETINGS.

Old Annual Members	New Annual Members	Associates	Ladies	Foreigners	Total	Amount received for Tickets	Sums paid on account of Grants for Scientific Purposes	Year
—	—	—	—	—	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 8 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	1855 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
510	244	1985	493	92	3838	4336 0 0	1186 18 0	1887
399	100	639	509	12	1984	2107 0 0	1511 0 5	1888
412	113	1024	579	21	2437	2441 0 0	1417 0 11	1889
368	92	680	334	12	1775	1776 0 0	789 16 8	1890
341	152	672	107	35	1497	1664 0 0	1029 10 0	1891
413	141	733	439	50	2070	2007 0 0	864 10 0	1892
328	57	773	268	17	1661	1653 0 0	907 15 6	1893
435	69	941	451	77	2321	2175 0 0	583 15 6	1894
290	31	493	261	22	1324	1236 0 0	977 15 5	1895
383	139	1384	873	41	3181	3228 0 0	1104 6 1	1896
286	125	682	100	41	1362	1398 0 0	1059 10 8	1897
327	96	1051	639	33	2446	2399 0 0	1212 0 0	1898
324	68	548	120	27	1403	1328 0 0	1430 14 2	1899

‡ Including Ladies. § Fellows of the American Association were admitted as Hon. Members for this Meeting

[*Continued on p.* xiii.

Table of

Date of Meeting	Where held	Presidents	Old Life Members	New Life Members
1900, Sept. 5	Bradford	Sir William Turner, D.C.L., F.R.S. ...	267	13
1901, Sept. 11	Glasgow..................	Prof. A. W. Rücker, D.Sc., Sec.R.S. ...	310	37
1902, Sept. 10	Belfast	Prof. J. Dewar, LL.D., F.R.S.	243	21
1903, Sept. 9	Southport	Sir Norman Lockyer, K.C.B., F.R.S.	250	21
1904, Aug. 17......	Cambridge...............	Rt. Hon. A. J. Balfour, M.P., F.R.S.	419	32
1905, Aug. 15......	South Africa	Prof. G. H. Darwin, LL.D., F.R.S. ...	115	40
1906, Aug. 1	York	Prof. E. Ray Lankester, LL.D., F.R.S.	322	10
1907, July 31	Leicester	Sir David Gill, K.C.B., F.R.S.	276	19
1908, Sept. 2	Dublin	Dr. Francis Darwin, F.R.S.	294	24
1909, Aug. 25......	Winnipeg	Prof. Sir J. J. Thomson, F.R.S.	117	13
1910, Aug. 31	Sheffield.................	Rev. Prof. T. G. Bonney, F.R.S.	293	26
1911, Aug. 30	Portsmouth	Prof. Sir W. Ramsay, K.C.B., F.R.S.	284	21
1912, Sept. 4	Dundee	Prof. E. A. Schäfer, F.R.S..............	288	14
1913, Sept. 10	Birmingham	Sir Oliver J. Lodge, F.R.S........... ...	376	40
1914, July-Sept....	Australia	Prof. W. Bateson, F.R.S.	172	13
1915, Sept. 7	Manchester	Prof. A. Schuster, F.R.S.	242	19
1916, Sept. 5	Newcastle-on-Tyne...	Sir Arthur Evans, F.R.S.	164	12
1917	(No Meeting)		—	—
1918	(No Meeting)		—	—
1919, Sept. 9	Bournemouth	Hon. Sir C. Parsons, K.C.B., F.R.S....	235	47
1920, Aug. 24......	Cardiff	Prof. W. A. Herdman, C.B.E., F.R.S.	288	11
1921, Sept. 7	Edinburgh	Sir T. E. Thorpe, C.B., F.R.S.	336	9
1922, Sept. 6	Hull	Sir C. S. Sherrington, G.B.E., Pres. R.S.	228	13
1923, Sept. 12	Liverpool	Sir Ernest Rutherford, F.R.S.	326	12

Annual Meetings—(continued).

Old Annual Members	New Annual Members	Associates	Ladies	Foreigners	Total	Amount received for Tickets	Sums paid on account of Grants for Scientific Purposes	Year
297	45	801	482	9	1915	£1801 0	£1072 10 0	1900
374	131	794	246	20	1912	2046 0	920 9 11	1901
314	86	647	305	6	1620	1644 0	947 0 0	1902
319	90	688	365	21	1754	1762 0	845 13 2	1903
449	113	1338	317	121	2789	2650 0	887 18 11	1904
937[1]	411	430	181	16	2130	2422 0	928 2 2	1905
356	93	817	352	22	1972	1811 0	882 0 9	1906
339	61	659	251	42	1647	1561 0	757 12 10	1907
465	112	1166	222	14	2297	2317 0	1157 18 8	1908
290[2]	162	789	90	7	1468	1623 0	1014 9 9	1909
379	57	563	123	8	1449	1439 0	963 17 0	1910
349	61	414	81	31	1241	1176 0	922 0 0	1911
368	95	1292	359	88	2504	2349 0	845 7 6	1912
480	149	1287	291	20	2643	2756 0	978 17 1	1913
139	4160[3]	539[4]	—	21	5044[3]	4873 0	1861 16 4[6]	1914
287	116	628[4]	141	8	1441	1406 0	1569 2 8	1915
250	76	251[4]	73	—	826	821 0	985 18 10	1916
—	—	—	—	—	—	—	677 17 2	1917
—	—	—	—	—	—	—	326 13 3	1918
254	102	688[4]	153	3	1482	1736 0	410 0 0	1919

Old Annual Regular Members	Annual Members: Meeting and Report	Annual Members: Meeting only	Transferable Tickets	Students' Tickets		Total	Amount received for Tickets	Sums paid on account of Grants for Scientific Purposes	Year
136	192	571	42	120	20	1380	1272 10	1251 13 0[8]	1920
133	410	1394	121	343	22	2768	2599 15	518 1 10	1921
90	294	757	89	235[5]	24	1730	1699 5	772 0 7	1922
					Complimentary.				
123	380	1434	163	550	308[7]	3296	2735 15	777 18 6[9]	1923

[1] Including 848 Members of the South African Association.
[2] Including 137 Members of the American Association.
[3] Special arrangements were made for Members and Associates joining locally in Australia, see Report, 1914, p. 686. The numbers include 80 Members who joined in order to attend the Meeting of L'Association Française at Le Havre.
[4] Including Students' Tickets, 10*s*.
[5] Including Exhibitioners granted tickets without charge.
[6] Including grants from the Caird Fund in this and subsequent years.
[7] Including Foreign Guests, Exhibitioners, and others.
[8] The Bournemouth Fund for Research, initiated by Sir C. Parsons, enabled grants on account of scientific purposes to be maintained.
[9] Including grants from the Caird Gift for research in radioactivity in this and subsequent years.

REPORT OF THE COUNCIL, 1922–23.

I. Major-General Sir David Bruce, K.C.B., F.R.S., has been unanimously nominated by the Council to fill the office of President of the Association for the year 1924-25 (Toronto Meeting).

II. The Council conveyed to Sir William Herdman their condolence on the lamented death of Lady Herdman, and to Lady Dewar on that of Sir James Dewar, ex-President.

III. The Hon. Sir Charles Parsons, ex-President, and Dr. E. H. Griffiths, General Treasurer, represented the Association at the Centenary celebration of the Yorkshire Philosophical Society, September 20, 1922, and presented an Address on behalf of the Council, in which it was stated that the Society 'is justly regarded by the Association as its mother-society.'

Representatives of the Association have been appointed as follows:—

Air Conference, Guildhall	Mr. F. E. Smith, Sir Richard Gregory and the Secretary.
Council of Honour, International Air Congress	Mr. R. V. Southwell.
Societa Italiana per il Progresso delle Scienze	Professor J. L. Myres and Dr. Randall MacIver.
Congrès International pour la Protection de la Nature	Dr. P. Chalmers Mitchell.
Royal Sanitary Institute Congress	Mr. W. Whitaker.
Royal Institute of Public Health Congress	Dr. C. S. Myers.
Pan-Pacific Science Congress	Professor W. A. Osborne.
Advisory Council, Scientific Expeditionary Research Association	Mr. F. E. Smith.
Massachusetts Institute of Technology: Inauguration of President	Professor W. MacDougall.
Huxley Centenary Committee	Professor E. B. Poulton.
Association Française (Bordeaux Meeting)	Dr. J. G. Garson.

IV. The Council expressed to Sir Robert Hadfield the grateful thanks of the Association for his generous gift designed to enable necessitous students to obtain scientific books. The gift is of £50 in each of three years, and that sum, for the first year, has been distributed in grants of £10 to each of five universities or colleges selected by lot, viz. University College of Bangor, North Wales; University College, Cardiff; Universities of Leeds, Liverpool, and Manchester.

V. In furtherance of the movement to establish a central institution for the encouragement of more general interest in anthropological studies (*Report*, Hull Meeting, p. xv., § III, *g*), it has been ascertained that the Royal Anthropological Institute is willing, under certain conditions, to undertake the functions of such an institution, and has established a

Joint Committee for Anthropological Training and Research, on which all other bodies concerned in these matters are entitled to representation by their delegates. The Joint Committee has already held its first meeting, and taken action in matters of immediate concern to the constituent bodies.

VI. Resolutions referred by the General Committee, at the Hull Meeting, to the Council for consideration and, if desirable, for action, were dealt with as follows:—

(*a*) On the instruction of the General Committee, the Council invited the co-operation of a number of societies in applying to the Railway Companies in Great Britain for a restoration of the travelling facilities and concessions allowed to members attending scientific meetings before the War. The Council were gratified to learn that this had been granted to the Association, and returned a vote of thanks to the Companies.

(*b*) The Council agreed to support Dr. Potts in an application to the Committee of the Institution of Civil Engineers on Sea Action for a grant in aid of his investigation into the life-history of Teredo. (Resolution of Section D.)

(*c*) The Council felt that they could take no action upon a suggestion that a fund should be raised for the relief of distinguished aged scientific men in need as the result of conditions on the Continent of Europe. (Resolution of Section G.)

(*d*) The Council, after full inquiry, decided to take no action upon a proposal that the Association should join the Museums Association in moving for the appointment of a Royal Commission to investigate the work of museums in relation to industries and general culture. (Resolution of the Committee of Recommendations.)

(*e*) The Council made a standing order that if, in connection with any application for a grant from the funds of the Association, any payment of travelling expenses (fares only) is contemplated, the amount to be so allocated must be stated in the application, and the payment of such expenses expressly sanctioned by the Committee of Recommendations and the General Committee, or, in the event of subsequent emergency, by the Council.

VII. The Council, on behalf of the Association, joined in protesting against proposed changes in the Egyptian laws relating to antiquities, and received, through the Foreign Office and the High Commissioner, the assurance that the Egyptian Government would not modify the existing law without further careful consideration of protests received.

VIII. The President signed, on behalf of the Council, a memorandum to the President of the Board of Education, urging that further accommodation should be provided for the Science collections at the Victoria and Albert Museum, the Association having been represented in 1909 on a deputation to the Board dealing with this question.

IX. The Council have received reports from the General Treasurer throughout the year. His accounts have been audited and are presented to the General Committee.

The Council made the following grants to research committees from the Caird Fund:—

Seismology Committee	£100
Naples Table Committee	£100
Bronze Implements Committee	£80
Tables of Constants Committee	£40

The General Treasurer was authorised to apply any balance of Caird Fund income to meeting other grants made by the General Committee at Hull.

The third grant of £250 from the Caird Gift for research in radioactivity (for the year ending March 24, 1924) has been made to Professor F. Soddy.

The British Association Exhibitions established in connection with the Hull Meeting were awarded to eighteen students nominated by the same number of universities and colleges, while six of these institutions made equivalent allowances for eight additional students. All were entertained by the Local Executive Committee at Hull, were enabled to meet the President and General Officers, and through an elected representative communicated to the Press their appreciation of the opportunity afforded to them of attending the Meeting. The Council have every hope of maintaining this system of exhibitions, which has already proved its value.

A small cost has been incurred for repairing the datum-level mark erected at Stogursey by the Association in 1837.

X. The Council approved a number of resolutions from the Conference of Delegates of Corresponding Societies. (*Report*, Hull Meeting, p. xxxiii.)

A number of societies have been admitted to affiliation or association, including, at the instance of the Organising Committee of Section M (Agriculture), certain agricultural societies which have not previously been represented.

Prof. H. H. Turner has been nominated as President, Prof. P. G. H. Boswell as Vice-President, and Miss E. Warhurst as Local Secretary of the Conference of Delegates at Liverpool.

The Corresponding Societies Committee has been nominated as follows: The President of the Association (*Chairman*, *ex officio*), Mr. T. Sheppard (*Vice-Chairman*), the General Treasurer, the General Secretaries, Dr. F. A. Bather, Mr. O. G. S. Crawford, Prof. P. F. Kendall, Mr. Mark L. Sykes, Dr. C. Tierney, Prof. W. W. Watts, Mr. W. Whitaker.

XI. The retiring Ordinary Members of the Council are:—

By seniority: Sir A. Strahan, Sir S. F. Harmer.

By least attendance: Dr. E. F. Armstrong, Sir J. Petavel, Sir W. J. Pope.

The Council nominated the following new members:—

Prof. W. Dalby, Dr. J. S. Flett, Mr. C. T. Heycock,

leaving two vacancies to be filled by the General Committee without nomination by the Council.

The full list of nominations of Ordinary Members is as follows:—

Dr. F. W. Aston, F.R.S.
Mr. J. Barcroft, F.R.S.
Rt. Hon. Lord Bledisloe, K.B.E.
Professor W. Dalby, F.R.S.
Mr. E. N. Fallaize.
Dr. J. S. Flett, F.R.S.
Professor H. J. Fleure.
Professor A. Fowler, F.R.S.
Sir R. A. Gregory.
Sir Daniel Hall, K.C.B., F.R.S.
Mr. C. T. Heycock, F.R.S.
Dr. W. Evans Hoyle.
Mr. J. H. Jeans, F.R.S.
Sir A. Keith, F.R.S.
Sir J. Scott Keltie.
Professor A. W. Kirkaldy.
Dr. P. Chalmers Mitchell, C.B.E., F.R.S.
Dr. C. S. Myers, F.R.S.
Professor A. W. Porter, F.R.S.
Professor A. C. Seward, F.R.S.
Professor A. Smithells, C.M.G., F.R.S.
Mr. A. G. Tansley, F.R.S.
Mr. W. Whitaker, F.R.S.

XII. The General Officers have been nominated by the Council as follows:—

General Treasurer, Dr. E. H. Griffiths.

General Secretaries, Prof. J. L. Myres, Mr. F. E. Smith.

XIII. The following have been admitted as members of the General Committee:—

Dr. W. L. Balls.
Professor J. W. Bews.
Professor A. H. R. Buller.
Mr. R. S. Clark.
Mr. J. R. Clarke.
Mr. N. M. Comber.
Mr. J. T. Cunningham.
Dr. E. M. Delf.
Mr. E. A. Fisher.
Miss R. M. Fleming.
Dr. R. H. Greaves.
Professor W. D. Henderson.
Mr. Julian S. Huxley.
Mr. H. Jeffreys.
Dr. A. F. Joseph.
Mrs. Forbes Julian.
Dr. M. V. Lebour.
Dr. E. B. R. Prideaux.
Mr. J. Ramsbottom.
Dr. E. J. Salisbury.
Professor W. Wright Smith.
Professor D. Thoday.

XIV. The Council take pleasure in nominating M. le Comte de St. Périer to be an honorary corresponding member of the Association.

XV. Arrangements for the Meeting in Toronto, 1924, are in progress, and the Council has appointed a committee to assist the General Officers in this matter, including Sir D. Bruce, Sir R. A. Gregory, Sir W. Herdman, Prof. A. W. Kirkaldy, Prof. J. C. McLennan, Sir E. Rutherford, Sir C. Sherrington, Prof. A. Smithells.

The General Committee at Hull desired the Council to consider the possibility of a meeting being held in England in 1924, following and supplementary to the Toronto Meeting. The Council have done so, but do not see the way clear to carrying out the suggestion.

XVI. The Council recommend the following change in Rule V., 1, in relation to ex-officio members of the Council, viz.:—

Present Rule.—The ex-officio members are . . . the President and Vice-Presidents for the year, the President and Vice-Presidents elect . . . and the Local Treasurers and Local Secretaries for the ensuing Annual Meeting.

Amendment.—The ex-officio members are . . . the President for the year, the President and Vice-Presidents for the ensuing Annual Meeting . . . and the Local Treasurers and Local Secretaries for the Annual Meetings immediately past and ensuing.

BRITISH ASSOCIATION EXHIBITIONS.

For the Liverpool Meeting, British Association Exhibitions (referred to in § IX. of the above report) were awarded to twenty students nominated by the same number of universities and colleges. Their travelling expenses (railway fares) were met by the Association, which also issued complimentary students' tickets of membership to them; they were entertained in Liverpool by the Local Executive Committee at University hostels in Liverpool. Six of the universities or colleges allowed travelling expenses for thirteen additional exhibitioners, who also received the other facilities indicated above. The exhibitioners were enabled to meet the President and general officers. One of their number (Mr. W. W. Allen, of King's College, London) was elected secretary for the purpose of communication by the exhibitioners as a body with the general officers.

GENERAL MEETINGS, SCIENTIFIC EXHIBITION, AND SOIRÉE AT LIVERPOOL.

Inaugural General Meeting.

On Wednesday, September 12, at 8.30 p.m., in the Philharmonic Hall, Prof. Sir Charles S. Sherrington, G.B.E., Pres.R.S., resigned the office of President of the Association to Prof. Sir Ernest Rutherford, F.R.S., who delivered an address on 'The Electrical Structure of Matter' (for which see p. 1).

The address was broadcast from all stations of the British Broadcasting Company, and was effectively heard in all parts of Great Britain; it was also reported as clearly received by a listener in Switzerland. Arrangements for land-line transmission were made by the Western Electric Company, and these also enabled the address to be repeated in the Small Concert Room, St. George's Hall, Liverpool, where a duplicate set of the lantern-sides used by the speaker was shown at the appropriate points in the address.

Evening Lecture.

On Friday, September 14, at 8.30 p.m., in the Philharmonic Hall, Prof. G. Elliot Smith, F.R.S., delivered a lecture on 'The Study of Man.'

Scientific Exhibition.

A Scientific Exhibition was opened in the Central Technical School from September 10 to 22, the public being admitted in addition to members of the Association. Exhibits were furnished by upwards of sixty firms, institutions, and individuals, and demonstrations were given and lectures delivered throughout the period of the exhibition.

Scientific Soirée.

A Scientific Soirée was held in Liverpool University on Tuesday evening, September 18, at which a large number of exhibits, demonstrations, and short lectures, in all departments of science covered by the Sections of the Association, illustrated recent advances.

Concluding General Meeting.

The concluding General Meeting was held in St. George's Hall on Wednesday, September 19, at 12 noon, when the following resolutions were adopted by acclamation:—

(1)

To express the thanks of the British Association to the City of Liverpool, through the Rt. Hon. the Lord Mayor, for its hospitable welcome; and to the City Council for its generous help, and the assistance afforded by its staff and various committees, especially the Sub-Committee for Technical and Commercial Education, which has allowed the Technical School to be used for the Scientific Exhibition, and the Tramways Committee, which has given free transport to members of the Association.

(2)

To thank the University of Liverpool, through the Vice Chancellor, for the use of its buildings and scientific equipment, and for the friendly co-operation of its Professors and staff.

(3)

To thank the Local Committee and its Vice-Chairmen, the Local Hon. Secretaries and Assistant Secretary, the Local Hon. Treasurer and Assistant Treasurer, and their staffs, for their provision for the needs of the Association and the entertainment of its members; the Chairman and Secretary of the Scientific Exhibition Committee and of the Scientific Soirée Committee for their work in connection with these interesting features of the meeting; the Liverpool Clubs for their hospitality, and the Overhead Railway for providing free transport; and generally to express the gratitude of the Association to all those who by throwing open works or other enterprises for inspection, and in many other ways, have contributed to the success of the meeting.

PUBLIC LECTURES IN LIVERPOOL AND NEIGHBOURHOOD.

Picton Hall, Liverpool.

Tuesday, September 11, at 8 p.m.: Professor G. W. O. Howe on 'The Evolution of the High Power Wireless Station.'

Thursday, September 13, at 8 p.m.: Professor A. S. Eddington, F.R.S., on 'Relativity.'

Friday, September 14, at 8 p.m.: Sir Wm. Pope, K.B.E., F.R.S., on 'Colour Photography.'

Monday, September 17, at 8 p.m. : Mr. J. Barcroft, C.B.E., F.R.S., on 'The Study of Life on the Roof of the New World.'

Wednesday, September 19, at 8 p.m. : Dr. F. A. E. Crew on 'The Riddle of Sex.'

ARTS THEATRE, UNIVERSITY OF LIVERPOOL.

Friday, September 14, at 5 p.m. : Dr. Johs. Schmidt on 'The "Dana" Expeditions and their work on the Life-History of the Eel.'

TOWN HALL, HAMILTON SQUARE, BIRKENHEAD.

Friday, September 14, at 7.30 p.m. : Professor A. C. Seward, F.R.S., on 'Greenland : Its Ice, Flowers, and People.'

Tuesday, September 18, at 3.30 p.m. : Professor E. B. Poulton, F.R.S., on 'Mimicry in Insects' (a Lecture for Young People).

TOWN HALL, BOOTLE.

Friday, September 14, at 8 p.m. : Professor T. H. Pear on 'The Acquisition of Skill in Work and Play.'

TOWN HALL, WALLASEY.

Wednesday, September 12, at 8 p.m. : Professor A. Dendy, F.R.S., on 'The Evolution Theory of To-day.'

PARR HALL, WARRINGTON.

Friday, September 14, at 7.30 p.m. : Sir John Russell, O.B.E., F.R.S., on 'Soil and Crop Growth.'

Friday, September 14, at 3 p.m. : Mr. F. Balfour Browne on 'Wild Bees and Wasps.'

TOWN HALL, ST. HELENS.

Monday, September 17, at 7.30 p.m. : Professor P. M. Roxby on 'Regional Survey.'

MINING AND TECHNICAL COLLEGE, LIBRARY STREET, WIGAN.

Monday, September 17, at 7.30 p.m. : Professor H. H. Turner, F.R.S., on 'The Size of a Star.'

TECHNICAL INSTITUTE, RUNCORN.

Monday, September 17, at 7.30 p.m. : Major G. W. C. Kaye on 'X-rays and their Uses.'

CHILDREN'S LECTURES IN LIVERPOOL.

ARTS THEATRE, UNIVERSITY OF LIVERPOOL.

Thursday, September 13, at 3 p.m. : Professor Arthur Smithells, C.M.G., F.R.S., on 'Flame.'

PICTON HALL, LIVERPOOL.

Friday, September 14, at 3 p.m. : Professor P. E. Newberry, O.B.E., on 'Toys and Games.'

GENERAL TREASURER'S ACCOUNT

JULY 1, 1922, TO JUNE 30, 1923.

Balance Sheet,

LIABILITIES.

	£ s. d.	£ s. d.	£ s. d. Corresponding Figures, 1922.
To Sundry Creditors		87 11 0	*246 15 1*
,, Capital Account—			
General Fund per contra	10,575 15 2		*10,575 15 2*
Caird Fund do.	9,582 16 3		*9,582 16 3*
Sir F. Bramwell's Gift for Inquiry into Prime Movers, 1931—			
£50 Consols accumulated to June 30, 1923, as per contra	56 11 0	20,215 2 5	*53 14 6*
,, Caird Fund—			
Balance as at July 1, 1922	573 12 0		
Add Excess of Income over Expenditure	113 10 4	687 2 4	*573 12 0*
(This is without allowance for Depreciation of Investments £1,861 10*s.* 3*d.*)			
,, Caird Gift—			
Radio-Activity Investigation, Balance at July 1, 1922	1,046 18 8		
Add Dividends on Treasury Bonds .	38 2 6		
Income Tax Recovered	22 18 3		
	1,107 19 5		
Less Grant to Sir E. Rutherford .	250 0 0	857 19 5	*1,046 18 8*
,, Sir Charles Parsons' Gift		10,000 0 0	*10,000 0 0*
,, John Perry Guest Fund— For cases of emergency connected with Guests of the Association . . .		75 0 0	*75 0 0*
,, Life Compositions as at July 1, 1922 . .	45 0 0		*45 0 0*
Add Received during year . .	240 0 0	285 0 0	
,, Legacy, T. W. Backhouse		450 0 0	*450 0 0*
,, Income and Expenditure Account—			
Balance at July 1, 1922	2,621 19 3		
Add Excess of Income over Expenditure	336 19 9	2,958 19 0	*2,621 19 3*
(MEM.—The above is subject to Depreciation of Investments amounting to a net sum of £2,398 9s. 6d.)			
		£35,616 14 2	*£35,271 10 11*

I have examined the foregoing Account with the Books and Vouchers, and certify the

Approved,

ARTHUR L. BOWLEY }
A. W. KIRKALDY } *Auditors.*

July 20, 1923.

July 1, 1922—June 30, 1923

ASSETS.

		£ s. d.	£ s. d.	£ s. d. Corresponding Figures, 1922.
By Sundry Debtors			45 13 4	*21 0 3*
,, Investments on Capital Accounts—				
£4,651 10*s*. 5*d*. Consolidated 2½ per cent. Stock at cost		3,942 3 3		
£3,600 India 3 per cent. Stock at cost		3,522 2 6		
£879 14*s*. 9*d*. £43 Great Indian Peninsula "B" Annuity at cost		827 15 0		
£52 12*s*. 7*d*. & £810 10*s*. 3*d*. War Stock, 1929/47 at cost		889 17 6		
£1,400 War Loan Bonds 5 per cent. 1929/47 at cost		1,393 16 11		
			10,575 15 2	*10,575 15 2*
£7,634 18s. 2d. Value at date, £7,955 16*s*. 1*d*.				
,, Caird Fund—				
£2,627 0*s*. 10*d*. India 3½ per cent. Stock at cost		2,400 13 3		
£2,100 London, Midland and Scottish Rly. Consolidated 4 per cent. Preference Stock at cost		2,190 4 3		
£2,500 Canada 3½ per cent. 1930/50 Registered Stock at cost		2,397 1 6		
£2,000 Southern Rly. Consolidated 5 per cent. Preference Stock at cost		2,594 17 3		
			9,582 16 3	*9,582 16 3*
£7,359 16s. 4d. Value at date, £7,721 6s. 0d.				
,, Sir F. Bramwell's Gift—				
£50 2½ per cent. Self-Cumulating Consolidated Stock as per last Balance Sheet	£111 11 1	53 14 6		*53 14 6*
Add accumulations to June 30, 1923	4 17 5	2 16 6		
	£116 8 6		56 11 0	
£63 11s. 8d. Value at date, £68 7s. 11d.				
,, Caird Gift—				
£1,000 Registered Treasury Bonds.			1,000 0 0	*1,000 0 0*
£1,105. Value at date, £1,018 15s. 0d.				
,, Sir Charles Parsons' Gift—				
£10,000 5 per cent. War Loan			10,000 0 0	*10,000 0 0*
£10,025. Value at date, £10,125.				
,, John Perry Guest Fund—				
£96 National Savings Certificates at cost			74 8 0	*74 8 0*
,, Investments out of Income—				
£2,098 1*s*. 9*d*. Consolidated 2½ per cent. Stock at cost		1,200 0 0		
£1,500 Registered Treasury Bonds at cost		1,482 0 0		
			2,682 0 0	*2,682 0 0*
£2,857 10s. 0d. Value at date, £2,778 9s. 7*d*.				
,, Life Compositions—				
£324 11*s*. 8*d*. Local Loans at cost. Value at date, £220 14*s*. 4*d*.			210 0 0	
,, Cash—On Deposit		500 0 0		
At Bank		889 10 5		
			1,389 10 5	*1,281 16 9*
Viz.:—Legacy	£450 0 0			
Caird Fund	687 2 4			
Life Compositions	75 0 0			
John Perry Guest Fund (Balance)	0 12 0			
	1,212 14 4			
Less Caird Gift	142 0 7			
	1,070 13 9			
General Purposes	318 16 8			
	£1,389 10 5			
			£35,616 14 2	*£35,271 10 11*

same to be correct. I have also verified the balances at the Bankers and the Investments.

W. B. KEEN,
Chartered Accountant.

Income and

FOR THE YEAR ENDED

EXPENDITURE.

	£ s. d.	£ s. d.	£ s. d. Corresponding Period, 1922.
To Heat and Lighting	14 12 1		*10 17 3*
,, Stationery	47 4 5		*27 12 9*
,, Rent	16 0 0		*8 5 0*
,, Postages	150 1 5(1)		*97 1 1*
,, *Electric Light Installation*			*45 15 5*
,, *Refund, re Australian Meeting*			*75 0 0*
,, Travelling Expenses	185 5 6		*381 11 0* (Travelling Expenses and Exhibitioners)
,, Exhibitioners	50 5 6		
,, General Expenses	201 16 10(2)		*124 17 3*
	665 5 9		*770 19 9*
,, Salaries and Wages	1,108 5 0(3)		*998 13 4*
,, Pension Contribution	75 0 0		*75 0 0*
,, Printing, Binding, etc.	1,396 3 6		*1,974 13 8*
		3,244 14 3	
,, Sir Robert Hadfield's Gift: Grants to Universities		50 0 0	
,, *Miss Stewardson, as per Contra*			*15 0 0*
,, Grants to Research Committees :—			
Absorption Spectra	10 0 0		
Stress Distributions	25 0 0		
Parthenogenesis	5 0 0		
Growth of Children	20 0 0		
Coldrum Megalithic Monument	20 0 0		
Geography Teaching	10 0 0		
Colloid Chemistry	5 0 0		
Old Red Sandstone of Bristol	15 0 0		
Stone Monuments	5 0 0		
Muscular Stiffness	15 0 0		
Corresponding Societies	40 0 0		
Bronze Implements	20 0 0		
Derbyshire Caves	25 0 0		
Zoological Bibliography	1 0 0		
Malta	25 0 0		
Fossils	5 0 0		
Oenothera	1 18 6		
Conjoint Board	10 0 0		
		257 18 6	*257 0 7*
,, Balance being excess of Income over Expenditure for the year		336 19 9	*567 0 1*
		£3,889 12 6	*£4,658 7 5*

(1) Postage of the Annual Report was formerly reckoned with the printing account.

(2) The increase is mainly accounted for by the purchase of an addressing and listing machine, which helps materially to reduce the printing account.

(3) Wages were formerly reckoned with General Expenses.

Caird

	£ s. d.	£ s. d.	£ s. d.
To Grants paid—			
Tables of Constants Committee	40 0 0		
Naples Station Committee	50 0 0		
Seismology Committee	100 0 0		
Bronze Implements Committee	80 0 0		
		270 0 0	*515 0 0*
,, Balance being Excess of Income over Expenditure		113 10 4	
		£383 10 4	*£515 0 0*

Expenditure Account

JUNE 30, 1923.

INCOME.

	£ s. d.	£ s. d.	£ s. d. Corresponding Period, 1922.
By *Life Compositions (Now Capitalised)*			*225 0 0*
,, Annual Members' Subscriptions, Regular—Including £76, 1923/24, and £1, 1924/25		307 0 0	*323 0 0*
,, Annual Members' Subscriptions, Temporary—(Including £111, 1923/24)		846 0 0	*1,364 0 0*
,, Annual Members' Subscriptions, with Report (Including £69 10s., 1923/24)		477 0 0	*544 10 0*
,, Transferable Tickets (Including £2 10s., 1923/24)		106 5 0	*154 0 0*
,, Students' Tickets (Including £2 10s., 1923/24)		109 10 0	*171 10 0*
,, *Life Members' Additional Subscriptions*			*17 2 0*
,, Donations		10 0 0	*5 0 0*
,, ,, *(Miss Stewardson), as per contra*			*15 0 0*
,, Interest on Deposits		10 17 3	*78 14 4*
,, Advertisements		60 12 9	
,, Sales of Publications		802 8 0	*734 6 0*
,, Sir Robert Hadfield's Gift		50 0 0	
,, *Transfer from Caird Fund*			*257 0 7*
,, Unexpended Balance of grants returned		111 12 1	*98 12 7*
,, Income Tax recovered		117 15 6	*95 8 2*
,, Dividends :—			
Consols	116 14 4		*81 8 0*
India 3 per cent.	81 0 0		*75 12 0*
Great Indian Peninsula "B" Annuity	24 19 4		*23 13 3*
War Stock	96 10 6		*93 18 0*
,, ,, (Sir Charles Parsons' Gift)	500 0 0		*250 0 0*
Treasury Bonds	59 1 3		*50 12 6*
Local Loans	1 16 6		
		880 1 11	*575 3 9*
		£3,889 12 6	*£4,658 7 5*

Fund.

	£ s. d.	£ s. d.	£ s. d.
By Dividends on Investments :—			
India 3½ per cent.	68 19 0		
Canada 3½ per cent.	65 12 6		
London, Midland & Scottish Railway Consolidated 4 per cent. Preference Stock	61 19 0		
Southern Railway Consolidated 5 per cent. Preference Stock	73 15 0		
		270 5 6	*264 5 7*
,, Income Tax recovered		113 4 10	*112 15 4*
,, *Balance being Excess of Expenditure over Income*		—	*137 19 1*
		£383 10 4	*£515 0 0*

RESEARCH COMMITTEES, Etc.

APPOINTED BY THE GENERAL COMMITTEE, MEETING IN LIVERPOOL: SEPTEMBER, 1923.

Grants of money, if any, from the Association for expenses connected with researches are indicated in heavy type.

SECTION A.—MATHEMATICS AND PHYSICS.

Seismological Investigations.—Prof. H. H. Turner (*Chairman*), Mr. J. J. Shaw (*Secretary*), Mr. C. Vernon Boys, Dr. J. E. Crombie, Dr. C. Davison, Sir F. W. Dyson, Sir R. T. Glazebrook, Prof. H. Lamb, Sir J. Larmor, Prof. A. E. H. Love, Prof. H. M. Macdonald, Prof. H. C. Plummer, Mr. W. E. Plummer, Prof. R. A. Sampson, Sir A. Schuster, Sir Napier Shaw, Dr. G. T. Walker. **£100** (Caird Fund grant).

Tides.—Prof. H. Lamb (*Chairman*), Dr. A. T. Doodson (*Secretary*), Dr. G. R. Goldsbrough, Dr. H. Jeffreys, Prof. J. Proudman, Major G. I. Taylor, Prof. D'Arcy W. Thompson, Commander H. D. Warburg.

Annual Tables of Constants and Numerical Data, chemical, physical, and technological.—Sir E. Rutherford (*Chairman*), Prof. A. W. Porter (*Secretary*), Mr. Alfred Egerton. **£15** (Caird Fund grant, to be applied for from Council).

Calculation of Mathematical Tables.—Prof. J. W. Nicholson (*Chairman*), Dr. J. R. Airey (*Secretary*), Mr. T. W. Chaundy, Prof. L. N. G. Filon, Prof. E. W. Hobson, Mr. G. Kennedy, and Profs. Alfred Lodge, A. E. H. Love, H. M. Macdonald, G. B. Mathews, G. N. Watson, and A. G. Webster. **£35** (for printing).

Determination of Gravity at Sea.—Prof. A. E. H. Love (*Chairman*), Dr. W. G. Duffield (*Secretary*), Mr. T. W. Chaundy, Prof. A. S. Eddington, Major E. O. Henrici, Sir A. Schuster, Prof. H. H. Turner.

Investigation of the Upper Atmosphere.—Sir Napier Shaw (*Chairman*), Mr. C. J. P. Cave (*Secretary*), Prof. S. Chapman, Mr. J. S. Dines, Mr. L. H. G. Dines, Mr. W. H. Dines, Sir R. T. Glazebrook, Col. E. Gold, Dr. H. Jeffreys, Sir J. Larmor, Mr. R. G. K. Lempfert, Prof. F. A. Lindemann, Dr. W. Makower, Sir J. E. Petavel, Sir A. Schuster, Dr. G. C. Simpson, Mr. F. J. W. Whipple, Prof. H. H. Turner.

To aid the work of Establishing a Solar Observatory in Australia.—Prof. H. H. Turner (*Chairman*), Dr. W. G. Duffield (*Secretary*), Rev. A. L. Cortie, Dr. W. J. S. Lockyer, Mr. F. McClean, Sir A. Schuster.

To investigate local variations of the Earth's Gravitational Field.—Col. H. G. Lyons (*Chairman*), Capt. H. Shaw (*Secretary*), Prof. C. Vernon Boys, Dr. C. Chree, Col. Sir G. P. Lenox-Conyngham, Dr. J. W. Evans, Mr. E. Lancaster-Jones, the Director-General, Ordnance Survey; the Director, Geological Survey of Great Britain. **£50.**

SECTION B.—CHEMISTRY.

Colloid Chemistry and its Industrial Applications.—Prof. F. G. Donnan (*Chairman*), Dr. W. Clayton (*Secretary*), Mr. E. Hatschek, Prof. W. C. McC. Lewis, Prof. J. W. McBain. **£5.**

Absorption Spectra and Chemical Constitution of Organic Compounds.—Prof. I. M. Heilbron (*Chairman*), Prof. E. C. C. Baly (*Secretary*), Prof. A. W. Stewart. **£10.**

The Position of the Quantum Theory in its relations to Chemistry.—Prof. W. C. McC. Lewis (*Chairman*), Dr. J. Rice (*Secretary*), Prof. E. C. C. Baly, Prof. F. A. Lindemann, Dr. E. K. Rideal, Dr. N. V. Sidgwick. **£10.**

SECTION C.—GEOLOGY.

The Old Red Sandstone Rocks of Kiltorcan, Ireland.—Prof. Grenville Cole (*Chairman*), Prof. T. Johnson (*Secretary*), Dr. J. W. Evans, Dr. R. Kidston, Dr. A. Smith Woodward. **£15.**

To excavate Critical Sections in the Palæozoic Rocks of England and Wales.—Prof. W. W. Watts (*Chairman*), Prof. W. G. Fearnsides (*Secretary*), Prof. W. S. Boulton, Mr. E. S. Cobbold, Prof. E. J. Garwood, Mr. V. C. Illing, Dr. J. E. Marr, Dr. W. K. Spencer. **£5.**

The Collection, Preservation, and Systematic Registration of Photographs of Geological Interest.—Prof. E. J. Garwood (*Chairman*), Prof. S. H. Reynolds (*Secretary*), Mr. G. Bingley, Messrs. C. V. Crook, R. Kidston, and A. S. Reid, Sir J. J. H. Teall, Prof. W.W. Watts, and Messrs. R. Welch and W. Whitaker.

To consider the preparation of a List of Characteristic Fossils.—Prof. P. F. Kendall (*Chairman*), Mr. H. C. Versey (*Secretary*), Prof. W. S. Boulton, Dr. A. R. Dwerryhouse, Profs. J. W. Gregory, Sir T. H. Holland, and S. H. Reynolds, Dr. Marie C. Stopes, Dr. J. E. Marr, Prof. W. W. Watts, Mr. H. Woods, and Dr. A. Smith Woodward. **£5.**

To investigate the Flora of Lower Carboniferous times as exemplified at a newly discovered locality at Gullane, Haddingtonshire.—Dr. R. Kidston (*Chairman*), Prof. W. T. Gordon (*Secretary*), Dr. J. S. Flett, Prof. E. J. Garwood, Dr. J. Horne, and Dr. B. N. Peach.

To investigate the Stratigraphical Sequence and Palæontology of the Old Red Sandstone of the Bristol district.—Dr. H. Bolton (*Chairman*), Mr. F. S. Wallis (*Secretary*), Miss Edith Bolton, Mr. D. E. I. Innes, Prof. C. Lloyd Morgan, Prof. S. H. Reynolds, Mr. H. W. Turner. **£20.**

To investigate the Quaternary Peats of the British Isles.—Prof. P. F. Kendall (*Chairman*), Mr. L. H. Tonks (*Secretary*), Prof. P. G. H. Boswell, Miss Chandler, Prof. H. J. Fleure, Dr. E. Greenly, Prof. J. W. Gregory, Prof. G. Hickling, Mr. J. de W. Hinch, Mr. R. Lloyd Praeger, Mrs. Reid, Mr. T. Sheppard, Mr. J. W. Stather, Mr. A. W. Stelfox, Mr. C. B. Travis, Mr. A. E. Trueman, Mr. W. B. Wright. **£50.**

Comparison of the Rocks of Pre-Cambrian and presumably Pre-Cambrian Inliers of England and Wales and the Dublin Area with the Rocks of the Mona Complex of Anglesey, with a view to possible correlation.—Dr. Gertrude Elles (*Chairman*), Dr. Edward Greenly (*Secretary*), Mr. T. C. Nicholas, Prof. S. H. Reynolds, Dr. C. E. Tilley. **£30** (including travelling fares).

To investigate Critical Sections in the Tertiary Rocks of the London Area. To tabulate and preserve records of new excavations in that area.—Prof. W. T. Gordon (*Chairman*), Dr. S. W. Wooldridge (*Secretary*), Miss M. C. Crosfield, Prof. H. L. Hawkins, Prof. G. Hickling, Mr. W. Whitaker. **£15.**

To attempt to obtain agreement regarding the significance to be attached to Zonal Terms used in connection with the lower Carboniferous.—Prof. P. F. Kendall (*Chairman*), Mr. R. G. Hudson (*Secretary*), Mr. J. W. Jackson, Mr. W. B. Wright. **£10.**

SECTION D.—ZOOLOGY.

To aid competent Investigators selected by the Committee to carry on definite pieces of work at the Zoological Station at Naples.—Prof. E. S. Goodrich (*Chairman*), Prof. J. H. Ashworth (*Secretary*), Dr. G. P. Bidder, Prof. F. O. Bower, Dr. W. B. Hardy, Sir S. F. Harmer, Prof. S. J. Hickson, Sir E. Ray Lankester, Prof. W. C. McIntosh. **£100** from Caird Fund, subject to approval of Council.

To summon meetings in London or elsewhere for the consideration of matters affecting the interests of Zoology, and to obtain by correspondence the opinion of Zoologists on matters of a similar kind, with power to raise by subscription from each Zoologist a sum of money for defraying current expenses of the organisation.—Prof. S. J. Hickson (*Chairman*), Mr. R. A. Wardle (*Secretary*), Prof. J. H. Ashworth, Prof. W. J. Dakin, Prof. A. Dendy, Prof. F. W. Gamble, Prof. J. Stanley Gardiner, Prof. W. Garstang, Sir S. Harmer, Sir W. A. Herdman, Prof. J. Graham Kerr, Prof. R. D. Laurie, Prof. E. W. MacBride, Prof. E. B. Poulton, Prof. W. M. Tattersall.

Zoological Bibliography and Publication.—Prof. E. B. Poulton (*Chairman*), Dr. F. A. Bather (*Secretary*), Mr. E. Heron-Allen, Dr. W. E. Hoyle, Dr. P. Chalmers Mitchell, Mr. W. L. Sclater. **£1.**

Parthenogenesis.—Prof. A. Meek (*Chairman*), Mr. A. D. Peacock (*Secretary*), Mr. R. S. Bagnall, Dr. J. W. Heslop-Harrison. **£5.**

To nominate competent Naturalists to perform definite pieces of work at the Marine Laboratory, Plymouth.—Prof. A. Dendy (*Chairman and Secretary*), Prof. J. H. Ashworth, Prof. W. J. Dakin, Prof. S. J. Hickson, Sir E. Ray Lankester. **£25** (Caird Fund grant, to be applied for from Council).

To co-operate with other Sections interested, and with the Zoological Society, for the purpose of obtaining support for the Zoological Record.—Sir S. Harmer (*Chairman*), Dr. W. T. Calman (*Secretary*), Prof. A. Dendy, Prof. E. S. Goodrich, Prof. D. M. S. Watson. **£50** (Caird Fund grant, to be applied for from Council).

Marine Biological Research in India.—Dr. E. J. Allen (*Chairman*), Dr. S. W. Kemp (*Secretary*), Prof. J. H. Ashworth, Prof. J. Stanley Gardiner, Prof. E. S. Goodrich, Dr. P. Chalmers Mitchell.

SECTION E.—GEOGRAPHY.

To consider the advisability of making a provisional Population Map of the British Isles, and to make recommendations as to the method of construction and reproduction.—Mr. H. O. Beckit (*Chairman*), Mr. F. Debenham (*Secretary*), Mr. J. Bartholomew, Prof. H. J. Fleure, Mr. R. H. Kinvig, Mr. A. G. Ogilvie, Mr. O. H. T. Rishbeth, Prof. P. M. Roxby. **£5.**

SECTIONS E, L.—GEOGRAPHY, EDUCATION.

To formulate suggestions for a syllabus for the teaching of Geography both to Matriculation Standard and in Advanced Courses; to report upon the present position of the geographical training of teachers, and to make recommendations thereon; and to report, as occasion arises, to Council through the Organising Committee of Section E, upon the practical working of Regulations issued by the Board of Education affecting the position of Geography in Training Colleges and Secondary Schools.—Prof. T. P. Nunn (*Chairman*), Mr. W. H. Barker (*Secretary*), Mr. L. Brooks, Prof. H. J. Fleure, Mr. O. J. R. Howarth, Sir H. J. Mackinder, Prof. J. L. Myres, and Prof. J. F. Unstead (*from Section E*): Mr. Adlam, Mr. D. Berridge, Mr. C. E. Browne, Sir R. Gregory, Mr. E. Sharwood Smith, Mr. E. R. Thomas, Miss O. Wright (*from Section L*).

SECTION G.—ENGINEERING.

To report on certain of the more complex Stress Distributions in Engineering Materials. —Prof. E. G. Coker (*Chairman*), Prof. L. N. G. Filon, and Prof. A. Robertson (*Secretaries*), Prof. T. B. Abell, Prof. A. Barr, Mr. Charles Brown, Dr. Gilbert Cook, Prof. W. E. Dalby, Sir J. A. Ewing, Sir H. Fowler, Mr. A. R. Fulton, Dr. A. A. Griffith, Mr. J. J. Guest, Dr. B. P. Haigh, Profs. Sir J. B. Henderson, C. E. Inglis, F. C. Lea, A. E. H. Love, and W. Mason, Sir J. E. Petavel, Dr. F. Rogers, Dr. W. A. Scoble, Mr. R. V. Southwell, Dr. T. E. Stanton, Mr. C. E. Stromeyer, Mr. G. I. Taylor, Mr. A. T. Wall, Mr. J. S. Wilson. **£25.**

SECTION H.—ANTHROPOLOGY.

To report on the Distribution of Bronze Age Implements.—Prof. J. L. Myres (*Chairman*), Mr. H. Peake (*Secretary*), Mr. Leslie Armstrong, Dr. G. A. Auden, Mr. H. Balfour, Mr. L. H. D. Buxton, Mr. O. G. S. Crawford, Sir W. Boyd Dawkins, Prof. H. J. Fleure, Mr. G. A. Garfitt, Prof. Sir W. Ridgeway. **£100** (including £60 from Caird Fund, to be applied for from Council).

To conduct Archæological Investigations in Malta.—Prof. J. L. Myres (*Chairman*), Sir A. Keith (*Secretary*), Dr. T. Ashby, Mr. H. Balfour, Dr. R. R. Marett, Mr. H. Peake.

To conduct Explorations with the object of ascertaining the Age of Stone Circles.—Sir C. H. Read (*Chairman*), Mr. H. Balfour (*Secretary*), Dr. G. A. Auden, Prof. Sir W. Ridgeway, Dr. J. G. Garson, Sir Arthur Evans, Sir W. Boyd Dawkins, Prof. J. L. Myres, Mr. H. J. E. Peake.

To excavate Early Sites in Macedonia.—Prof. Sir W. Ridgeway (*Chairman*), Mr. S. Casson (*Secretary*), Prof. R. C. Bosanquet, Dr. W. L. H. Duckworth, Prof. J. L. Myres, Mr. M. Thompson.

To report on the Classification and Distribution of Rude Stone Monuments.—Mr. G. A. Garfitt (*Chairman*), Prof. H. J. Fleure (*Secretary*), Mr. O. G. S. Crawford, Miss R. M. Fleming, Dr. C. Fox, Mr. G. Marshall, Prof. J. L. Myres, Mr. H. J. E. Peake. **£5.**

The Collection, Preservation, and Systematic Registration of Photographs of Anthropological Interest.—Mr. E. Torday (*Chairman*), Mr. E. N. Fallaize (*Secretary*), Dr. G. A. Auden, Dr. H. A. Auden, Mr. E. Heawood, Prof. J. L. Myres.

To conduct Archæological and Ethnological Researches in Crete.—Dr. D. G. Hogarth (*Chairman*), Prof. J. L. Myres (*Secretary*), Prof. R. C. Bosanquet, Dr. W. L. H. Duckworth, Sir A. Evans, Prof. Sir W. Ridgeway, Dr. F. C. Shrubsall.

To co-operate with Local Committees in excavation on Roman Sites in Britain.—Prof. Sir W. Ridgeway (*Chairman*), Mr. H. J. E. Peake (*Secretary*), Dr. T. Ashby, Mr. Willoughby Gardner, Prof. J. L. Myres.

To report on the present state of knowledge of the Ethnography and Anthropology of the Near and Middle East.—Dr. A. C. Haddon (*Chairman*), Mr. E. N. Fallaize (*Secretary*), Mr. S. Casson, Prof. H. J. Fleure, Mr. H. J. E. Peake.

To report on the present state of knowledge of the relation of early Palæolithic Implements to Glacial Deposits.—Mr. H. J. E. Peake (*Chairman*), Mr. E. N. Fallaize (*Secretary*), Mr. H. Balfour, Prof. P. G. H. Boswell, Mr. M. Burkitt, Prof. P. F. Kendall, Mr. G. Lamplugh, Prof. J. E. Marr. **£30.**

To investigate the Lake Villages in the neighbourhood of Glastonbury in connection with a Committee of the Somerset Archæological and Natural History Society.—Sir W. Boyd Dawkins (*Chairman*), Mr. Willoughby Gardner (*Secretary*), Mr. H. Balfour, Mr. A. Bulleid, Mr. F. S. Palmer, Mr. H. J. E. Peake.

To co-operate with a Committee of the Royal Anthropological Institute in the exploration of Caves in the Derbyshire district.—Sir W. Boyd Dawkins (*Chairman*), Mr. G. A. Garfitt (*Secretary*), Mr. Leslie Armstrong, Mr. M. Burkitt, Mr. E. N. Fallaize, Dr. Favell, Mr. Wilfrid Jackson, Dr. R. R. Marett, Mr. L. S. Palmer, Mr. H. J. E. Peake. **£25** (including £16 4*s*. 4*d*. unexpended balance).

To investigate processes of Growth in Children, with a view to discovering Differences due to Race and Sex, and further to study Racial Differences in Women.—Sir A. Keith (*Chairman*), Prof. H. J. Fleure (*Secretary*), Dr. A. Low, Prof. F. G. Parsons, Dr. F. C. Shrubsall. **£20.** (A proportion not exceeding two-thirds of this grant may be expended on railway fares incurred in course of the investigation.)

To conduct Excavations and prepare a Survey of the Coldrum Megalithic Monument.—Sir A. Keith (*Chairman*), Prof. H. J. Fleure (*Secretary*), Mr. H. J. E. Peake.

To report on the existence and distribution of Megalithic Monuments in the Isle of Man.—Prof. H. J. Fleure (*Chairman*), Dr. Cyril Fox (*Secretary*), Mr. O. G. S. Crawford, Sir W. Herdman, Mr. P. M. C. Kermode, Rev. Canon Quine.

To report on proposals for an Anthropological and Archæological Bibliography, with power to co-operate with other bodies.—Dr. A. C. Haddon (*Chairman*), Mr. E. N. Fallaize (*Secretary*), Dr. T. Ashby, Mr. W. H. Barker, Mr. O. G. S. Crawford, Prof. H. J. Fleure, Prof. J. L. Myres, Mr. H. J. E. Peake, Dr. D. Randall-MacIver, Mr. T. Sheppard.

To report on the progress of Anthropological Teaching in the present century.—Dr. A. C. Haddon (*Chairman*), Prof. J. L. Myres (*Secretary*), Prof. H. J. Fleure, Dr. R. R. Marett, Prof. C. G. Seligman.

To conduct Ethnographical investigations in British Columbia.—Prof. G. Elliot Smith (*Chairman*), Dr. F. C. Shrubsall (*Secretary*), Prof. H. J. Fleure, Prof. C. G. Seligman. **£60**.

To conduct Explorations on early Neolithic Sites in Holderness.—Mr. H. J. E. Peake (*Chairman*), Mr. A. Leslie Armstrong (*Secretary*), Mr. M. Burkitt, Dr. R. V. Favell, Mr. G. A. Garfitt, Mr. Wilfrid Jackson, Mr. L. S. Palmer.

SECTION I.—PHYSIOLOGY.

Muscular Stiffness in relation to Respiration.—Prof. A. V. Hill (*Chairman*), Dr. Ff. Roberts (*Secretary*), Mr. J. Barcroft. **£25.**

The Cost of Cycling with varied rate and work.—Prof. J. S. Macdonald (*Chairman*), Dr. F. A. Duffield (*Secretary*). **£50.**

SECTION J.—PSYCHOLOGY.

The Place of Psychology in the Medical Curriculum.—Prof. G. Robertson (*Chairman*), Dr. W. Brown (*Secretary*), Dr. J. Drever, Dr. R. G. Gordon, Dr. C. S. Myers, Prof. T. H. Pear, Dr. F. C. Shrubsall.

Vocational Tests.—Dr. C. S. Myers (*Chairman*), Dr. G. H. Miles (*Secretary*), Mr. C. Burt, Prof. T. H. Pear, Mr. F. Watts, Dr. Ll. Wynn-Jones.

The Character of a first-year University Course in Experimental Psychology.—Dr. J. Drever (*Chairman*), Dr. May Collins (*Secretary*), Mr. F. C. Bartlett, Mr. R. J. Bartlett, Dr. C. Burt, Dr. Shepherd Dawson, Mr. A. E. Heath, Dr. Ll. Wynn-Jones, Prof. T. H. Pear.

The uniformity of Terminology and Standards in the Diagnosis of Mental Deficiency.—Dr. C. Burt (*Chairman*), Miss Evelyn Fox (*Secretary*), Miss L. G. Fildes, Dr. Kennedy Fraser, Dr. F. C. Shrubsall.

SECTION K.—BOTANY.

The Physiology and Life-history of Marine Algæ at Port Erin.—Prof. J. McLean Thompson (*Chairman*), Dr. M. Knight (*Secretary*), Prof. F. E. Weiss. **£25** (including £15 for travelling fares).

Index Kewensis.—Sir D. Prain (*Chairman*), Dr. A. W. Hill (*Secretary*), Prof. J. B. Farmer, Dr. A. B. Rendle, Prof. W. Wright Smith. **£60.**

Botanical Survey of Sherwood Forest.—Prof. R. H. Yapp (*Chairman*), Dr. H. S. Holden (*Secretary*), Mr. A. G. Tansley. **£20** (including £5 for travelling fares).

SECTION L.—EDUCATIONAL SCIENCE.

Training in Citizenship.—Rt. Rev. J. E. C. Welldon (*Chairman*), Mr. C. H. Blakiston, Mr. G. D. Dunkerley, Mr. W. D. Eggar, Mr. J. C. Maxwell Garnett, Sir R. A. Gregory, Miss E. P. Hughes, Sir T. Morison. (With power to retain balance in hand from proceeds of sale of reports.)

To inquire into the Practicability of an International Auxiliary Language.—Dr. H. Forster Morley (*Chairman*), Dr. E. H. Tripp (*Secretary*), Mr. E. Bullough, Prof. F. G. Donnan, Prof. J. J. Findlay, Sir Richard Gregory, Mr. W. B. Hardy, Dr. C. W. Kimmins, Sir E. Cooper Perry, Mr. Nowell Smith, Mr. A. E. Twentyman. **£3.**

To consider the educational training of boys and girls in Secondary Schools for overseas life.—Rev. H. B. Gray (*Chairman*), Mr. C. E. Browne (*Secretary*), Dr. J. Vargas Eyre, Sir R. A. Gregory, Sir J. Russell. **£5.**

CORRESPONDING SOCIETIES.

Corresponding Societies Committee.—The President of the Association (*Chairman ex-officio*), Mr. T. Sheppard (*Vice-Chairman*), the General Secretaries, the General Treasurer, Dr. F. A. Bather, Mr. O. G. S. Crawford, Prof. P. F. Kendall, Mr. Mark L. Sykes, Dr. C. Tierney, Prof. W. W. Watts, Mr. W. Whitaker; with authority to co-opt representatives of Scientific Societies in the locality of the Annual Meeting. **£40** for preparation of bibliography and report.

THE CAIRD FUND.

An unconditional gift of £10,000 was made to the Association at the Dundee Meeting, 1912, by Mr. (afterwards Sir) J. K. Caird, LL.D., of Dundee.

The Council, in its report to the General Committee at the Birmingham Meeting, made certain recommendations as to the administration of this Fund. These recommendations were adopted, with the Report, by the General Committee at its meeting on September 10, 1913.

The allocations made from the Fund by the Council to September 1922 will be found stated in the *Report* for 1922, p. xxxi.

In and since 1921, the Council have authorised expenditure from accumulated income of the fund upon grants to Research Committees approved by the General Committee by way of supplementing sums available from the general funds of the Association, and in addition to grants ordinarily made by, or applied for from, the Council.

Sir J. K. Caird, on September 10, 1913, made a further gift of £1,000 to the Association, to be devoted to the study of Radio-activity. In 1920 the Council decided to devote the principal and interest of this gift at the rate of £250 per annum for five years to purposes of the research intended. The grants for the year ending March 24, 1922 and 1923, were made to Sir E. Rutherford, F.R.S. The grant for the year ending March 24, 1924, was made to Prof. F. Soddy, F.R.S.

RESOLUTIONS & RECOMMENDATIONS.

The following Resolutions and Recommendations were referred to the Council by the General Committee at Liverpool for consideration and, if desirable, for action:—

Resolutions Relating to Science Museum Building, South Kensington.

From Section A.

(1a) The Committee of Section A, having learned with regret that it is the intention of the Government to complete at present only a portion of the accommodation for the science collections, which Sir Hugh Bell's Committee considered urgently required, request the Council to take such steps as may seem to them most suitable to secure a reconsideration of the question with a view to the early completion of the whole plan.

From Section B.

(1b) That in the opinion of this Section the establishment of a Science Museum, representative of all branches of Science, in which Chemistry shall be fully represented, is of great importance, and urges that the scheme proposed in 1912 be carried out with the least possible delay.

From Section C.

(1c) The Sectional Committee of Section C is strongly of opinion that the general scheme for museum buildings should be continued and regarded as urgent, and that, in particular, part of the scheme relating to the transfer of the Museum of Practical Geology and the offices of the Geological Survey should be effected without delay.

The Committee believes that it would be of great advantage to the public that the stratigraphical, palæontological, mineralogical, and economic exhibits in the National Museum should be housed in close proximity with one another.

From Section D.

(1d) That this Section hopes that the scheme of 1913 for the complete housing of the Science Museums in South Kensington be proceeded upon with all possible expedition.

From Section E.

(1e) The Committee of Section E learn with regret that the science collections at the Science Museum, South Kensington, are being withdrawn from exhibition for a considerable period on account of lack of space.

They recommend that the General Committee should urge strongly upon H.M. Government the importance of completing the whole of the eastern block of the new Science Museum buildings forthwith, and of carrying out as soon as may be practicable the building scheme prepared by the Departmental Committee of 1910-12.

From Section G.

(1f) The Committee, having considered the letter of Sir Hugh Bell, desire to place on record (1) their regret at learning that the already inadequate accommodation of the Science Museum has been further curtailed to make room for the War Museum, and (2) their disapproval of the delay in bringing the buildings and equipment of our National Museum of Science up to a standard commensurate with the national importance of pure and applied science.

The Committee consider that the Council of the British Association should, either alone or in conjunction with other bodies, take steps to urge upon the authorities the vital importance of providing adequate museum accommodation in subjects so fundamentally essential to our national development and well-being.

From Section H.

To recommend that the Council of the British Association urge upon the Government the desirability of providing at not too distant a date adequate and suitable accommodation for the proper housing and display of the national scientific collections. **(1g)**

From Section K.

That the Council of the British Association urge the Government to expedite the completion of the Science Museum and the transfer of the Jermyn Street Geological Museum to South Kensington as recommended in the Report presented in 1911 and 1912 by the Departmental Committee. **(1h)**

From Section L.

That Section L cordially agrees with the protest being presented against the delay which has taken place in the completion of the scheme of the National Museum for Science. **(1i)**

From Section M.

The Committee of Section M is strongly of opinion that every effort should be made at the present time to secure as rapidly as possible the accommodation necessary for the adequate housing of the Science collection. **(1k)**

It is particularly anxious that suitable provision should be made for an agricultural exhibit worthy of the prominent position which agriculture occupies among the industries of this country.

From the Conference of Delegates of Corresponding Societies.

To represent to His Majesty's Government the urgent need for more ample provision for the Science Museum, and for closer co-ordination between the principal national collections of scientific material. **(1l)**

Other Resolutions.

From Sections C, D, G, H, I, M, and the Conference of Delegates of Corresponding Societies.

To represent to His Majesty's Government, in view of recent proposals to utilise for naval, military, or commercial purposes sites of historic or scientific interest or of natural beauty, such as Avebury, Holmbury Hill, and Lulworth Cove and its neighbourhood, the urgent need of more effective protection of such sites from disfigurement or obstruction. **(2)**

From Sections C, E, G, H, I, M, and the Conference of Delegates of Corresponding Societies.

To request the Director-General of the Ordnance Survey to reconsider his decision to discontinue the issue by the Ordnance Survey of quarter-sheets of the six-inch map on the ground that, if quarter-sheets are not available, teachers, students, and others engaged in various kinds of research on local and regional distributions will be put to expense and inconvenience in providing themselves with the sheets necessary for their work. **(3)**

From Section E.

(4a) That this Committee of Section E recommends that the Report of the Research Committee on Geography be issued on sale as a Reprint of the British Association, and that the Secretary of the British Association be authorised to take such steps as are deemed necessary for the wide publicity of the pamphlet.

From Section L.

(4b) That the Report on teaching of Geography shall be included in the publications of the Association.

From Section G.

(5) That this Committee should endeavour to obtain a wider publication of the work of the Committee on Complex Stresses, and that with this object, in the first place, the Reports published in 1913 on the subjects of 'Combined Stresses' and 'The Collapse of Tubes' should be brought up to date by their authors, and, after discussion by the Complex Stress Committee, steps should be taken with a view to their republication. As a first step the Council of the British Association should be approached and its general approval of the foregoing proposal obtained.

From Section H.

(6) The Sectional Committee recommends the adoption of the suggestion of the Committee on the Age of Stone Circles that 'finds' from Avebury may be deposited in Devizes Museum and duplicates be distributed among other museums. It is recommended further that in the distribution of duplicates preference be given to museums in the vicinity.

From the Conference of Delegates of Corresponding Societies.

(7) To recommend that the publications of scientific societies should conform so far as possible to a standard size of page for convenience in dealing with off-prints; and that for octavo publications the size of the British Association's Report be adopted as the standard.

(8) To urge the adoption by scientific societies of the bibliographical recommendations contained in the current Report of the Zoological Publications Committee.

(9) To call the attention of local scientific societies to the need for prompt and systematic supervision, in the interests of scientific record, of all sections and other excavations which were opened during the construction of new roads or other public works.

(10) That this Conference suggests for the consideration of the Council that the change of the British gallon to 4 litres would be objectionable, because the gallon of water weighs 10 lb., which is an important fact in physical and engineering practice.

(11) To recommend the General Committee to accept the invitation received from the President of the Museums Association to hold the Conference of Delegates in connection with that Association's meeting at Wembley in July 1924, without prejudice to any provision which may be possible for a Conference of Representatives of local societies at the Toronto meeting.

COMMUNICATIONS RECOMMENDED FOR PRINTING IN EXTENDED FORM.

Section A.—Extended Abstracts of Professor P. Ehrenfest's Paper, 'Remarks on Quantisation,' and Professor Langevin's Paper on 'The Structure of Atoms and their Magnetic Properties.'

THE PRESIDENTIAL ADDRESS.

THE ELECTRICAL STRUCTURE OF MATTER.

BY

PROFESSOR SIR ERNEST RUTHERFORD,
D.Sc., LL.D., Ph.D., F.R.S.,

PRESIDENT OF THE ASSOCIATION.

It was in 1896 that this Association last met in Liverpool, under the presidency of the late Lord Lister, that great pioneer in antiseptic surgery, whose memory is held in affectionate remembrance by all nations. His address, which dealt mainly with the history of the application of antiseptic methods to surgery and its connection with the work of Pasteur, that prince of experimenters, whose birth has been so fittingly celebrated this year, gave us in a sense a completed page of brilliant scientific history. At the same time, in his opening remarks, Lister emphasised the importance of the discovery by Röntgen of a new type of radiation, the X-rays, which we now see marked the beginning of a new and fruitful era in another branch of science.

The visit to your city in 1896 was for me a memorable occasion, for it was here that I first attended a meeting of this Association, and here that I read my first scientific paper. But of much more importance, it was here that I benefited by the opportunity, which these gatherings so amply afford, of meeting for the first time many of the distinguished scientific men of this country and the foreign representatives of science who were the guests of this city on that occasion. The year 1896 has always seemed to me a memorable one for other reasons, for on looking back with some sense of perspective we cannot fail to recognise that the last Liverpool Meeting marked the beginning of what has been aptly termed the heroic age of Physical Science. Never before in the history of physics has there been witnessed such a period of intense activity when discoveries of fundamental importance have followed one another with such bewildering rapidity.

The discovery of X-rays by Röntgen had been published to the world in 1895, while the discovery of the radioactivity of uranium by Becquerel was announced early in 1896. Even the most imaginative of our scientific men could never have dreamed at that time of the extension of our knowledge of the structure of matter that was to develop from these two fundamental discoveries, but in the records of the Liverpool Meeting we see the dawning recognition of the possible consequences of the discovery of X-rays, not only in their application to medicine and surgery, but as a new and powerful agent for attacking some of the fundamental problems of physics. The address of Professor J. J. Thomson, President of Section A, was devoted mainly to a discussion of the nature of the X-rays and the remarkable properties induced in gases by the passage of X-rays through them—the beginning of a new and fruitful branch of study.

In applied physics, too, this year marked the beginning of another advance. In the discussion of a paper which I had the honour to read, on a new magnetic detector of electrical waves, the late Sir William Preece told the meeting of the successful transmission of signals for a few hundred yards by electric waves which had been made in England by a young Italian, G. Marconi. The first public demonstration of signalling for short distances by electric waves had been given by Sir Oliver Lodge at the Oxford Meeting of this Association in 1894. It is startling to recall the rapidity of the development from such small beginnings of the new method of wireless intercommunication over the greatest terrestrial distances. In the last few years this has been followed by the even more rapid growth of the allied subject of radiotelephony as a practical means of broadcasting speech and music to distances only limited by the power of the transmitting station. The rapidity of these technical advances is an illustration of the close interconnection that must exist between pure and applied science if rapid and sure progress is to be made. The electrical engineer has been able to base his technical developments on the solid foundation of Maxwell's electromagnetic theory and its complete verification by the researches of Hertz, and also by the experiments of Sir Oliver Lodge in this University—a verification which was completed long before the practical possibilities of this new method of signalling had been generally recognised. The later advances in radiotelegraphy and radiotelephony have largely depended on the application of the results of fundamental researches on the properties of electrons, as illustrated in the use of the thermionic valve or electron tube which has proved such an invaluable agent both for the transmission and reception of electric waves.

It is of great interest to note that the benefits of this union of pure and applied research have not been one-sided. If the fundamental researches of the workers in pure science supply the foundations on which the applications are surely built, the successful practical application in turn quickens and extends the interest of the investigator in the fundamental problem, while the development of new methods and appliances required for technical purposes often provides the investigator with means of attacking still more difficult questions. This important reaction between pure and applied science can be illustrated in many branches of knowledge. It is particularly manifest in the industrial development of X-ray radiography for therapeutic and industrial purposes, where the development on a large scale of special X-ray tubes and improved methods of excitation has given the physicist much more efficient tools to carry out his researches on the nature of the rays themselves and on the structure of the atom. In this age no one can draw any sharp line of distinction between the importance of so-called pure and applied research. Both are equally essential to progress, and we cannot but recognise that without flourishing schools of research on fundamental matters in our universities and scientific institutions technical research must tend to wither. Fortunately there is little need to labour this point at the moment, for the importance of a training in pure research has been generally recognised. The Department of Scientific and Industrial Research has made a generous provision of grants to train qualified young men of promise in research methods in our scientific institutions, and has aided special fundamental researches which are clearly beyond the capacity of a laboratory to finance from its own funds. Those who have the responsibility of administering the grants in aid of research both for pure and applied science will need all their wisdom and experience to make a wise allocation of funds to secure the maximum of results for the minimum of expenditure. It is fatally easy to spend much money in a direct frontal attack on some technical problem of importance when the solution may depend on some addition to knowledge which can be gained in some other field of scientific inquiry possibly at a trifling cost. It is not in any sense my purpose to criticise those bodies which administer funds for fostering pure and applied research, but to emphasise how difficult it is to strike the correct balance between the expenditure on pure and applied science in order to achieve the best results in the long run.

It is my intention this evening to refer very briefly to some of the main features of that great advance in knowledge of the nature of electricity and matter which is one of the salient features of the interval since the last meeting of this Association in Liverpool.

In order to view the extensive territory which has been conquered by science in this interval, it is desirable to give a brief summary of the state of knowledge of the constitution of matter at the beginning of this epoch. Ever since its announcement by Dalton the atomic theory has steadily gained ground, and formed the philosophic basis for the explanation of the facts of chemical combination. In the early stages of its application to physics and chemistry it was unnecessary to have any detailed knowledge of the dimensions or structure of the atom. It was only necessary to assume that the atoms acted as individual units, and to know the relative masses of the atoms of the different elements. In the next stage, for example, in the kinetic theory of gases, it was possible to explain the main properties of gases by supposing that the atoms of the gas acted as minute perfectly elastic spheres. During this period, by the application of a variety of methods, many of which were due to Lord Kelvin, rough estimates had been obtained of the absolute dimensions and mass of the atoms. These brought out the minute size and mass of the atom and the enormous number of atoms necessary to produce a detectable effect in any kind of measurement. From this arose the general idea that the atomic theory must of necessity for ever remain unverifiable by direct experiment, and for this reason it was suggested by one school of thought that the atomic theory should be banished from the teaching of Chemistry, and that the law of multiple proportions should be accepted as the ultimate fact of Chemistry.

While the vaguest ideas were held as to the possible structure of atoms, there was a general belief among the more philosophically minded that the atoms of the elements could not be regarded as simple unconnected units. The periodic variations of the properties of the elements brought out by Mendeléef were only explicable if atoms were similar structures in some way constructed of similar material. We shall see that the problem of the constitution of atoms is intimately connected with our conception of the nature of electricity. The wonderful success of the electromagnetic theory had concentrated attention on the medium or ether surrounding the conductor of electricity, and little attention had been paid to the actual carriers of the electric current itself. At the same time the idea was generally gaining ground that an explanation of the results of Faraday's experiments on electrolysis was only possible on the assumption that electricity, like matter, was atomic in nature. The name 'electron' had even been given to this fundamental unit by Johnstone Stoney, and its magnitude roughly estimated, but the full recognition of the significance and importance of this conception belongs to the new epoch.

For the clarifying of these somewhat vague ideas, the proof in 1897 of the independent existence of the electron as a mobile electrified unit, of mass minute compared with that of the lightest atom, was of extraordinary importance. It was soon seen that the electron must be of a constituent of all the atoms of matter, and that optical spectra had their origin in their vibrations. The discovery of the electron and the proof of its liberation by a variety of methods from all the atoms of matter was of the utmost significance, for it strengthened the view that the electron was probably the common unit in the structure of atoms which the periodic variation of the chemical properties had indicated. It gave for the first time some hope of the success of an attack on that most fundamental of all problems—the detailed structure of the atom. In the early development of this subject science owes much to the work of Sir J. J. Thomson, both for the boldness of his ideas and for his ingenuity in developing methods for estimating the number of electrons in the atom, and of probing its structure. He early took the view that the atom must be an electrical structure, held together by electrical forces, and showed in a general way lines of possible explanation of the variation of physical and chemical properties of the elements, exemplified in the periodic law.

In the meantime our whole conception of the atom and of the magnitude of the forces which held it together were revolutionised by the study of radioactivity. The discovery of radium was a great step in advance, for it provided the experimenter with powerful sources of radiation specially suitable for examining the nature of the characteristic radiations which are emitted by the radioactive bodies in general. It was soon shown that the atoms of radioactive matter were undergoing spontaneous transformation, and that the characteristic radiations emitted, viz. the α, β, and γ rays, were an accompaniment and consequence of these atomic explosions. The wonderful succession of changes that occur in uranium, more than thirty in number, was soon disclosed and simply interpreted on the transformation theory. The radioactive elements provide us for the first time with a glimpse into Nature's laboratory, and allow us to watch and study but not control the changes that have their origin in the heart of the radioactive atoms. These atomic explosions involve energies which are gigantic compared with those involved in any ordinary physical or chemical process. In the majority of cases an α particle is expelled at high speed, but in others a swift electron is ejected often accompanied by a γ ray, which is a very penetrating X-ray of high frequency. The proof that the α particle is a charged helium atom for the first time disclosed the importance of helium as one of the units in the structure of the radioactive atoms, and probably also in that of the atoms of most of the ordinary elements. Not only then have the radioactive elements had the greatest direct influence on natural philosophy, but in subsidiary ways they have provided us with experimental methods of almost equal importance. The use of α particles as projectiles with which to explore the interior of the atom has definitely exhibited its nuclear structure, has led to artificial disintegration of certain light atoms, and promises to yield more information yet as to the actual structure of the nucleus itself.

The influence of radioactivity has also extended to yet another field of study of fascinating interest. We have seen that the first rough estimates of the size and mass of the atom gave little hope that we could detect the effect of a single atom. The discovery that the radioactive bodies expel actual charged atoms of helium with enormous energy altered this aspect of the problem. The energy associated with a single α particle is so great that it can readily be detected by a variety of methods. Each α particle, as Sir Wm. Crookes first showed, produces a flash of light easily visible in a dark room when it falls on a screen coated with crystals of zinc sulphide. This scintillation method of counting individual particles has proved invaluable in many researches, for it gives us a method of unequalled delicacy for studying the effects of single atoms. The α particle can also be detected electrically or photographically, but the most powerful and beautiful of all methods is that perfected by Mr. C. T. R. Wilson for observing the track through a gas not only of an α particle but of any type of penetrating radiation which produces ions or of electrified particles along its path. The method is comparatively simple, depending on the fact, first discovered by him, that if a gas saturated with moisture is suddenly cooled each of the ions produced by the radiation becomes the nucleus of a visible drop of water. The water-drops along the track of the α particle are clearly visible to the eye, and can be recorded photographically. These beautiful photographs of the effect produced by single atoms or single electrons appeal, I think, greatly to all scientific men. They not only afford convincing evidence of the discrete nature of these particles, but give us new courage and confidence that the scientific methods of experiment and deduction are to be relied upon in this field of inquiry; for many of the essential points brought out so clearly and concretely in these photographs were correctly deduced long before such confirmatory photographs were available. At the same time, a minute study of the detail disclosed in these photographs gives us most valuable information and new clues on many recondite effects produced by the passage through matter of these flying projectiles and penetrating radiations.

In the meantime a number of new methods had been devised to fix with some accuracy the mass of the individual atom and the number in any given quantity of matter. The concordant results obtained by widely different physical principles gave great confidence in the correctness of the atomic idea of matter. The method found capable of most accuracy depends on the definite proof of the atomic nature of electricity and the exact valuation of this fundamental unit of charge. We have seen that it was early surmised that electricity was atomic in nature. This view was confirmed and extended by a study of the charges carried by electrons, α particles, and the ions produced in gases by X-rays and the rays from radioactive matter. It was first shown by Townsend that the positive or negative charge carried by an ion in gases was invariably equal to the charge carried by the hydrogen ion in the electrolysis of water, which we have seen was assumed, and assumed correctly, by Johnstone Stoney to be the fundamental unit of charge. Various methods were devised to measure the magnitude of this fundamental unit; the best known and most accurate is Millikan's, which depends on comparing the pull of an electric field on a charged droplet of oil or mercury with the weight of the drop. His experiments gave a most convincing proof of the correctness of the electronic theory, and gave a measure of this unit, the most fundamental of all physical units, with an accuracy of about one in a thousand. Knowing this value, we can by the aid of electrochemical data easily deduce the mass of the individual atoms and the number of molecules in a cubic centimetre of any gas with an accuracy of possibly one in a thousand, but certainly better than one in a hundred. When we consider the minuteness of the unit of electricity and of the mass of the atom this experimental achievement is one of the most notable even in an era of great advances.

The idea of the atomic nature of electricity is very closely connected with the attack on the problem of the structure of the atom. If the atom is an electrical structure it can only contain an integral number of charged units, and, since it is ordinarily neutral, the number of units of positive charge must equal the number of negative. One of the main difficulties in this problem has been the uncertainty as to the relative part played by positive and negative electricity in the structure of the atom. We know that the electron has a negative charge of one fundamental unit, while the charged hydrogen atom, whether in electrolysis or in the electric discharge, has a charge of one positive unit. But the mass of the electron is only 1/1840 of the mass of the hydrogen atom, and though an extensive search has been made, not the slightest evidence has been found of the existence of a positive electron of small mass like the negative. In no case has a positive charge been found associated with a mass less than that of the charged atom of hydrogen. This difference between positive and negative electricity is at first sight very surprising, but the deeper we pursue our inquiries the more this fundamental difference between the units of positive and negative electricity is emphasised. In fact, as we shall see later, the atoms are quite unsymmetrical structures with regard to the positive and negative units contained in them, and indeed it seems certain that if there were not this difference in mass between the two units, matter, as we know it, could not exist.

It is natural to inquire what explanation can be given of this striking difference in mass of the two units. I think all scientific men are convinced that the small mass of the negative electron is to be entirely associated with the energy of its electrical structure, so that the electron may be regarded as a disembodied atom of negative electricity. We know that an electron in motion, in addition to possessing an electric field, also generates a magnetic field around it, and energy in the electromagnetic form is stored in the medium and moves with it. This gives the electron an apparent or electrical mass which, while nearly constant for slow speeds, increases rapidly as its velocity approaches that of light. This increase of mass is in good accord with calculation, whether based on the ordinary electrical theory or on the theory of relativity. Now we know that the hydrogen atom is the lightest of all atoms, and is presumably the simplest in structure, and that the charged hydrogen atom, which we shall see is to be regarded as the hydrogen nucleus, carries a unit positive charge. It is thus natural to suppose that the hydrogen nucleus is the atom of positive electricity, or positive electron, analogous to the negative electron, but differing from it in mass. Electrical theory shows that the mass of a given charge of electricity increases with the concentration, and the greater mass of the hydrogen nucleus would be accounted for if its size were much smaller than that of the electron. Such a conclusion is supported by evidence obtained from the study of the close collisions of α particles with hydrogen nuclei. It is found that the hydrogen nucleus must be of minute size, of radius less than the electron, which is usually supposed to be about 10^{-13} cms.; also the experimental evidence is not inconsistent with the view that the hydrogen nucleus may actually be much smaller than the electron. While the greater mass of the positive atom of electricity may be explained in this way, we are still left with the enigma why the two units of electricity should differ so markedly in this respect. In the present state of our knowledge it does not seem possible to push this inquiry further, or to discuss the problem of the relation of these two units.

We shall see that there is the strongest evidence that the atoms of matter are built up of these two electrical units, viz. the electron and the hydrogen nucleus or proton, as it is usually called when it forms part of the structure of any atom. It is probable that these two are the fundamental and indivisible units which build up our universe, but we may reserve in our mind the possibility that further inquiry may some day show that these units are complex, and divisible into even more fundamental entities. On the views we have outlined the mass of the atom is the sum of the electrical masses of the individual charged units composing its structure, and there is no need to assume that any other kind of mass exists. At the same time, it is to be borne in mind that the actual mass of an atom may be somewhat less than the sum of the masses of component positive and negative electrons when in the free state. On account of the very close proximity of the charged units in the nucleus of an atom, and the consequent disturbance of the electric and magnetic field surrounding them, such a decrease of mass is to be anticipated on general theoretical grounds.

We must now look back again to the earlier stages of the present epoch in order to trace the development of our ideas on the detailed structure of the atom. That electrons as such were important constituents was clear by 1900, but little real progress followed until the part played by the positive charges was made clear. New light was thrown on this subject by examining the deviation of α particles when they passed through the atoms of matter. It was found that occasionally a swift α particle was deflected from its rectilinear path through more than a right angle by an encounter with a single atom. In such a collision the laws of dynamics ordinarily apply, and the relation between the velocities of the colliding atoms before and after collision are exactly the same as if the two colliding particles are regarded as perfectly elastic spheres of minute dimensions. It must, however, be borne in mind that in these atomic collisions there is no question of mechanical impacts such as we observe with ordinary matter. The reaction between the two particles occurs through the intermediary of the powerful electric fields that surround them. Beautiful photographs illustrating the accuracy of these laws of collision between an α particle and an atom have been obtained by Messrs. Wilson, Blackett, and others, while Mr. Wilson has recently obtained many striking illustrations of collisions between two electrons. Remembering the great kinetic energy of the α particle, its deflection through a large angle in a single atomic encounter shows clearly that very intense deflecting forces exist inside the atom. It seemed clear that electric fields of the required magnitude could be obtained only if the main charge of the atom were concentrated in a minute nucleus. From this arose the conception of the nuclear atom, now so well known, in which the heart of the atom is supposed to consist of a minute but massive nucleus, carrying a positive charge of electricity, and surrounded at a distance by the requisite number of electrons to form a neutral atom.

A detailed study of the scattering of α particles at different angles, by Geiger and Marsden, showed that the results were in close accord with this theory, and that the intense electric forces near the nucleus varied according to the ordinary inverse square law. In addition, the experiments allowed us to fix an upper limit for the dimensions of the nucleus. For a heavy atom like that of gold the radius of the nucleus, if supposed to be spherical, was less than one thousandth of the radius of the complete atom surrounded by its electrons, and certainly less than 4×10^{-12} cms. All the atoms were found to show this nuclear structure, and an approximate estimate was made of the nuclear charge of different atoms. This type of nuclear atom, based on direct experimental evidence, possesses some very simple properties. It is obvious that the number of units of resultant positive charge in the nucleus fixes the number of the outer planetary electrons in the neutral atom. In addition, since these outer electrons are in some way held in equilibrium by the attractive forces from the nucleus, and, since we are confident from general physical and chemical evidence that all atoms of any one element are identical in their external structure, it is clear that their arrangement and motion must be governed entirely by the magnitude of the nuclear charge. Since the ordinary chemical and physical properties are to be ascribed mainly to the configuration and motion of the outer electrons, it follows that the properties of an atom are defined by a whole number representing its nuclear charge. It thus becomes of great importance to determine the value of this nuclear charge for the atoms of all the elements.

Data obtained from the scattering of α particles, and also from the scattering of X-rays by light elements, indicated that the nuclear charge of an element was numerically equal to about half the atomic weight in terms of hydrogen. It was fairly clear from general evidence that the hydrogen nucleus had a charge one, and the helium nucleus (the α particle) a charge two. At this stage another discovery of great importance provided a powerful method of attack on this problem. The investigation by Laue on the diffraction of X-rays by crystals had shown definitely that X-rays were electromagnetic waves of much shorter wave-length than light, and the experiments of Sir William Bragg and W. L. Bragg had provided simple methods for studying the spectra of a beam of X-rays. It was found that the spectrum in general shows a continuous background on which is superimposed a spectrum of bright lines. At this stage H. G. J. Moseley began a research with the intention of deciding whether the properties of an element depended on its nuclear charge rather than on its atomic weight as ordinarily supposed. For this purpose the X-ray spectra emitted by a number of elements were examined and found to be all similar in type. The frequency of a given line was found to vary very nearly as the square of a whole number which varied by unity in passing from one element to the next. Moseley identified this whole number with the atomic or ordinal number of the elements when arranged in increasing order of atomic weight, allowance being made for the known anomalies in the periodic table and for certain gaps corresponding to possible but missing elements. He concluded that the atomic number of an element was a measure of its nuclear charge, and the correctness of this deduction has been recently verified by Chadwick by direct experiments on the scattering of α particles. Moseley's discovery is of fundamental importance, for it not only fixes the number of electrons in all the atoms, but shows conclusively that the properties of an atom, as had been surmised, are determined not by its atomic weight but by its nuclear charge. A relation of unexpected simplicity is thus found to hold between the elements. No one could have anticipated that with few exceptions all atomic numbers between hydrogen 1, and uranium 92, would correspond to known elements. The great power of Moseley's law in fixing the atomic number of an element is well illustrated by the recent discovery by Coster and Hevesy in Copenhagen of the missing element of atomic number 72, which they have named 'hafnium.'

Once the salient features of the structure of atoms have been fixed and the number of electrons known, the further study of the structure of the atom falls naturally into two great divisions: one, the arrangement of the outer electrons which controls the main physical and chemical properties of an element, and the other the structure of the nucleus on which the mass and radioactivity of the atom depends. On the nuclear theory the hydrogen atom is of extreme simplicity, consisting of a singly-charged positive nucleus with only one attendant electron. The position and motions of the single electron must account for the complicated optical spectrum, and whatever physical and chemical properties are to be attributed to the hydrogen atom. The first definite attack on the problem of the electronic structure of the atom was made by Niels Bohr. He saw clearly that, if this simple constitution was assumed, it is impossible to account for the spectrum of hydrogen on the classical electrical theories, but that a radical departure from existing views was necessary. For this purpose he applied to the atom the essential ideas of the Quantum Theory which had been developed by Planck for other purposes, and had been found of great service in explaining many fundamental difficulties in other branches of science. On Planck's theory radiation is emitted in definite units or quanta, in which the energy E of a radiation is equal to $h\nu$ where ν is the frequency of the radiation measured by the ordinary methods and h a universal constant. This quantum of radiation is not a definite fixed unit like the atom of electricity, for its magnitude depends on the frequency of the radiation. For example, the energy of a quantum is small for visible light, but becomes large for radiation of high frequency corresponding to the X-rays or the γ rays from radium.

Time does not allow me to discuss the underlying meaning of the quantum theory or the difficulties connected with it. Certain aspects of the difficulties were discussed in the Presidential Address before this Association by Sir Oliver Lodge at Birmingham in 1913. It suffices to say that this theory has proved of great value in several branches of science, and is supported by a large mass of direct experimental evidence.

In applying the quantum theory to the structure of the hydrogen atom Bohr supposed that the single electron could move in a number of stable orbits, controlled by the attractive force of the nucleus, without losing energy by radiation. The position and character of these orbits were defined by certain quantum relations depending on one or more whole numbers. It was assumed that radiation was only emitted when the electron for some reason was transferred from one stable orbit to another of lower energy. In such a case it was supposed that a homogeneous radiation was emitted of frequency ν determined by the quantum relation $E=h\nu$ where E was the difference of the energy of the electron in the two orbits. Some of these possible orbits are circular, others elliptical, with the nucleus as a focus, while if the change of mass of the electron with velocity is taken into account the orbits, as Sommerfeld showed, depend on two quantum numbers, and are not closed, but consist of a nearly elliptical orbit slowly rotating round the nucleus. In this way it is possible not only to account for the series relations between the bright lines of the hydrogen spectrum, but also to explain the fine structure of the lines and the very complicated changes observed when the radiating atoms are exposed in a strong magnetic or electric field. Under ordinary conditions the electron in the hydrogen atom rotates in a circular orbit close to the nucleus, but if the atoms are excited by an electric discharge or other suitable method, the electron may be displaced and occupy any one of the stable positions specified by the theory. In a radiating gas giving the complete hydrogen spectrum there will be present many different kinds of hydrogen atoms, in each of which the electron describes one of the possible orbits specified by the theory. On this view it is seen that the variety of modes of vibration of the hydrogen atom is ascribed, not to complexity of the structure of the atom, but to the variety of stable orbits which an electron may occupy relative to the nucleus. This novel theory of the origin of spectra has been developed so as to apply not only to hydrogen but to all the elements, and has been instrumental in throwing a flood of light on the relations and origin of their spectra, both X-ray and optical. The information thus gained has been applied by Bohr to determine the distribution of the electrons round the nucleus of any atom. The problem is obviously much less complicated for hydrogen than for a heavy atom, where each of the large number of electrons present acts on the other, and where the orbits described are much more intricate than the orbit of the single electron in hydrogen. Notwithstanding the great difficulties of such a complicated system of electrons in motion, it has been possible to fix the quantum numbers that characterise the motion of each electron, and to form at any rate a rough idea of the character of the orbit.

These planetary electrons divide themselves up into groups, according as their orbits are characterised by one or more equal quantum numbers. Without going into detail a few examples may be given to illustrate the conclusions which have been reached. As we have seen, the first element hydrogen has a nuclear charge of 1 and 1 electron; the second, helium, has a charge 2 and 2 electrons, moving in coupled orbits on the detailed nature of which there is still some uncertainty. These two electrons form a definite group, known as the K group, which is common to all the elements except hydrogen. For increasing nuclear charge the K group of electrons retain their characteristics, but move with increasing speed, and approach closer to the nucleus. As we pass from helium of atomic number 2 to neon, number 10, a new group of electrons is added consisting of two sub-groups, each of four electrons, together called the L group. This L group appears in all atoms of higher atomic number, and, as in the case of the K group, the speed of motion of the electrons increases, and the size of their orbits diminishes with the atomic number. When once the L group has been completed a new and still more complicated M group of electrons begins forming outside it, and a similar process goes on until uranium, which has the highest atomic number, is reached.

It may be of interest to try to visualise the conception of the atom we have so far reached by taking for illustration the heaviest atom, uranium. At the centre of the atom is a minute nucleus surrounded by a swirling group of 92 electrons, all in motion in definite orbits, and occupying but by no means filling a volume very large compared with that of the nucleus. Some of the electrons describe nearly circular orbits round the nucleus; others, orbits of a more elliptical shape whose axes rotate rapidly round the nucleus. The motion of the electrons in the different groups is not necessarily confined to a definite region of the atom, but the electrons of one group may penetrate deeply into the region mainly occupied by another group, thus giving a type of inter-connection or coupling between the various groups. The maximum speed of any electron depends on the closeness of the approach to the nucleus, but the outermost electron will have a minimum speed of more than 1,000 kilometres per second, while the innermost K electrons have an average speed of more than 150,000 kilometres per second, or half the speed of light. When we visualise the extraordinary complexity of the electronic system we may be surprised that it has been possible to find any order in the apparent medley of motions.

In reaching these conclusions, which we owe largely to Professor Bohr and his co-workers, every available kind of data about the different atoms has been taken into consideration. A study of the X-ray spectra, in particular, affords information of great value as to the arrangement of the various groups in the atom, while the optical spectrum and general chemical properties are of great importance in deciding the arrangements of the superficial electrons. While the solution of the grouping of the electrons proposed by Bohr has been assisted by considerations of this kind, it is not empirical in character, but has been largely based on general theoretical considerations of the orbits of electrons that are physically possible on the generalised quantum theory. The real problem involved may be illustrated in the following way. Suppose the gold nucleus be in some way stripped of its attendant seventy-nine electrons and that the atom is reconstituted by the successive addition of electrons one by one. According to Bohr, the atom will be reorganised in one way only, and one group after another will successively form and be filled up in the manner outlined. The nucleus atom has often been likened to a solar system where the sun corresponds to the nucleus and the planets to the electrons. The analogy, however, must not be pressed too far. Suppose, for example, we imagined that some large and swift celestial visitor traverses and escapes from our solar system without any catastrophe to itself or the planets. There will inevitably result permanent changes in the lengths of the month and year, and our system will never return to its original state. Contrast this with the effect of shooting an electron or α particle through the electronic structure of the atom. The motion of many of the electrons will be disturbed by its passage, and in special cases an electron may be removed from its orbit and hurled out of its atomic system. In a short time another electron will fall into the vacant place from one of the outer groups, and this vacant place in turn will be filled up, and so on until the atom is again reorganised. In all cases the final state of the electronic system is the same as in the beginning. This illustration also serves to indicate the origin of the X-rays excited in the atom, for these arise in the process of reformation of an atom from which an electron has been ejected, and the radiation of highest frequency arises when the electron is removed from the K group.

It is possibly too soon to express a final opinion on the accuracy of this theory which defines the outer structure of the atom, but there can be no doubt that it constitutes a great advance. Not only does it offer a general explanation of the optical and X-ray spectra of the atom, but it accounts in detail for many of the most characteristic features of the periodic law of Mendeléef. It gives us for the first time a clear idea of the reason for the appearance in the family of elements of groups of consecutive elements with similar chemical properties, such as the groups analogous to the iron group and the unique group of rare earths. The theory of Bohr, like all living theories, has not only correlated a multitude of isolated facts known about the atom, but has shown its power to predict new relations which can be verified by experiment. For example, the theory predicted the relations which must subsist between the Rydberg constants of the arc and spark spectra, and generally between all the successive optical spectra of an element, a prediction so strikingly confirmed by Paschen's work on the spectrum of doubly ionized aluminium and Fowler's work on the spectrum of trebly ionized silicon. Finally, it predicted with such great confidence the chemical properties of the missing element, number 72, that it gave the necessary incentive for its recent discovery.

While the progress of our knowledge of the outer structure of atoms has been much more rapid than could have been anticipated, we clearly see that only a beginning has been made on this great problem, and that an enormous amount of work is still required before we can hope to form anything like a complete picture even of the outer structure of the atom. We may be confident that the main features of the structure are clear, but in a problem of such great complexity progress in detail must of necessity be difficult and slow.

We have not so far referred to the very difficult question of the explanation on this theory of the chemical combination of atoms. In fact, as yet the theory has hardly concerned itself with molecular structure. On the chemical side, however, certain advances have already been made, notably by G. N. Lewis, Kossel, and Langmuir, in the interpretation of the chemical evidence by the idea of shared electrons, which play a part in the electronic structure of two combined atoms. There can be little doubt that the next decade will see an intensified attack by physicists and chemists on this very important but undoubtedly very complicated question.

Before leaving this subject, it may be of interest to refer to certain points in Bohr's theory of a more philosophical nature. It is seen that the orbits and energies of the various groups of electrons can be specified by certain quantum numbers, and the nature of the radiation associated with a change of orbit can be defined. But at the same time we cannot explain why these orbits are alone permissible under normal conditions, or understand the mechanism by which radiation is emitted. It may be quite possible to formulate accurately the energy relation of the electrons in the atom on a simple theory, and to explain in considerable detail all the properties of an atom, without any clear understanding of the underlying processes which lead to these results. It is natural to hope that with advance of knowledge we may be able to grasp the details of the process which leads to the emission of radiation, and to understand why the orbits of the electrons in the atom are defined by the quantum relations. Some, however, are inclined to take the view that in the present state of knowledge it may be quite impossible in the nature of things to form that detailed picture in space and time of successive events that we have been accustomed to consider as so important a part of a complete theory. The atom is naturally the most fundamental structure presented to us. Its properties must explain the properties of all more complicated structures, including matter in bulk, but we may not, therefore, be justified in expecting that its processes can be explained in terms of concepts derived entirely from a study of molar properties. The atomic processes involved may be so fundamental that a complete understanding may be denied us. It is early yet to be pessimistic on this question, for we may hope that our difficulties may any day be resolved by further discoveries.

We must now turn our attention to that new and comparatively unexplored territory, the nucleus of the atom. In a discussion on the structure of the atom ten years ago, in answer to a question on the structure of the nucleus, I was rash enough to say that it was a problem that might well be left to the next generation, for at that time there seemed to be few obvious methods of attack to throw light on its constitution. While much more progress has been made than appeared possible at that time, the problem of the structure of the nucleus is inherently more difficult than the allied problem already considered of the structure of the outer atom, where we have a wealth of information obtained from the study of light and X-ray spectra and from the chemical properties to test the accuracy of our theories.

In the case of the nucleus, we know its resultant charge, fixed by Moseley's law, and its mass, which is very nearly equal to the mass of the whole atom, since the mass of the planetary electrons is relatively very small and may for most purposes be neglected. We know that the nucleus is of size minute compared with that of the whole atom, and can with some confidence set a maximum limit to its size. The study of radioactive bodies has provided us with very valuable information on the structure of the nucleus, for we know that the α and β particles must be expelled from it, and there is strong evidence that the very penetrating γ rays represent modes of vibration of the electrons contained in its structure. In the long series of transformations which occur in the uranium atom, eight α particles are emitted and six electrons, and it seems clear that the nucleus of a heavy atom is built up, in part at least, of helium nuclei and electrons. It is natural to suppose that many of the ordinary stable atoms are constituted in a similar way. It is a matter of remark that no indication has been obtained that the lightest nucleus, viz. that of hydrogen, is liberated in these transformations, where the processes occurring are of so fundamental a character. At the same time, it is evident that the hydrogen nucleus must be a unit in the structure of some atoms, and this has been confirmed by direct experiment. Dr. Chadwick and I have observed that swift hydrogen nuclei are released from the elements boron, nitrogen, fluorine, sodium, aluminium, and phosphorus when they are bombarded by swift α particles, and there is little room for doubt that these hydrogen nuclei form an essential part of the nuclear structure.

The speed of ejection of these nuclei depends on the velocity of the α particle and on the element bombarded. It is of interest to note that the hydrogen nuclei are liberated in all directions, but the speed in the backward direction is always somewhat less than in the direction of the α particle. Such a result receives a simple explanation if we suppose that the hydrogen nuclei are not built into the main nucleus but exist as satellites probably in motion round a central core. There can be no doubt that bombardment by α particles has effected a veritable disintegration of the nuclei of this group of elements. It is significant that the liberation of hydrogen nuclei occurs only in elements of odd atomic number, viz. 5, 7, 9, 11, 13, 15, the elements of even number appearing quite unaffected. For a collision of an α particle to be effective, it must either pass close to the nucleus or actually penetrate its structure. The chance of this is excessively small on account of the minute size of the nucleus. For example, although each individual α particle will pass through the outer structure of more than 100,000 atoms of aluminium in its path, it is only about one α particle in a million that gets close enough to the nucleus to effect the liberation of its hydrogen satellite.

This artificial disintegration of elements by α particles takes place only on a minute scale, and its observation has only been possible by the counting of individual swift hydrogen nuclei by the scintillations they produce in zinc sulphide.

These experiments suggest that the hydrogen nucleus or proton must be one of the fundamental units which build up a nucleus, and it seems highly probable that the helium nucleus is a secondary building unit composed of the very close union of four protons and two electrons. The view that the nuclei of all atoms are ultimately built up of protons of mass nearly one and of electrons has been strongly supported and extended by the study of *isotopes*. It was early observed that some of the radioactive elements which showed distinct radioactive properties were chemically so alike that it was impossible to effect their separation when mixed together. Similar elements of this kind were called 'isotopes' by Soddy, since they appeared to occupy the same place in the periodic table. For example, a number of radioactive elements in the uranium and thorium series have been found to have physical and chemical properties identical with those of ordinary lead, but yet to have atomic weights differing from ordinary lead, and also distinctive radioactive properties. The nuclear theory of the atom offers at once a simple interpretation of the relation between isotopic elements. Since the chemical properties of an element are controlled by its nuclear charge and little influenced by its mass, isotopes must correspond to atoms with the same nuclear charge but of different nuclear mass. Such a view also offers a simple explanation why the radiocative isotopes show different radioactive properties, for it is to be anticipated that the stability of a nucleus will be much influenced by its mass and arrangement.

Our knowledge of isotopes has been widely extended in the last few years by Aston, who has devised an accurate direct method for showing the presence of isotopes in the ordinary elements. He has found that some of the elements are 'pure'—*i.e.* consist of atoms of identical mass—while others contain a mixture of two or more isotopes. In the case of the isotopic elements, the atomic mass, as ordinarily measured by the chemist, is a mean value depending on the atomic masses of the individual isotopes and their relative abundance. These investigations have not only shown clearly that the number of distinct species of atoms is much greater than was supposed, but have brought out a relation between the elements of great interest and importance. The atomic masses of the isotopes of most of the elements examined have been found, to an accuracy of about one in a thousand, to be whole numbers in terms of oxygen, 16. This indicates that the nuclei are ultimately built up of protons of mass very nearly one and of electrons. It is natural to suppose that this building unit is the hydrogen nucleus, but that its average mass in the complex nucleus is somewhat less than its mass in the free state owing to the close packing of the charged units in the nuclear structure. We have already seen that the helium nucleus of mass 4 is probably a secondary unit of great importance in the building up of many atoms, and it may be that other simple combinations of protons and electrons of mass 2 and 3 occur in the nucleus, but these have not been observed in the free state.

While the mass of the majority of the isotopes are nearly whole numbers, certain cases have been observed by Aston where this rule is slightly departed from. Such variations in mass may ultimately prove of great importance in throwing light on the arrangement and closeness of packing of the protons and electrons, and for this reason it is to be hoped that it may soon prove possible to compare atomic masses of the elements with much greater precision even than at present.

While we may be confident that the proton and the electron are the ultimate units which take part in the building up of all nuclei, and can deduce with some certainty the number of protons and electrons in the nuclei of all atoms, we have little, if any, information on the distribution of these units in the atom or on the nature of the forces that hold them in equilibrium. While it is known that the law of the inverse square holds for the electrical forces some distance from the nucleus, it seems certain that this law breaks down inside the nucleus. A detailed study of the collisions between α particles and hydrogen atoms, where the nuclei approach very close to each other, shows that the forces between nuclei increase ultimately much more rapidly than is to be expected from the law of the inverse square, and it may be that new and unexpected forces may come into importance at the very small distances separating the protons and electrons in the nucleus. Until we gain more information on the nature and law of variation of the forces inside the nucleus, further progress on the detailed structure of the nucleus may be difficult. At the same time, there are still a number of hopeful directions in which an attack may be made on this most difficult of problems. A detailed study of the γ rays from radioactive bodies may be expected to yield information as to the motion of the electrons inside the nucleus, and it may be, as Ellis has suggested, that quantum laws are operative inside as well as outside the nucleus. From a study of the relative proportions of the elements in the earth's crust, Harkins has shown that elements of even atomic number are much more abundant than elements of odd number, suggesting a marked difference of stability in these two classes of elements. It seems probable that any process of stellar evolution must be intimately connected with the building up of complex nuclei from simpler ones, and its study may thus be expected to throw much light on the evolution of the elements.

The nucleus of a heavy atom is undoubtedly a very complicated system, and in a sense a world of its own, little, if at all, influenced by the ordinary physical and chemical agencies at our command. When we consider the mass of a nucleus compared with its volume it seems certain that its density is many billions of times that of our heaviest element. Yet, if we could form a magnified picture of the nucleus, we should expect that it would show a discontinuous structure, occupied but not filled by the minute building units, the protons and electrons, in ceaseless rapid motion controlled by their mutual forces.

Before leaving this subject it is desirable to say a few words on the important question of the energy relations involved in the formation and disintegration of atomic nuclei, first opened up by the study of radioactivity. For example, it is well known that the total evolution of energy during the complete disintegration of one gramme of radium is many millions of times greater than in the complete combustion of an equal weight of coal. It is known that this energy is initially mostly emitted in the kinetic form of swift α and β particles, and the energy of motion of these bodies is ultimately converted into heat when they are stopped by matter. Since it is believed that the radioactive elements were analogous in structure to the ordinary inactive elements the idea naturally arose that the atoms of all the elements contained a similar concentration of energy, which would be available for use if only some simple method could be discovered of promoting and controlling their disintegration. This possibility of obtaining new and cheap sources of energy for practical purposes was naturally an alluring prospect to the lay and scientific man alike. It is quite true that, if we were able to hasten the radioactive processes in uranium and thorium so that the whole cycle of their disintegration could be confined to a few days instead of being spread over thousands of millions of years, these elements would provide very convenient sources of energy on a sufficient scale to be of considerable practical importance. Unfortunately, although many experiments have been tried, there is no evidence that the rate of disintegration of these elements can be altered in the slightest degree by the most powerful laboratory agencies. With increase in our knowledge of atomic structure there has been a gradual change of our point of view on this important question, and there is by no means the same certainty to-day as a decade ago that the atoms of an element contain hidden stores of energy. It may be worth while to spend a few minutes in discussing the reason for this change in outlook. This can best be illustrated by considering an interesting analogy between the transformation of a radioactive nucleus and the changes in the electron arrangement of an ordinary atom. It is now well known that it is possible by means of electron bombardment or by appropriate radiation to excite an atom in such a way that one of its superficial electrons is displaced from its ordinary stable position to another temporarily stable position further removed from the nucleus. This electron in course of time falls back into its old position, and its potential energy is converted into radiation in the process. There is some reason for believing that the electron has a definite average life in the displaced position, and that the chance of its return to its original position is governed by the laws of probability. In some respects an 'excited' atom of this kind is thus analogous to a radioactive atom, but of course the energy released in the disintegration of a nucleus is of an entirely different order of magnitude from the energy released by return of the electron in the excited atom. It may be that the elements, uranium and thorium, represent the sole survivals in the earth to-day of types of elements that were common in the long distant ages, when the atoms now composing the earth were in course of formation. A fraction of the atoms of uranium and thorium formed at that time has survived over the long interval on account of their very slow rate of transformation. It is thus possible to regard these atoms as having not yet completed the cycle of changes which the ordinary atoms have long since passed through, and that the atoms are still in the 'excited' state where the nuclear units have not yet arranged themselves in positions of ultimate equilibrium, but still have a surplus of energy which can only be released in the form of the characteristic radiation from active matter. On such a view, the presence of a store of energy ready for release is not a property of all atoms, but only of a special class of atoms like the radioactive atoms which have not yet reached the final state for equilibrium.

It may be urged that the artificial disintegration of certain elements by bombardment with swift α particles gives definite evidence of a store of energy in some of the ordinary elements, for it is known that a few of the hydrogen nuclei, released from aluminium for example, are expelled with such swiftness that the particle has a greater individual energy than the α particle which causes their liberation. Unfortunately, it is very difficult to give a definite answer on this point until we know more of the details of this disintegration.

On the other hand, another method of attack on this question has become important during the last few years, based on the comparison of the relative masses of the elements. This new point of view can best be illustrated by a comparison of the atomic masses of hydrogen and helium. As we have seen, it seems very probable that helium is not an ultimate unit in the structure of nuclei, but is a very close combination of four hydrogen nuclei and two electrons. The mass of the helium nucleus, 4.00 in terms of $O=16$, is considerably less than the mass 4.03 of four hydrogen nuclei. On modern views there is believed to be a very close connection between mass and energy, and this loss in mass in the synthesis of the helium nucleus from hydrogen nuclei indicates that a large amount of energy in the form of radiation has been released in the building of the helium nucleus from its components. It is easy to calculate from this loss of mass that the energy set free in forming one gramme of helium is large even compared with that liberated in the total disintegration of one gramme of radium. For example, calculation shows that the energy released in the formation of one pound of helium gas is equivalent to the energy emitted in the complete combustion of about eight thousand tons of pure carbon. It has been suggested by Eddington and Perrin that it is mainly to this source of energy that we must look to maintain the heat emission of the sun and hot stars over long periods of time. Calculations of the loss of heat from the sun show that this synthesis of helium need only take place slowly in order to maintain the present rate of radiation for periods of the order of one thousand million years. It must be acknowledged that these arguments are somewhat speculative in character, for no certain experimental evidence has yet been obtained that helium can be formed from hydrogen.

The evidence of the slow rate of stellar evolution, however, certainly indicates that the synthesis of helium, and perhaps other elements of higher atomic weight, may take place slowly in the interior of hot stars. While in the electric discharge through hydrogen at low pressure we can easily reproduce the conditions of the interior of the hottest star as far as regards the energy of motion of the electrons and hydrogen nuclei, we cannot hope to reproduce that enormous density of radiation which must exist in the interior of a giant star. For this and other reasons it may be very difficult, or even impossible, to produce helium from hydrogen under laboratory conditions.

If this view of the great heat emission in the formation of helium be correct, it is clear that the helium nucleus is the most stable of all nuclei, for an amount of energy corresponding to three or four α particles would be required to disrupt it into its components. In addition, since the mass of the proton in nuclei is nearly 1.000 instead of its mass 1.0072 in the free state, it follows that much more energy must be put into the atom than will be liberated by its disintegration into its ultimate units. At the same time, if we consider an atom of oxygen, which may be supposed to be built up of four helium nuclei as secondary units, the change of mass, if any, in its synthesis from already formed helium nuclei is so small that we cannot yet be certain whether there will be a gain or loss of energy by its disintegration into helium nuclei, but in any case we are certain that the magnitude of the energy will be much less than for the synthesis of helium from hydrogen. Our information on this subject of energy changes in the formation or disintegration of atoms in general is as yet too uncertain and speculative to give any decided opinion on future possibilities in this direction, but I have endeavoured to outline some of the main arguments which should be taken into account.

I must now bring to an end my survey, I am afraid all too brief and inadequate, of this great period of advance in physical science. In the short time at my disposal it has been impossible for me, even if I had the knowledge, to refer to the great advances made during the period under consideration in all branches of pure and applied science. I am well aware that in some departments the progress made may justly compare with that of my own subject. In these great additions to our knowledge of the structure of matter every civilised nation has taken an active part, but we may be justly proud that this country has made many fundamental contributions. With this country I must properly include our Dominions overseas, for they have not been behindhand in their contributions to this new knowledge. It is, I am sure, a matter of pride to this country that the scientific men of our Dominions have been responsible for some of the most fundamental discoveries of this epoch, particularly in radioactivity.

This tide of advance was continuous from 1896, but there was an inevitable slackening during the War. It is a matter of good omen that, in the last few years, the old rate of progress has not only been maintained but even intensified, and there appears to be no obvious sign that this period of great advances has come to an end. There has never been a time when the enthusiasm of the scientific workers was greater, or when there was a more hopeful feeling that great advances were imminent. This feeling is no doubt in part due to the great improvement during this epoch of the technical methods of attack, for problems that at one time seemed unattackable are now seen to be likely to fall before the new methods. In the main, the epoch under consideration has been an age of experiment, where the experimenter has been the pioneer in the attack on new problems. At the same time, it has been also an age of bold ideas in theory, as the Quantum Theory and the Theory of Relativity so well illustrate.

I feel it is a great privilege to have witnessed this period, which may almost be termed the Renaissance of Physics. It has been of extraordinary intellectual interest to watch the gradual unfolding of new ideas and the ever-changing methods of attack on difficult problems. It has been of great interest, too, to note the comparative simplicity of the ideas that have ultimately emerged. For example, no one could have anticipated that the general relation between the elements would prove to be of so simple a character as we now believe it to be. It is an illustration of the fact that Nature appears to work in a simple way, and that the more fundamental the problem often simpler are the conceptions needed for its explanation. The rapidity and certitude of the advance in this epoch have largely depended on the fact that it has been possible to devise experiments so that few variables were involved. For example, the study of the structure of the atom has been much facilitated by the possibility of examining the effects due to a single atom of matter, or, as in radioactivity or X-rays, of studying processes going on in the individual atom which were quite uninfluenced by external conditions.

In watching the rapidity of this tide of advance in physics I have become more and more impressed by the power of the scientific method of extending our knowledge of Nature. Experiment, directed by the disciplined imagination either of an individual, or still better, of a group of individuals of varied mental outlook, is able to achieve results which far transcend the imagination alone of the greatest natural philosopher. Experiment without imagination, or imagination without recourse to experiment, can accomplish little, but, for effective progress, a happy blend of these two powers is necessary. The unknown appears as a dense mist before the eyes of men. In penetrating this obscurity we cannot invoke the aid of supermen, but must depend on the combined efforts of a number of adequately trained ordinary men of scientific imagination. Each in his own special field of inquiry is enabled by the scientific method to penetrate a short distance, and his work reacts upon and influences the whole body of other workers. From time to time there arises an illuminating conception, based on accumulated knowledge, which lights up a large region and shows the connection between these individual efforts, so that a general advance follows. The attack begins anew on a wider front, and often with improved technical weapons. The conception which led to this advance often appears simple and obvious when once it has been put forward. This is a common experience, and the scientific man often feels a sense of disappointment that he himself had not foreseen a development which ultimately seems so clear and inevitable.

The intellectual interest due to the rapid growth of science to-day cannot fail to act as a stimulus to young men to join in scientific investigation. In every branch of science there are numerous problems of fundamental interest and importance which await solution. We may confidently predict an accelerated rate of progress of scientific discovery, beneficial to mankind certainly in a material but possibly even more so in an intellectual sense. In order to obtain the best results certain conditions must, however, be fulfilled. It is necessary that our universities and other specific institutions should be liberally supported, so as not only to be in a position to train adequately young investigators of promise, but also to serve themselves as active centres of research. At the same time there must be a reasonable competence for those who have shown a capacity for original investigation. Not least, peace throughout the civilised world is as important for rapid scientific development as for general commercial prosperity. Indeed, science is truly international, and for progress in many directions the co-operation of nations is as essential as the co-operation of individuals. Science, no less than industry, desires a stability not yet achieved in world conditions.

There is an error far too prevalent to-day that science progresses by the demolition of former well-established theories. Such is very rarely the case. For example, it is often stated that Einstein's general theory of relativity has overthrown the work of Newton on gravitation. No statement could be farther from the truth. Their works, in fact, are hardly comparable, for they deal with different fields of thought. So far as the work of Einstein is relevant to that of Newton, it is simply a generalisation and broadening of its basis; in fact, a typical case of mathematical and physical development. In general, a great principle is not discarded but so modified that it rests on a broader and more stable basis.

It is clear that the splendid period of scientific activity which we have reviewed to-night owes much of its success and intellectual appeal to the labours of those great men in the past, who wisely laid the sure foundations on which the scientific worker builds to-day, or to quote from the words inscribed in the dome of the National Gallery, 'The works of those who have stood the test of ages have a claim to that respect and veneration to which no modern can pretend.'

SECTIONAL ADDRESSES.

ON THE ORIGIN OF SPECTRA (RECENT PROGRESS).

ADDRESS TO SECTION A (MATHEMATICS AND PHYSICS) BY

PROFESSOR J. C. McLENNAN, F.R.S.,

PRESIDENT OF THE SECTION.

Introduction.

THE problem of the origin of spectra is intimately bound up with that of the constitution and structure of atoms. Models of atoms of different types have been proposed from time to time, and these all have served, in a measure, to explain some at least of the chemical, optical, and mechanical properties of matter. The conception, however, that inspires and co-ordinates the whole of modern atomic physics in so far as radiation is concerned is the remarkably simple atomic model of Rutherford and Bohr.

According to this model the neutral atom consists of a central positively charged nucleus with dimensions of the same order as those of the electron itself (10^{-13} cm.),[1] and surrounded by a system of electrons whose aggregate negative charge is equal in amount to that of the positive charge carried by the nucleus. The *atomic number*—*i.e.* the number that indicates the places occupied by the element under consideration in the Periodic Table—gives for a neutral atom the number of electrons surrounding the nucleus, and is at the same time a measure of the positive electric charge carried by the latter.

Rutherford, by his brilliant experiments on the scattering of alpha rays, has shown that the electric field due to the charge on the nucleus is central, and that it follows the inverse square law practically up to the effective boundary of the nucleus. Close to the nucleus the electric field is very intense, and therefore sufficient to produce those remarkably interesting deflections of alpha rays that are being studied so widely and so successfully at the present time by the use of C. T. R. Wilson's beautiful method of photographing cloud tracks.

As regards the problem of the origin of spectra, but little progress was made so long as one limited oneself to the use of classical mechanics. With the introduction of the theory of *quanta* into the mechanics of the atom it became possible to analyse in detail the structure of atoms and to make quantitative comparisons between the properties of matter and those deducible from the different atomic models. In the developments that have taken place in this direction Niels Bohr has been the leader; but very notable and important contributions to the theory have

[1] Neuberger, *Ann. der Phys.*, Bd. 70, Heft 2, p. 139, 1923.

been made by Wilson, Sommerfeld, Ehrenfest, Kramers, Lande, and others.

Bohr in his theory supposes that each electron in an atom describes a central or quasi-central orbit under the attraction of the nucleus in combination with the fields of the other extra-nuclear electrons present in the atom. He imposes, moreover, upon these motions of the electrons in atoms something in the nature of a quantum censorship.

As a generalised postulate it is laid down that from the continuous manifold of all conceivable states of motion that may be ascribed to an atomic system there exists a definable number of stationary states that possess a peculiar stability, and that are of such a kind that every permanent change of motion within the system must involve a complete transition from one stationary state to another.

It is postulated further that while no radiation is emitted by the atomic system when it is in one of its stationary states, the process of transition from one stationary state to another is accompanied by the emission of monochromatic radiation with a frequency given by the relation

$$\nu h = E_1 - E_2,$$

where h is Planck's constant and E_1 and E_2 are the values of the energy of the atom in the initial and final stationary states between which the transition takes place. Conversely, it is to be understood that the absorption by the atomic system of radiation with the frequency ν given above results in a transition back from the final stationary state to the initial one. These postulates, it will be seen, form the basis of an interpretation of the laws of series spectra, for the most general of these—the combination principle of Ritz—asserts that the frequency ν of each of the lines in the spectrum of a selected element can be represented by the formula

$$\nu = T_1 - T_2,$$

where T_1 and T_2 are two spectral terms taken from a number that are characteristic of the element in question.

On Bohr's theory[2] the interpretation of the law of Ritz would be that the spectrum of the element referred to must originate in transitions between stationary states for which the atomic energy values are obtained simply by multiplying by Planck's constant the values of those spectral terms of which T_1 and T_2 are types.

This, it is evident, indicates the feasibility of establishing a connection between the series spectrum of an element and the constitution and structure of its atoms. From the spectrum of the element the series spectral terms can be selected and evaluated, and these values when multiplied by Planck's constant will give the various energy levels within and associated with the atom of the element. As the number of electrons within the said atom is given by the atomic number of the element, the problem becomes one of assigning to these constituent electrons orbits of a size and form that will provide the values of the energy levels determined by the spectral series terms.

[2] Bohr, *Nature* Supplement, July 7, 1923.

The reciprocal nature of this relationship between the series spectrum of an element and its atomic structure will be evident. In a case where the series spectrum of an element is not known a knowledge of it may be obtained by determining the energy levels in the atoms of this element independently. This can be done after the manner of Moseley and Franck and Hertz by causing atoms to emit limited portions of its spectrum under bombardment by electrons of selected speeds.

In illustration of the foregoing it may be pointed out that empirically determined spectral relationships obtained in a study of the radiation emitted by such elements as hydrogen and helium have enabled us to determine with some precision the constitution, structure, and stationary states of the atoms of these comparatively simple elements. Moreover, explicit and definite knowledge of the temporary modifications that can be impressed upon the structure of the normal atoms of these elements has been acquired through spectral relationships established by observations on the fine structure of these spectral lines, and by a study of the resolutions of these lines obtainable through the application of external electric or magnetic fields.

Stationary States—Quantum Conditions.

To illustrate the manner in which stationary states are defined on Bohr's theory we may take the simple case of an atom of hydrogen which consists of a nucleus with charge $+e$ and an electron with charge $-e$. It is known that the frequencies of the series spectra of this element are given with great accuracy by the generalised Balmer formula

$$\nu = K\left(\frac{1}{n''^2} - \frac{1}{n'^2}\right) \quad . \quad . \quad . \quad . \quad (1)$$

where n'' and n' are two integers and K is the well-known Rydberg constant. From this formula we see that all the spectral terms are of the form K/n^2, and it follows at once that the energy corresponding to the various stationary states of the atom of hydrogen must be given by Kh/n^2 with n having all possible integral values.

Now it can be shown that when an electron describes an elliptic orbit about the nucleus of a hydrogen atom the major axis of the orbit described is inversely proportional to w the work required completely to remove the electron from the field of the nucleus. The major axis is, in fact, given by $2a = \frac{e^2}{w}$. If, therefore, we take $2a = \frac{e^2 n^2}{Kh}$ we have determined for the hydrogen atom a set of clearly defined stationary states consisting of a series of elliptical orbits for which the major axis takes on discrete values proportional to the squares of the whole numbers. Transitions from one to another of such a set of stationary states will suffice on Bohr's theory to account for all the lines in the series spectrum of atomic hydrogen.

In the early development of Bohr's theory it was noted that for each value of n in the equation $2a = \frac{e^2 n^2}{Kh}$ it was possible to have a number of orbits with the same major axis but with different eccentricities, while all were characterised by the same energy value. For each value of n the number of such orbits was given by the number of ways in which n could be made equal to the sum of two integers, including zero. For example, if n were equal to 1 only a single orbit could exist. If n were equal to 2, then since $2=2+0$ and $2=1+1$ we could have two orbits. If n were equal to 3, we see again, since $3=3+0$ or $3=2+1$ or $3=1+2$, that we could have three orbits, &c. For each value of n there could exist a definite number of equivalent orbits. If we put $n=n_1+n_2$ it can be readily shown that the eccentricities of these equivalent orbits are given by

$$1-\varepsilon^2=\frac{n_1^2}{n^2}=\frac{n_1^2}{(n_1+n_2)^2} \quad . \quad . \quad . \quad . \quad (2)$$

If $2b$ be taken to represent the minor axis of the different equivalent elliptical orbits, it follows that the ratio of the semi-axes is given by

$$\frac{b}{a}=\frac{n_1}{n} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

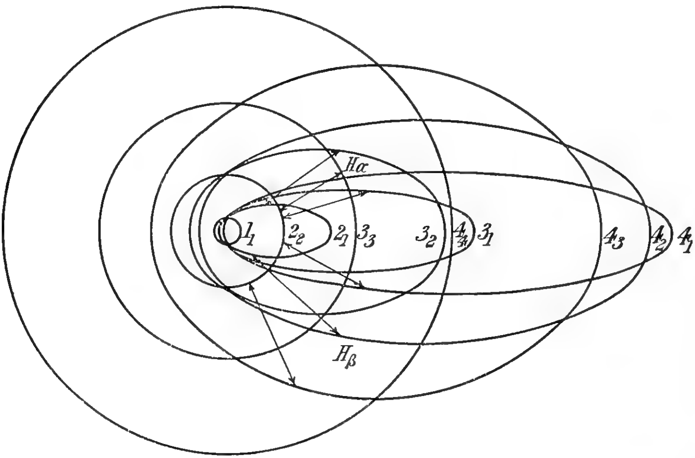


FIG. 1.—H Orbits.

Illustrations of such equivalent orbits for the hydrogen atom with differing values of n are shown in Fig I. On this view the Lymans spectral series $\nu=K\left(1-\frac{1}{m^2}\right)$ originates in transitions to the $n=1$ orbit, the Balmer series $\nu=K\left(\frac{1}{2^2}-\frac{1}{m^2}\right)$ in transitions to either of the $n=2$ orbits, and the Paschen series $\nu=K\left(\frac{1}{3^2}-\frac{1}{m^2}\right)$ in transitions to one or other of the orbits of the $n=3$ group.

Though the single principal quantum number suffices to define the energy levels for the atom of hydrogen, the introduction of the subordinate quantum numbers n_1 and n_2 extended the basis of the theory, and, as is well known, led to developments by Sommerfeld of profound importance in dealing with the question of the fine structure of spectral lines.

Bohr's theory of the origin of spectra as it exists to-day is approached from a somewhat different angle from that given above. Through extensions initiated independently by Wilson and by Sommerfeld the quantising conditions are made to apply to momentum rather than to energy, and in dealing with the problem of the *stationary states* of a system such as that of the hydrogen atom the angular and radial momenta of the electron in its orbit are both quantised.

In more complicated systems the quantisation principle is extended to all degrees of freedom that are characteristic of the motion. The analytical conditions laid down are

$I_1 = n_1h$, $I_2 = n_2h$ . . . . . $I_x = n_xh$ where n_1n_2 . . . . . n_x are quantum integers independent of each other, and where $I_x = \int p_x d\varphi_x$ integrated over a complete cycle with reference to the generalised co-ordinates p_x and φ_x that describe the states and motions of the constituents of the system.

If we confine ourselves to the use of the two conditions $I_1 = n_1h$ and $I_2 = n_2h$, representing respectively the quantisation of the angular and radial momenta of a system consisting of a nucleus of mass M and charge Ne and an electron of mass m, we find that the frequencies of the radiation that can be emitted are given by

$$\nu = \frac{2\pi^2 N^2 e^4 M m}{h^3(M+m)} \left\{ \frac{1}{n''^2} - \frac{1}{n'^2} \right\} \text{ where } n'' = n_1'' + n_2'' \text{ and } n' = n'_1 + n'_2.$$

This formula possesses the advantage that it enables us to evaluate the Rydberg constant K for the spectral terms of the hydrogen spectrum, or of any system consisting of a single nucleus and one electron. It will be recalled in this connection that through the use of this formula Fowler was able to evaluate the mass of an electron from experimentally determined differences in the values of the Rydberg constant in the spectral series of hydrogen and the atom ion of helium.

Quantum Numbers and their Significance.

From the illustrations that have been given in the previous section, it will be seen that for a given atomic system the quantum numbers define the stationary states, and the energy values and moments of momentum of the system in these states. Moreover, they define the kinematical character of the electron obits in the atomic edifice, and, on account of the simple relation connecting the values of spectral terms in the series spectrum of an element with the energy of the atom of this element in its various stationary states, they define these spectral terms and enable us to calculate their values.

In the simplest possible treatment of a system such as that of the atom of hydrogen one quantum number n suffices to define the various factors just mentioned. In the theory of the fine structure of the spectral lines of hydrogen two quantum numbers n and k were required. In the case of a series spectrum of single lines two quantum numbers n and k are requisite to define its terms and the orbits corresponding to them. For a series spectrum consisting of doublets, triplets or multiplets, three quantum numbers are required, n, k and j, to define its spectral terms and the corresponding electronic orbits. In the case of the resolution of a spectral line by the application of an external magnetic field a fourth quantum number m is necessary in order to distinguish the stationary states and to evaluate the spectral terms corresponding to the Zeeman components.

Taking the case of the stationary states associated with the outer electrons in an atom for illustration the kinematic significance of these quantum numbers is as follows: n characterises the orbit forms of these outer electrons. If $n=k$ the orbit is circular, but if $n>k$ it is elliptical, having the greater eccentricity the greater n is compared with k. The quantum number k, on the other hand, connotes kinematically a rotation of the perihelion of the elliptical orbit confined in its own plane, and on account of this turning of the perihelion the orbit takes on the form of a rosette (as shown in Fig. 5). The normal to the orbital plane about which the perihelion is progressing is called the k axis. The quantum number j indicates the total moment of momentum of the atomic state at a given instant, and the axis of this moment is called the j axis. It is in general different from the k axis, and the orbital plane performs a turning or precession about the j axis determined by the value of j the moment of momentum of the atom. If an atom endowed with the motions described above be situated in an external magnetic field, the whole system thus in motion will carry out a rotation, *i.e.* a Larmor precession about the direction of the lines of force of this magnetic field. The axis for this rotation is called the m axis, and m is a measure of the moment of momentum about it.

In spectroscopy it has become customary, in order to distinguish series of different kinds, to designate singlet systems by the use of capital letters, doublet series by Greek letters, and triplet series by small letters. Thus:

[3] P S D F = singlet systems.
π σ δ φ = doublet systems.
p s d f = triplet systems.

In the same way it has become customary to use the same letters to designate the spectral terms whose differences determine the frequencies of the lines in a series. As example we may cite 1S, 2S, &c., 1π, 2π, &c.; $1d$, $2d$, &c.; and $1f$, $2f$, &c.

Practically all efforts of spectroscopists towards arranging lines into series have had for their goal, even before the arrival of the quantum theory, in an unconscious way the establishment of the quantum numbers that define the various types of spectral terms indicated above. As a result of the progress that has been made in the last year or two, it is now generally agreed that the principal quantum number n determines the current number of the series term. For

[3] Fowler, 'Report on Series in Line Spectra.'

example, the 1S term is defined by $n=1$, the 2P term by $n=2$, the $3d$ term by $n=3$, and the 4F term by $n=4$, &c. The azimuthal quantum number k indicates the type to which a term belongs. For $k=1$ an s, σ or S term is signified, for $k=2$ a p, π or P term, for $k=3$ a d, δ D term, and for $k=4$ an f, φ or F term. A 3_1 term, for example, would signify a $3s$, a $3\ \sigma$, or a 3S term, and a 4_2 term would be one which in spectroscopy is usually designated as a $4p$, 4π or 4P term. We have then in the symbol n_k a means of defining a particular spectral term as well as a particular electronic orbit.

Principles of Selection—The Correspondence Principle.

In the early development of Bohr's theory it was found that the censorship imposed by the quantum conditions referred to above were not sufficiently drastic to account completely either for the observed complexity of the fine structure of spectral lines originating in the variation of the mass of an electron with its velocity or for the observed complexity and state of polarisation of the components of spectral lines that had their origin in the application of an external electric or magnetic field.

To make up for this deficiency arbitrary Principles of Selection, involving such factors as intensity and polarisation, were brought forward by Rubinowicz and by Sommerfeld, that found immediate and remarkable verifications in the relativity fine structure of the Balmer lines, in the Stark effect, in the Zeeman effect, and in the spectra of rotation, *i.e.* the band spectra of Deslandres.

Although these principles of selection furnished rules that have served as useful guides in unravelling the intricacies of various types of spectral resolution, it has all along been recognised by the proposers, as well as by others, that the principles as formulated rested upon a dynamical basis that was rather limited and scarcely adequate.

The whole matter, however, was given an entirely new orientation and an enhanced significance by Bohr's enunciation of the Correspondence Principle.

To elucidate this principle we may revert for a moment to the properties of the stationary orbits of the atom of hydrogen. It can be easily shown that the frequency with which the electron revolves in the *n*th orbit is given by

$$\omega = \frac{4\pi^2 m\,\mathrm{M}e^4}{(m+\mathrm{M})n^3h^3},$$

and the frequency of the light emitted when a transition occurs of the electron from the *nth* to *n'*th orbit is given by

$$\nu = \frac{2\pi^2 m\mathrm{M}e^4}{m+\mathrm{M}}\,\frac{1}{h^3}\left(\frac{1}{n'^2}-\frac{1}{n^2}\right).$$

From these two relations it follows that

$$\frac{\nu}{\omega} = \left(\frac{1}{n'^2}-\frac{1}{n^2}\right)\Big/\frac{2}{n^3}$$

If now n and n' be taken to be large integers and not very different from each other we have

$$\nu = \Delta n \,.\, \omega \text{ numerically.}$$

As Δn must be an integer it follows that the frequencies of the light that can be emitted by the system under the conditions laid down are those of the harmonics of the frequency of the electron's orbital motion.

The explicit hypothesis made by Bohr in his Correspondence Principle is that what has been shown above to be true necessarily for very great orbital periods is also sensibly true for finite ones as well. To put the matter in another way—if the orbit described by an electron were carried out under a law of action proportional to the distance, the development of the law of motion in a Fourier series would permit the use of a fundamental term only. The Correspondence Principle would under these conditions demand that the electron could pass spontaneously only from the nth quantum orbit to the $n-1$ quantum orbit immediately below it. If these conditions were to apply in the case of the hydrogen atom, for example, it would limit each series to a single wave-length, and the Balmer series would be reduced to its first component.

The existence of series made up of numerous terms shows that the electronic orbits of an atom cannot be described under a central force varying as the direct distance, but points rather in the direction of the orbits being ellipses following approximately the Keplerian law.

In general, if the electronic motion within an atom is periodic and not simply of a pure sinusoidal character, Fourier's theory shows that the vibration of the electron is represented by a superposition of pure periodic motions that are harmonics of a fundamental one. To this classical notion there corresponds in the theory of quanta the notion of transitions from one stationary state to another with variations in the quantum number no longer equal to one only. If the Fourier series representing the motion contains effectively an harmonic of rank, 1, 2, 3 . . . or m, for example, the Correspondence Principle postulates that the atom can be the seat of transitions corresponding to differences in the characterising quantum number of 1, 2, 3 . . . or m. If on the contrary, the coefficient of a term in the Fourier series under consideration is small or equal to zero, this signifies that the probability of corresponding transitions in the atom becomes small or vanishes.

The Correspondence Principle co-ordinates every transition process between two stationary states with a corresponding harmonic vibration component in such a way that the probability of the occurrence of the transition is dependent on the amplitude of this particular vibration. On the classical theory the intensity and state of polarisation in the wave system emitted by an atom as a consequence of the existence of some vibration component are determined respectively by the amplitude and certain other characteristics of this vibration. On the quantum theory the Correspondence Principle asserts that these other special characteristics of the vibration referred to determine in an analogous manner the state of polarisation of the radiation emitted during a transition for whose occurrence the amplitude of the vibration measures the probability.

With the aid of the Correspondence Principle it has been possible to develop a complete quantum theory of the normal Zeeman effect for the hydrogen lines, and in the case of the Stark effect for these lines, where the classical theory failed to provide an explanation, the quantum theory has been so developed that it is now possible, as Kramers has shown, to account with the aid of the Correspondence Principle for the polarisation of the different components into which the lines are split, and for the characteristic intensity distribution exhibited by these components.

These and other equally interesting examples leave no doubt of the fecundity of the Correspondence Principle and of its far-reaching compass and applicability. It has endowed with precision the application of the principles of selection of Rubinowicz and Sommerfeld, and has eliminated the somewhat arbitrary formalism that has hitherto characterised them. Through its use Bohr has been able to show that the Quantum Theory can no longer be looked upon as displacing the Classical Theory, but must be considered to be a fruitful means of systematically amplifying and extending it.

The Genesis of Atoms.

One of the more interesting of the recent developments of Bohr's theory is that which concerns the genesis of atoms of different types. Bohr has put forward the view that the fundamental process that must apply consists in the successive binding of electrons one after another by a nucleus originally naked.

On this view the electrons as they are successively bound to the nulceus take up certain final and definite orbits that are characteristic of the particular atom selected in its *normal* state, and that can to a first approximation be specified by two quantum numbers—namely, the principal and subordinate quantum numbers n and k. This means that the motion of each single electron of the atomic system can be approximately described as a plane periodic motion on which is superimposed a uniform rotation in the plane of the orbit.

It is assumed as a general postulate that during the binding of an electron by a nucleus the values of the quantum numbers n and k that characterise the orbits of the earlier bound electrons remain unchanged, and that at most, apart from a few exceptional cases, the addition of the later bound electrons merely results in slight alterations in the orientations in space of the orbits of the electrons already bound.

In arriving at his conclusions regarding the characteristics of the orbits of the bound electron Bohr has, of course, been guided in large measure by considerations derived from a study of the arc spectra of the different elements, a type of spectrum that it is now generally agreed is emitted during the process of binding the last electron in the formation of a neutral atom. Data derivable from the characteristics of the X-ray spectra of the elements have also been utilised by Bohr to check the validity of his conclusions regarding the characteristics of the orbits of the electrons bound in neutral atoms. As X-ray lines may be considered to give evidence of stages in a process by which an

TABLE I.

ELECTRONIC ORBITS IN ATOMS OF THE ELEMENTS.

N \ n_k	1_1	2_1	2_2	3_1	3_2	3_3	4_1	4_2	4_3	4_4	5_1	5_2	5_3	5_4	5_5	6_1	6_2	6_3	6_4	6_5	6_6	7_1	7_2
1 H	1																						
2 He	2																						
3 Li	2	1																					
4 Be	2	2																					
5 B	2	2	(1)																				
— —	—	—	—																				
10 Ne	2	4	4																				
11 Na	2	4	4	1																			
12 Mg	2	4	4	2																			
13 Al	2	4	4	2	1																		
— —	—	—	—	—	—																		
18 A	2	4	4	4	4																		
19 K	2	4	4	4	4		1																
20 Ca	2	4	4	4	4		2																
21 Sc	2	4	4	4	4	1	(2)																
22 Ti	2	4	4	4	4	2	(2)																
— —	—	—	—	—	—	—	—																
29 Cu	2	4	4	6	6	6	1																
30 Zn	2	4	4	6	6	6	2																
31 Ga	2	4	4	6	6	6	2	1															
— —	—	—	—	—	—	—	—	—															
36 Kr	2	4	4	6	6	6	4	4															
37 Rb	2	4	4	6	6	6	4	4			1												
38 Sr	2	4	4	6	6	6	4	4			2												
39 Y	2	4	4	6	6	6	4	4	1		(2)												
40 Zr	2	4	4	6	6	6	4	4	2		(2)												
— —	—	—	—	—	—	—	—	—	—		—												
47 Ag	2	4	4	6	6	6	6	6	6		1												
48 Cd	2	4	4	6	6	6	6	6	6		2												
49 In	2	4	4	6	6	6	6	6	6		2	1											
— —	—	—	—	—	—	—	—	—	—		—	—											
54 X	2	4	4	6	6	6	6	6	6		4	4											
55 Cs	2	4	4	6	6	6	6	6	6		4	4				1							
56 Ba	2	4	4	6	6	6	6	6	6		4	4				2							
57 La	2	4	4	6	6	6	6	6	6		4	4	1			(2)							
58 Ce	2	4	4	6	6	6	6	6	6	1	4	4	1			(2)							
59 Pr	2	4	4	6	6	6	6	6	6	2	4	4	1			(2)							
— —	—	—	—	—	—	—	—	—	—	—	—	—	—			—							
71 Lu	2	4	4	6	6	6	8	8	8	8	4	4	1			(2)							
72 Hf	2	4	4	6	6	6	8	8	8	8	4	4	2			(2)							
— —	—	—	—	—	—	—	—	—	—	—	—	—	—			—							
79 Au	2	4	4	6	6	6	8	8	8	8	6	6	6			1							
80 Hg	2	4	4	6	6	6	8	8	8	8	6	6	6			2							
81 Tl	2	4	4	6	6	6	8	8	8	8	6	6	6			2	1						
— —	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—						
86 Nt	2	4	4	6	6	6	8	8	8	8	6	6	6			4	4						
87 —	2	4	4	6	6	6	8	8	8	8	6	6	6			4	4					1	
88 Ra	2	4	4	6	6	6	8	8	8	8	6	6	6			4	4					2	
89 Ac	2	4	4	6	6	6	8	8	8	8	6	6	6			4	4	1				(2)	
90 Th	2	4	4	6	6	6	8	8	8	8	6	6	6			4	4	2				(2)	
— —	—	—	—	—	—	—	—	—	—	—	—	—	—			—	—	—				—	
— —	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—	—				—	—
118 ?	2	4	4	6	6	6	8	8	8	8	8	8	8	8		6	6	6				4	4

atom undergoes *reorganisation* after a disturbance in its interior, the energy levels obtainable for a neutral atom from the values of the frequencies of its X-radiation must agree with those representing the final orbits provided for this atom by the characteristics of its own arc spectrum as well as by those of the arc spectra of its ions or of the elements of lower atomic number.

As stated above, the basis of Bohr's classification of the orbits of atoms in their normal state is largely of an experimental character. It is not altogether so, however, for he has been able in the case of a number of the simpler atoms to work out the relative stabilities of orbits that are conceivable ones for these atoms, and by the use of the quantum theory, supported by the Correspondence Principle, has obtained a theoretical justification for the classification that he has adopted.

The results of Bohr's work in this direction are given in Table I., where N denotes the atomic number and n and k give the values of the principal and subordinate quantum numbers respectively of the orbits indicated. According to the scheme, it will be seen, the orbits are divided into groups corresponding to the various values of the principal quantum number n, and into sub-groups designated by different values of the subscript quantum number k. While orbits for which n has the value 1 are all of one type, those for which n has the value 2 are of two types, those for which n has the value 3 are of three types, and so on.

Illustrations of the structure of a number of neutral atoms are given by the diagrams on Plates I. and II. These have been copied from a paper by Kramers[4] that has recently appeared, and are stated to be similar to those prepared by Bohr for use in his own lectures. The electron orbits in the neutral atoms selected are arranged in groups from the centre of the atom outwards according to increasing values of the principal quantum number. The diagrams do not take account of the rotation of the orbits in their own plane, nor in the case of the heavier atoms is there any attempt to indicate the characteristics of the orbits close to the nucleus. They merely serve to illustrate in a general way Bohr's ideas regarding the genesis of atoms. A characteristic feature of the scheme is brought out by the illustrations of the orbits of the atoms of the rare gases. These, it will be seen, provide for the recurrence of the structure of a lighter atom as a constituent part of the structure of each of the heavier ones.

An illustration given by Bohr of the process of binding an electron to a nucleus is shown in Fig. 2. In this diagram the representation is that of the stationary states corresponding to the emission of the arc spectrum of potassium. No attempt is made to depict the duplex character of each of the stationary states. The curves show the form of the orbits described in the stationary states by the last electron captured in the potassium atom. They can be considered to represent stages in the process whereby the 19th electron is bound after eighteen previous electrons have already been bound in their normal orbits. The orbits are marked with the symbol n_k, where n and k are respectively the principal and subordinate quantum numbers.

[4] Kramers, *Die Naturwissenschaften*, Heft 27, July 6, 1923.

The states 4_1 5_1 6_1 . . . are to be considered as those which give rise to the σ terms in the series arc spectrum of potassium. The states 4_2 5_2 6_2 connote the π spectral terms, and the states 3_3, 4_3 the δ spectral terms. The state 4_4 will give rise to one of the ϕ or fundamental terms in the series spectrum.

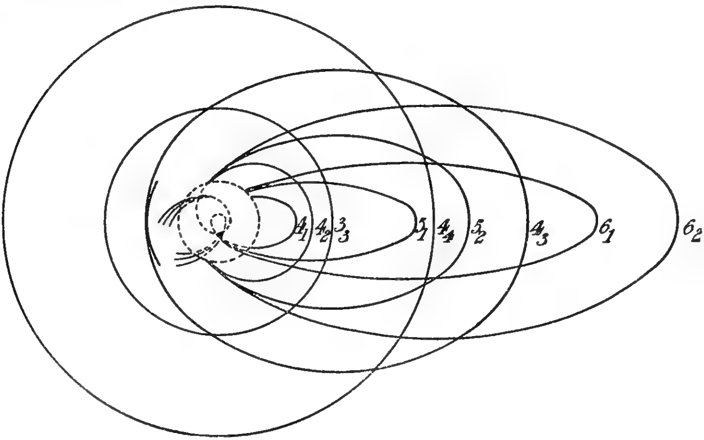


FIG. 2.—Binding Potassium Orbits.

Grotrian's method of exhibiting these relationships is instructive. Its application to the case of the stationary orbits of the potassium atom is shown in Fig. 3.

A few outstanding features of the classification given in Table I. may be referred to. In the first place, the scheme provides for periodicity in the properties of the elements. For example, in the case of

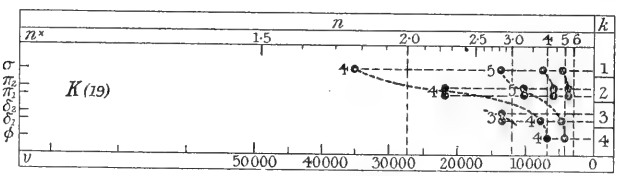
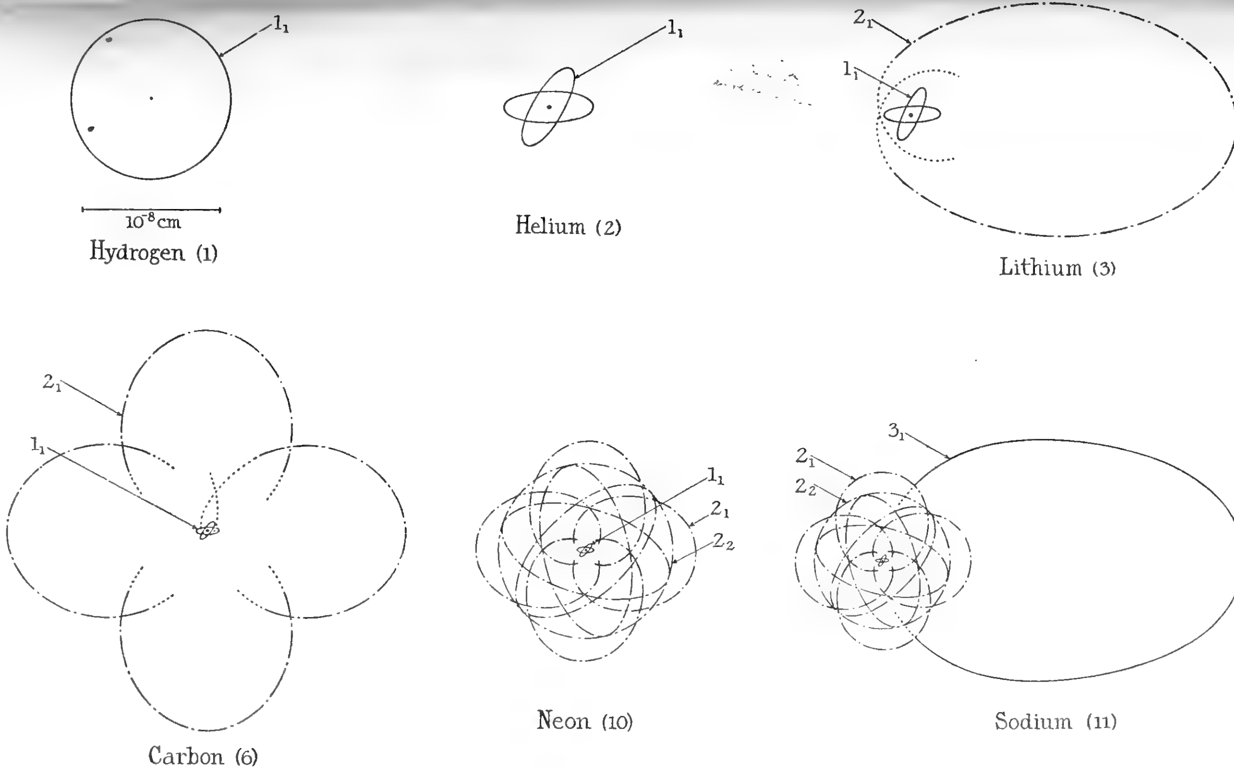


FIG. 3.—Grotrian Diagram.

the heavier inert gases the outer group of electrons is made up of two sub-groups with four electronic orbits of the same type in each. For these sub-groups the subordinate quantum number has the values 1 and 2. The principal quantum number increases by unity from element to element. Again, in the case of the alkali elements the outer group contains but one orbit. For it the subordinate quantum number k has the characteristic value 1, and the principal quantum number again



1_1
10^{-8} cm
Hydrogen (1)
1_1
Helium (2)
2_1
1_1
Lithium (3)
2_1
1_1
Carbon (6)
1_1
2_1
2_2
Neon (10)
3_1
2_1
2_2
Sodium (11)

PLATE I.

increases by unity as we pass from a lighter to a heavier element in the alkali group.

Another interesting feature of the classification is that in the genesis of the different kinds of atoms provision is made for the appearance at certain stages of sets of homologous elements such as those of the iron, palladium, platinum, and rare-earth groups. For example, the appearance of the iron group accompanies the establishment in the normal atom of an inner group of orbits of the 3_3 type beginning with the element scandium. These 3_3 orbits begin in the fourth period and differentiate it from the second and third because for the first time the charge on the nucleus is sufficiently great to make it possible for the successive atoms to differ by an extra electron in such an inner group instead of in an outer one. The appearance of the palladium group also is associated with the beginning of a development of inner orbits of the 4_3 type at a stage in the binding process when the outer orbits of the next lighter atoms consist of 5_1 quantum orbits. The appearance of the platinum and rare-earth groups of elements, too, it will be seen, is associated with the beginnings of developments of inner orbits of the 5_2 and 4_4 types respectively at stages in the binding process when the outer orbits of the neighbouring lighter elements are of the 6_1 type.

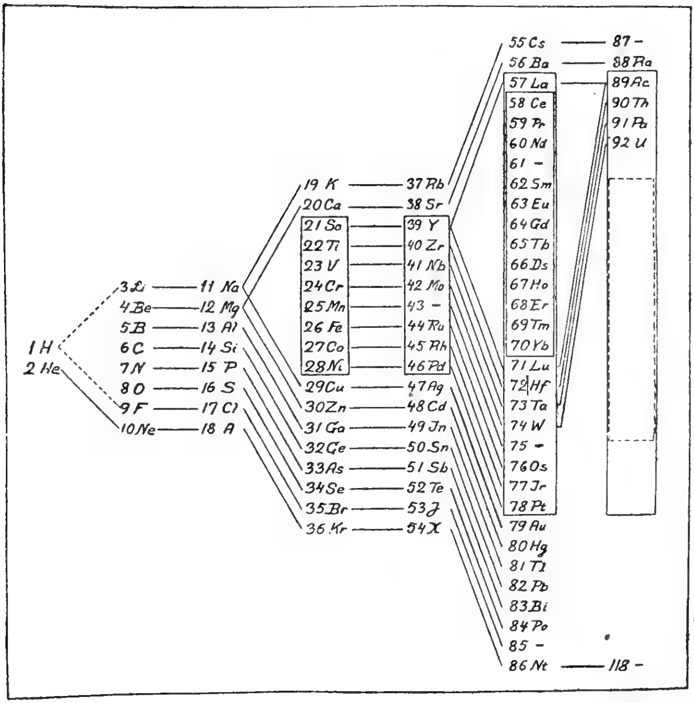
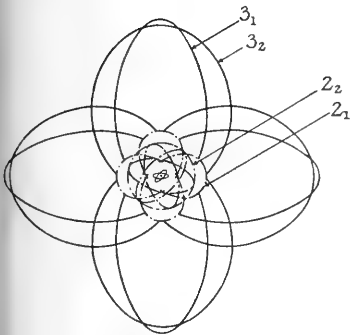
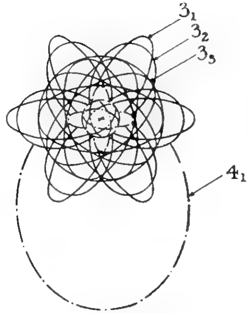


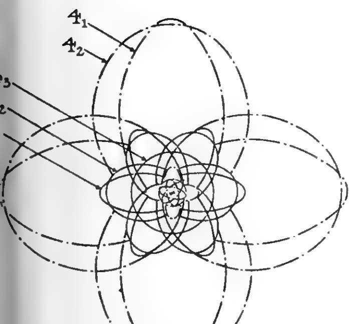
FIG. 4.—Elements.



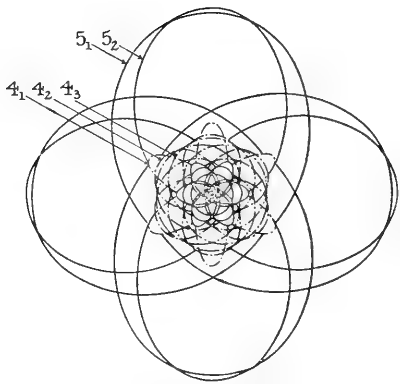
Argon (18)



Copper (29)



Krypton (36)



Xenon (54)

PLATE II.

These and other features of the classification that might be referred to are illustrated by the arrangement of the elements shown in Fig. 4. In this representation, it will be noted, those elements that belong to the same period are given in vertical columns, and those that from their chemical and optical properties can be considered homologous are connected with one another by straight lines. Groups of elements that possess analogous physical properties, and that differ from one another by variations in the number of electrons belonging to inner groups, are enclosed, as the diagram shows, by rectangular spacings.

Peculiar interest attaches to the newly discovered element of atomic number 72, to which the name 'Hafnium'[5] has been given. Conditions imposed by the quantum theory, in Bohr's view, make it imperative to assign this element to the platinum group instead of to the rare-earth group, as Dauvillier[6] and others have suggested. Theoretically, this element would appear to be a homologue of zirconium, and it is interesting to note that Coster and Henesy, who have been chiefly concerned with its discovery, have been able to obtain from zircon-bearing minerals considerable quantities of a substance whose chemical properties are similar to those of zirconium, and whose X-ray spectrum is that of an element with atomic number 72.

In the remainder of my address I propose, with your permission, to deal with a number of matters that are closely associated with developments of the quantum theory of the origin of spectra and that appear to merit some special attention and consideration at the present time.

The Fine Structure of the Balmer Lines of Hydrogen.

In the simplest treatment by the quantum theory of the origin of the spectrum of atomic hydrogen no allowance is made for a variation in the mass of the electron with its speed. If this factor be taken into account, as it has been by Sommerfeld, it is found that the motion of the electron is reducible to a motion in an elliptic orbit upon which is imposed a slow rotation in its own plane about the nucleus as focus. The resulting orbit has the form of a rosette, and is similar to that shown in Fig. 5.

In this treatment the chief factor in determining the stationary states is the principal quantum number n, but the subordinate quantum number k is also contributory. The former practically determines the major axis and the period of the elliptical orbit, while the latter defines the parameter of the ellipse—*i.e.* the shortest chord through its focus. The subordinate quantum number k also determines the period of rotation of the elliptic orbit in its plane. The energy corresponding to each stationary state is in the main determined by the value of the quantum number n, but stationary states determined by the same value of n are characterised by energy values that vary slightly with different values of the quantum number k.

[5] Coster and Henesy, *Nature*, Jan. 20, Feb. 10, 24, and April 7, 1923.

[6] Dauvillier, *C.R.*, t. 174, p. 1347, May 1922; Urbain, *C.R.*, t. 174, p. 1349, May 1922, and t. 152, p. 141, 1911.

The diagram shown in Fig. 1 represents an instantaneous aspect of the orbits of the different stationary states, and the designations n_k give the values of the quantum numbers characterising the different orbits.

According to this treatment each of the numbers of the Balmer series

$$\nu = K\left(\frac{1}{2^2} - \frac{1}{m^2}\right)$$

should consist of a doublet, and each of the components of these doublets should possess a fine structure. Calculations made by Sommerfeld showed that the frequency difference for these doublets should be constant over the whole of the Balmer series, and should be equal to 0.36cm.$^{-1}$.

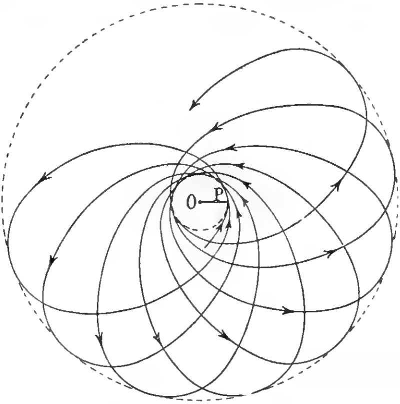


FIG. 5.—Rosette.

As the theory applies equally well to the corresponding series in the spectrum of positively charged helium, the doublets of this series were investigated by Paschen, and were found to have separations that led to a value of 0.3645 ± 0.0045 for the frequency difference of the doublets of the hydrogen Balmer series.

Since the publication of Paschen's work on the helium doublets a number of investigators [7] have attempted, from measurements on the

[7] Michelson and Morley, *Phil. Mag.*, vol. 24, p. 46, 1887.
Ebert, *Wied. Ann.*, vol. 43, p. 800, 1891.
Michelson, *Bur. Int. des Poids et Mesures*, vol. 11, p. 139, 1895.
Houston, *Phil. Mag.*, vol. 7, p. 460, 1904.
Fabry and Buisson, *C.R.*, vol. 154, p. 1501, 1912.
Paschen, *Ann. der Phys.*, vol. 50, p. 933, 1916.
Merton and Nicholson, *Roy. Soc. Proc.*, A, vol. 93, p. 28, 1917.
Merton, *Roy. Soc. Proc.*, A, vol. 87, p. 307, 1920.
Gehrcke and Lau, *Phys. Zeit.*, vol. 21, p. 634, 1920.
McLennan and Lowe, *Roy. Soc. Proc.*, A, vol. 100, p. 217, 1921.
Gehrcke and Lau, *Phys. Zeit.*, vol. 22, p. 556, 1921.
Oldenburg, *Ann. der Phys.*, vol. 67, p. 69, 1922.
Gehrcke and Lau, *Ann. der Phys.*, vol. 67, p. 388, 1922.
Oldenburg, *Ann. der Phys.*, vol. 67, p. 253, 1922.
Geddes, *Proc. Roy. Soc. Edin.*, vol. 43, p. 37, 1923.

separations of H_α and H_β, and in some cases of H_γ and H_δ, to look for evidence that would lead to a confirmation of Sommerfeld's theory. Up to the present the results obtained could not be considered as satisfactory. There was a lack of agreement in the values obtained for the separations by different investigators, and on the whole the values obtained were less than that demanded by the theory. The matter was reinvestigated recently, at my suggestion, by one of the research workers in the Physical Laboratory of the University of Toronto, Mr. G. M. Shrum, and in his experiments he succeeded in eliminating practically the whole of the secondary spectrum, and as a result was able to include in his measurements of the doublet separations that of H_ϵ as well as those of H_α, H_β, H_γ, and H_δ.

The results are the following:—

Line	Wave-length	Separation of the Components		Probable Error
		$d\lambda$	$d\nu$	
H_α	6562·79 A	0·143 A	0·33 cm.$^{-1}$	0·02 cm.$^{-1}$
H	4861·33 ,,	0·085 ,,	0·36 ,,	0·01 ,,
H_γ	4340·46 ,,	0·070 ,,	0·37 ,,	0·02 ,,
H_δ	4101·73 ,,	0·061 ,,	0·36 ,,	0·02 ,,
H	3970·07 ,,	0·055 ,,	0·35 ,,	0·02 ,,

It will be seen that as far as the doublet separations are concerned they afford a striking confirmation of Sommerfeld's theory.

Model of the Atom of Helium.

Considerable interest attaches to the atom of Helium. From the chemical point of view it has been considered to be inert, and consequently not likely to enter into chemical combination. Of all atoms it is the most stable, for it has the highest ionisation potential, namely 24.5 volts. A study of the X-radiation emitted by the elements generally makes it appear that the configuration we assign to the electronic orbits in helium atoms is maintained intact throughout the whole of the remaining heavier elements. These orbits, as Table I. shows, constitute for all atoms the K X-ray group the innermost and most stable system. For these reasons it is highly desirable that a model of the atom of helium be realised possessing high stability endowed with the capacity to emit radiation exhibiting the characteristic features of the helium spectrum, and having energy values for its normal and temporary stationary states that fit in with the experimentally determined values of its ionisation, resonance, and other critical excitation potentials.

The earlier models of the atom of helium put forward failed entirely to meet these requirements. Models recently conceived by Lande[8] and by Bohr[9] are at the present time receiving considerable attention. In these the two electrons in the normal atom are taken to move in equivalent 1_1 orbits. As a first approximation these may be described as

[8] Lande, *Phys. Zeit.*, No. 20, p. 228, 1919.
[9] Bohr, *Zeit. für Phys.*, No. 2, p. 464, 1920.

circular orbits with planes inclined at an angle to each other. Bohr assumes this angle to be 120°, and on account of the interaction between the two electrons the two orbits are supposed to be slowly turning about a fixed momentum axis in the atom. A diagrammatic representation of this model is shown in Fig. 6.

Such a model, however, will not account for the whole of the spectrum of helium, which is known to consist of two complete but separate sets of series, the one being made up of single lines and the other of doublets. An important feature of the spectrum of helium, too, is that it contains no lines that are the result of combinations between spectral terms belonging to one of the sets of series and those belonging to the other. The explanation put forward is that while helium in its normal state exists in the form of atoms with crossed orbits, designated by the name parhelium, it can also exist in a metastable form, known as orthohelium, as well. In the latter state the electronic orbits are supposed to be in the same plane with the electrons revolving in the same direction. In the most stable form of ortho-

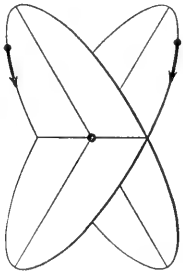


FIG. 6.—Helium Model.

helium one of the electrons is supposed to move in a 1_1 orbit and the second in a 2_1 orbit. The singlet series in the spectrum of helium are assigned to parhelium and the doublet series to orthohelium.

If parhelium be bombarded by electrons it appears to be possible to transform its atoms into the metastable form, but once the atoms are in the latter state it does not seem to be possible for them to revert directly to the normal form by means of a simple transition accompanied by the emission of radiation. They can only do so by a process analogous to a chemical reaction involving interaction with atoms of other elements.

The fact that helium, under certain conditions, can be made to emit a band spectrum in addition to its line spectrum connotes the possibility of helium existing in the molecular form. Since helium in the form of orthohelium has its outer electron in a 2_1 orbit, the atoms of orthohelium in so far as chemical combination is concerned occupy a position analogous to atoms of lithium, which also possess a 2_1 orbit in their normal state. As this feature enables lithium to react vigorously with other atoms, one would expect orthohelium also to be capable of entering into chemical combinations. From this it would appear that molecular helium originates in atoms that have undergone a transition into the metastable state. As to the atoms of parhelium, there appears to be no warrant of this or any other character for supposing that they can participate in any kind of chemical union.

It is probable that orthohelium, if obtainable in sufficient amounts, may be found to be more easily liquefied and solidified than parhelium. It would, however, in the liquid or solid state be highly explosive. This will be seen from the data in Table II. A study of the band spectrum of helium or of its compounds at low temperatures would be interesting for what it might reveal regarding the origin of the spectrum of nebulæ.

The views just presented have gained strong support from Frank and Knipping's experiments on the excitation potentials of helium atoms by electronic bombardment, and by Lyman's recent work on the extreme ultra-violet spectrum of helium, in which it has been shown that radiation of the wave-lengths 600.5 A, 584.4 A, 537.1 A, 522.3 A, and 515.7 A are absorbed by helium in its normal state. The scheme[10] set forth in Fig. 7 and the data collated in Table II. are self-explanatory, and show how on the view just put forward the radiation whose wave-lengths were measured by Lyman can originate, and how the excitation potentials observed by Frank and Knipping can be realised.

According to this scheme electrons with a speed corresponding to a potential of 19.75 volts will be able to transform parhelium into orthohelium, and those with speeds corresponding to 20.55 volts and 21.2 volts will be able to lift the electrons from 1, S orbits to 2, S and 2, P orbits respectively. Under bombardment by electrons with speeds the equivalent of 24.5 volts the helium atoms will be ionised. The scheme shown in Fig. 7 also indicates how the series spectrum of orthohelium originates.

The considerations set forth above would seem to clear up some of the difficulties that have hitherto been encountered in realising a satisfactory model of the helium atom, and in reaching an explanation of the origin of the radiation that atoms of helium can emit. The complete solution of the problem, however, has received a set-back from the results of an investigation recently carried out by Kramers,[11] for according to his calculations the ionisation potential of the crossed orbit model comes out 3.8 volts less than the experimentally determined value. His calculations also show that in a mechanical sense the crossed orbit model cannot be considered to be a stable one. Although real progress has been made, it cannot be said that finality has been reached in the determination of the form of a completely satisfactory model of the atom of so simple an element as helium.

A somewhat novel aspect of the problem has recently been emphasised by Silberstein.[12] He assumes the crossed orbit model of the helium atom to be capable of taking up a number of stationary states

[10] Grotrian, *Die Naturwissenschaften*, Heft 17, p. 321, 1923.
[11] H. A. Kramers, *Zeit. für Phys.*, vol. 13, p. 339, 1923.
[12] Silberstein, *Nature*, Ap. 28, p. 567, 1923, and July 14, p. 53, 1923.

with the planes of the orbits at a series of angles other than 120°. On this basis he has been able, by taking for granted the dynamical legitimacy of the crossed orbit system, to calculate values for the ionisation

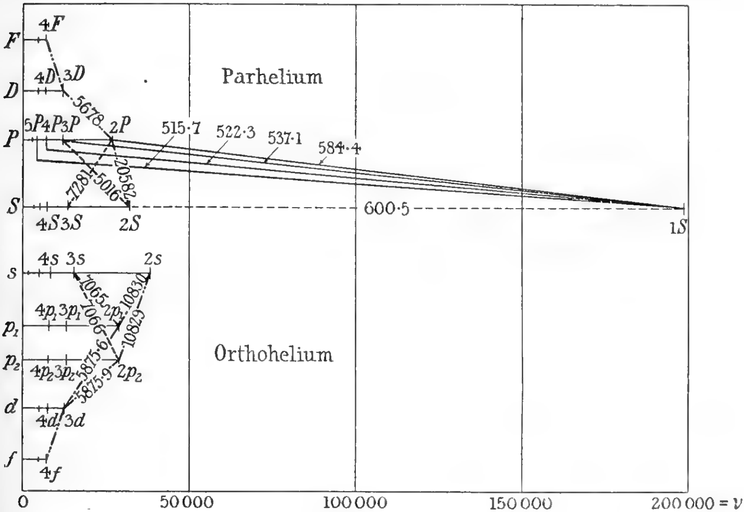


FIG. 7.—Scheme of He Lines.

and other excitation potentials that are in remarkably good agreement with the experimental values found by Frank and Knipping, Horton, and others.

TABLE II.

Lines Observed by Lyman	Series Representation	Calculated Excitation Potentials	F. & K.'s Measured Excitation Potentials	Remarks
—	1, S—2, *s*	19·77	19·75	Transition voltage connoting change from parhelium to orthohelium.
600·5 A	2, S—1, S	20·55	20·55	A weak radiation and one not provided for by the principle of selection.
584·4 „	2, P—1, S	21·12	21·2	First member of absorption series of parhelium.
537·1 „	3, P—1, S	22·97	22·9	Second member of absorption series of parhelium.
522·3 „	4, P—1, S	23·62	—	Third member, &c.
515·7 „	5, P—1, S	23·92	—	Fourth member, &c.
502·0 „ (calculated)	— —1, S	24·5	24·6	Series limit and ionisation potential.

Resonance and Ionisation Potentials.

The results of investigations on the absorption spectra of zinc, cadmium, and mercury, and on the resonance and ionisation potentials of these elements, have shown that for this group of elements the ionisation potentials are given by $V = h\nu/e$, where ν is the frequency denoted by (n, S), namely, that of the last member of the series $\nu = (n, S) - (m, P)$.[13] It is also known that their resonance potentials are given by the same relation with ν having the value $(n, S) - (2, p_2)$ the frequency of the first member of a combination series. In the case of the alkaline earths similar relations obtain. With the alkali elements the frequencies that determine the resonance and ionisation potentials are given by $\nu = (n, \sigma) - (n, \pi)$[14] and $\nu = (n, \sigma)$ respectively. It is, therefore, clear from the characteristics of the spectral terms involved that, while the electron concerned in phenomena associated with resonance and ionisation potentials must be the one that is most easily displaced in or removed from the atom, this electron must be bound in atoms of the elements mentioned—when these are in their normal state—in orbits of the n_1 type, *i.e.* in orbits for which the subordinate quantum number has the value 1. Now, a reference to Table I. will show that this characteristic is exactly the one possessed by the electron that is last bound in the atoms of the elements cited.

It follows, then, that if we know the type of orbit occupied by the last bound electron in the normal atom of any element we can at once deduce the type of the series whose first and last members will enable us to calculate the resonance and ionisation potentials of the element. Moreover, the wave-lengths of such a series will be the ones that will be selectively absorbed by the vapour of the element, provided its temperature is sufficiently low to ensure that the atoms constituting the vapour are in their normal state.

Previous to the publication by Bohr of the scheme in Table I. it had been thought that for all elements the resonance and ionisation potentials should be obtainable from spectral frequencies of the $(n, \sigma) - (m, \pi)$ or $(n, S) - (m, P)$ type. Numerous attempts were made by investigators of the absorption spectra of such elements as thallium, lead, tin, &c., to group the wave-lengths of the radiation absorbed into a principal series that would enable one to calculate the critical potentials for these elements. These efforts, however, ended in failure, for though wave-lengths were found that were selectively absorbed by the vapours of the elements referred to, and though it was found possible to fit these partially at least into series, it was clear that the series obtained did not satisfy the conditions demanded by series of the principal type.

By the publication of Bohr's scheme of atomic orbits, however, it became evident that since in the case of the aluminium group of elements, for example, the electron last acquired in making the atoms neutral is bound in an orbit of the n_2 type, the first member of the

[13] According to Bohr's scheme n has the value 4 for Zn, 5 for Cd, and 6 for Hg, while m has the value 2.

[14] In this formula n has the value 2 for Li, 3 for Na, 4 for K, 5 for Rb, and 6 for Cs.

spectral series that would enable us to calculate the resonance and ionisation potentials for this group of elements must be of the type $\nu=(n,\pi)-(m,x)$ and not of the type $\nu=(n,\sigma)-(m,\pi)$. Moreover, this makes it clear that the series of wave-lengths that should be selectively absorbed by vapours in the normal state of the elements of the aluminium group would be the first and second subordinate ones represented by $\nu=(n,\pi)-(m,\sigma)$ and $\nu=(n,\pi)-(m,\delta)$.

Recent experiments by Carroll [15] and by Grotrian,[16] as well as earlier ones by Wood and Guthrie [17] and by the writer,[18] show that the wave-lengths most readily absorbed by non-luminous thallium vapour all belong to the sharp or diffuse subordinate series in the spectrum of this element. With indium vapour Grotrian has obtained similar results. With aluminium, as with thallium, the wave-lengths absorbed by the comparatively cool vapour that surrounds an electric arc in the metal belong to the sharp and diffuse subordinate series.

From these results it is clear that the evidence furnished by spectral data amply confirms the view put forward by Bohr that in the case of the heavier elements of the aluminium group at least, the electron last acquired by the neutral atom of the respective elements is bound in an orbit of the n_2 type. In the case of the light element boron, the series data available are so meagre that it is not possible as yet to affirm that the same law applies.

From the known values of the frequency $\nu=(n,\pi_2)$ in the spectra of the elements aluminium, gallium, indium, and thallium, it follows that the resonance potentials for these elements are respectively 3.12 v., 3.08 v., 3.00 v., and 3.26 v., and that the ionisation potentials are respectively 5.94 v., 5.96 v., 5.75 v., and 6.07 v.

For thallium, the only element of this group as yet investigated by the method of electronic impact, Foote and Mohler found the resonance and ionisation potentials to have the respective values 1.07 v. and 7.3 v. The agreement, it will be seen, is not very close. It should be noted, however, that Foote and Mohler, in giving their results, indicate that they should be considered to be approximate only.

Electronic Orbits of the Atoms of the Lead-Tin Group.

It will be seen that the scheme of orbits given in Table I. makes no provision for the elements of the Lead-Tin group. The reason for this is that hitherto but little spectroscopic data have been available for these elements. Besides, the development of the quantum theory does not appear to have been sufficiently advanced to include the atoms of these elements within the scope of its application. Progress with these elements is, however, now possible owing to the fact that Thorsen [19] has been able to organise a part of the spectrum of lead into a triplet set of first and second subordinate series. These series

[15] Carroll, *Proc. Roy. Soc.*, Series A, vol. 103, p. 334, May 1923.
[16] Grotrian, *Zeit. für Phys.*, Bd. 12, p. 218, 1923.
[17] Wood and Guthrie, *Ast. Phys. Jl.*, vol. 29, p. 211, 1909.
[18] McLennan, Young and Ireton, *Proc. Roy. Soc. of Canada*, Section III., p. 7, 1919.
[19] Thorsen, *Die Naturwissenschaften*, Heft 5, Feb. 2, 1923. Recent experiments by Thorsen lead to the value of 9.18 v. for the ionisation potential of gold.

have frequencies given by $\nu=(n, p_x)-(m, s)$[20] and $\nu=(n, p_x)-(m, d)$ where x has the values 1, 2, 3. In all about 54 wave-lengths have been allocated into places in these series. In this connection it is of importance to note that Thorsen does not seem to have been able to assign any of the wave-lengths in the lead spectrum to a related principal series.

Following up this work, Grotrian[21] has recently pointed out that of the wave-lengths known to be selectively absorbed by non-luminous lead vapour,[22] the prominent ones $\lambda=2833$ A, $\lambda=2170$ A, $\lambda=2053.8$ A, and $\lambda=3683$ A were not included in the series formulated by Thorsen. He has been able to show, further, that they can be included in a more extended scheme of first and second subordinate series that includes, in addition to those of Thorsen, two others that have for their highest frequencies $\nu=(2, p_4)=59826\text{cm}^{-1}$ and $\nu=2, p_5=51677\text{ cm}^{-1}$. According to this scheme $\lambda=2833$ A would have the frequency $\nu=(2,p_4)-(2,s)$, $\lambda=2053$ A the frequency $\nu=(2,p_4)-(3,s)$, $\lambda=2170$ A the frequency $\nu=(2,p_4)-(3,d_2)$, and $\lambda=3683$ A the frequency $(2,p_5)-(2,s)$. These results lead at once to definite conclusions regarding the outermost orbit in the normal atoms of lead. Since all the wave-lengths absorbed are members of subordinate series, it follows that the electron last acquired by a neutral atom of lead must be bound in an orbit for which the subordinate quantum number k has the value 2. This leads to the conclusion that the scheme of orbits for lead will include two of the 6_1 type and two of the 6_2 type.

From the frequencies

$$\nu=(2,p_4)-(2,s)=35296\text{cm}^{-1} \text{ and } \nu=(2,p_4)=59826\text{cm}^{-1}$$

it follows that the resonance and ionisation potentials of lead should be respectively 4.35 v. and 7.4 v. As Foote and Mohler have found by the method of electronic impact these critical potentials to be 1.26 v. and 7.93 v., it will be seen that while the values for the resonance potentials show no agreement, there is a fair agreement in the case of the values of the ionisation potentials.

As very little is known about the series spectra of tin[23] and germanium, one cannot as yet write with precision about the outermost orbits of the normal atoms of these elements. Considerations of periodicity make it highly probable that they will be of the same type as those of lead. This would mean that tin should have its two outermost electrons bound in the normal atoms of equivalent 5_2 orbits, and the normal atoms of germanium their two outermost electrons bound in 4_2 orbits. The results obtained with the series spectra of lead will no doubt lead immediately to the organisation of the spectral lines of tin and germanium into series.

Though but little has been published about the series spectra of neutral atoms of silicon, Fowler reports that he has been able to show that the arc spectrum of this element includes a number of related

[20] According to Thorsen n has the effective value 2 in this formula.

[21] Grotrian, *Die Naturwissenschaften*, Heft 13, March 30, 1923.

[22] McLennan and Zumstein, *Proc. Roy. Soc. of Canada*, Section III., vol. xiv., p. 9, 1920.

[23] The writer has been able to show recently that the spectrum of tin includes series of the same type as those of lead.

triplets. In this regard it is analogous to the spectrum of lead as originally classified into series by Thorsen. From general considerations the existence of these triplet series would connote that there are two valency electrons in the atoms of silicon. As the outermost electron in normal atoms of aluminium is bound in a 3_2 orbit, the two outermost electrons in the normal atoms of silicon would appear to be bound in equivalent orbits of this type.

As to normal atoms of carbon, Bohr has expressed the opinion that the four last bound electrons may be expected to form an exceptionally symmetrical configuration, in which the normals to the planes of the orbits occupy positions relative to one another nearly the same as the lines from the centre to the vertices of a regular tetrahedron. Such a configuration would, it is evident, furnish a suitable foundation for explaining the structure of organic compounds. Thus, considerations of symmetry would undoubtedly lead to the view that the four outer electrons in carbon atoms were all bound in 2_1 quantum orbits symmetrically arranged in space.

This scheme of outer orbits is radically different from that ascribed above to the outer orbits of the atoms of lead, tin, germanium, and silicon, and the explanation of the difference is at yet not at all clear.

The fact that the spectrum of lead has been shown to include at least five sharp subordinate series and four diffuse subordinate series suggests in a measure a parallel to the spectrum of neon for which Paschen[24] has identified at least thirty sharp series and seventy-two diffuse series. Multiple series of this character have also been shown by Meissner[25] and by Nissen[26] to be included in the spectrum of argon. Though this parallel might be taken to indicate that the orbits of the four last bound electrons in the atoms of lead and in those of the allied elements are all of the n_1 type, it would seem that since the wave-lengths selectively absorbed by lead vapour all belong to subordinate series, we must conclude that in the case of lead at least its outermost orbits must be two in number and of the 6_2 type. Carbon, too, in all probability will be found to have two of its outermost electrons in 2_1 orbits and two in 2_2 orbits.

The Kossel-Sommerfeld Displacement Law.

I have stated that Bohr in arriving at his scheme of atomic orbits was guided by the view that the fundamental process to keep in mind was that when a nucleus originally naked acquired electrons sufficient in number to neutralise its charge, it did so by binding them according to a programme that was definite and fixed for each value of the nuclear charge.

If this view be accepted, it follows that if we were to detach from the neutral atom of an element its most loosely bound electron, we should expect to find that the orbits which remained were characterised by the same quantum numbers as defined them in the neutral atom. Moreover, except in certain special cases, these orbits would be identical

[24] Paschen-Götze, *Seriengesetze der Linienspektren*, p. 30.
[25] Meissner, *Ann. d. Phys.*, Bd. 51, p. 95, 1915.
[26] Nissen, *Phys. Zeit.*, vol. 21, p. 25, 1920.

in type with those of the neutral atoms of the next lighter element. The exceptional cases would include those elements whose atomic structure involved the commencement of the development of an inner system of orbits, such as those of the 3_3, 4_3, 4_4, &c., groups. Subject to these limitations, we should expect to find that if the n last-bound electrons were removed from a neutral atom of an element the orbits that remained in this atom would be identical in type with those of the neutral atoms of the nth lighter element. This would mean that the arc spectrum of the monovalent positive ion of arc element would be identical as to types of series involved with the arc spectrum of the neutral atoms of the next lighter element. There would be this difference, however, that in the series formulæ of the spectrum of the ion the Rydberg constant would be 4K, whereas in the series of the spectrum of the neutral atoms of the lighter element it would be K. Putting the matter as it is ordinarily stated, the spark spectrum of an element should be made up of series of the same type as those of the arc spectrum of the next lighter element. This is known as the Kossel-Sommerfeld Displacement Law.

Numerous illustrations of this law might be cited. For example, the series in the spectrum of the monovalent positive helium ion are of the same type as those of the spectrum of atomic hydrogen. Again, the series in the spark spectra of the alkali elements have been shown to be similar in type to those of the arc spectra of the rare gases. In the case of potassium,[27] it has been shown that in addition to its arc spectrum it can, under moderate excitation, emit a series spectrum identical in type with that of the red spectrum of argon, and under violent excitation a spectrum having all the characteristics of the blue spectrum of this inert gas. In the case of the alkaline earths, the series spark spectra have the same characteristics as the arc spectra of the alkali elements.

But perhaps the most striking confirmation of the correctness of Bohr's view of the process of binding electrons to nuclei, and also at the same time of the validity of the Kossel-Sommerfeld Law, is found in recent work by Paschen [28] and by Fowler [29] on the spectra of doubly ionised aluminium and trebly ionised silicon.

It will be recalled that Fowler some years ago showed that the wave-lengths of the spark spectrum of magnesium could be organised into series having 4K for their Rydberg constant. Early this year Paschen carried the matter farther by showing that under strong excitation aluminium emits a spectrum that can be arranged into series with a Rydberg constant equal to 9K. Now Fowler has capped it all by showing in a brilliant piece of work that in the spark spectrum of silicon certain wave-lengths can be grouped into series with a Rydberg constant of 16K. With both elements the series referred to are doublet series of the type obtained in the arc spectrum of sodium.

[27] McLennan, *Proc. Roy. Soc.*, vol. 100, p. 182, 1921, and Zeeman and Dik, *Konin. Akad. Van Weten, Amsterdam, Proc.*, vol. xxv., p. 1, April 29, 1922, and *Ann. der Phys.*, Bd. 71, Heft 1/4, p. 188, 1923.

[28] Paschen, *Ann. der Phys.*, Bd. 71, Heft 1/4, p. 142, Heft 8, p. 537, 1923.

[29] Fowler, *Proc. Roy. Soc.*, vol. 103, No. A, 722, June 1923.

In terms of Bohr's theory the 9-fold value of the Rydberg constant would be interpreted as meaning that aluminium atoms which emitted this spectrum had lost two electrons, and were represented by Al + +, or, as it is now written, Al(III). The 16-fold Rydberg constant would, on the same theory, also be interpreted as meaning that the atoms of silicon which emitted this spectrum were those that had lost three electrons, *i.e.* Si(IV). These results, it will be seen, amply confirm the view that the bound electrons in the neutral atoms of sodium, Na(I), are of the same type and are characterised by the same quantum numbers as those of the singly ionised atom of magnesium, Mg(II), of the doubly-ionised atom of aluminium, Al(III), and of the trebly-ionised atom of silicon, Si(IV).

What has been found to be true of the spectra of sodium, magnesium, aluminium, and silicon, will no doubt be found to be true of the spectra of the elements lithium, beryllium, boron, and carbon. The spectra of beryllium and boron are extremely meagre in wave-lengths, and but little is known of their spectral series. The spectrum of carbon, however, especially in the extreme ultra-violet, has been well worked out by a number of observers, and particularly so by Simeon.[30]

In the spectrum of beryllium the doublet $\lambda = 3131.194$ A, $\lambda = 3130.546$ A has been shown to be the first member of a principal and a second subordinate series of doublets. Moreover, Back,[31] who recently investigated its magnetic resolution, has found that the magnetic components are of the D_1 and D_2 type, just as Kent has shown the magnetic components of the close lithium doublet $\lambda = 6708$ A to be. It will, therefore, probably be found when the spectrum of beryllium has been extended that the doublet $\lambda = 3131.194$ A, $\lambda = 3130.546$ A will prove to be the first member of the doublet series of the positive singly-charged atom of beryllium, with a Rydberg constant for the series of 4K. In the spectrum of boron the doublets $\lambda = 2497.73$ A, $\lambda = 2496.78$ A and $\lambda = 2089.49$ A, $\lambda = 2088.84$ A, particularly the latter, merit attention in looking for a 9K series. In the ultra-violet spectrum of carbon there is a strong doublet at $\lambda = 1335.66$ A, $\lambda = 1334.44$ A, and another nearly as strong at $\lambda = 1329.60$ A, $\lambda = 1329.07$ A. These two also merit attention in any attempt to identify 16K series for this element.

In considering the general validity of the Kossel-Sommerfeld Displacement Law the recent work of Catalan [32] on the series spectra of manganese, chromium and molybdenum is of interest.

The spectra of the neutral and singly ionised atoms of manganese, as well as that of the neutral atoms of chromium, have been shown by him to consist of sets of sharp diffuse and principal triplet series. Moreover, he has found that in all these spectra there are certain groups of prominent lines, to which the name 'multiplet' has been given, that have similar characteristics, and that show similar variations with changes in temperature. This has led Catalan to put forward

30 Simeon, *Proc. Roy. Soc.*, A, vol. 102, p. 490, 1923.

31 Back, *Ann. der Phys.*, No. 5, p. 333, 1923.

32 Catalan, *Phil. Trans.*, *Roy. Soc.*, Series A, vol. 223, pp. 127-173, 1922; *C.R.*, Jan. 8 and 22, and April 16, 1923.

the view that the neutral atom of manganese has an outer system of two electrons, and that when this atom loses one of its most loosely bound ones another electron from the next inner system comes out to take its place in the outermost system, so that the latter again contains two electrons. The similarity of the spectra of the neutral and singly ionised atoms of manganese would thus be accounted for. By assuming that this final configuration of the orbits in the singly ionised atoms of manganese was the same as the configuration of the outer orbits in the neutral atoms of chromium, the similarity of the arc spectrum of chromium to those of the singly ionised and neutral atoms of manganese would also be explained.

Catalan's series relations show that the two last acquired electrons in the neutral atoms of manganese and chromium are bound in equivalent orbits of the 4_1 type, and that as a consequence the ionisation potentials of these two elements are given by a frequency of the form $\nu = (1.5)$, and have the values 7.4 v. and 6.7 v. respectively.

In some later work Catalan[33] has shown that the scheme of series in the spectrum of molybdenum is identical with that which applies to the spectrum of chromium. With this element he deduced the value 7.1 volts for the ionisation potential. The two last acquired electrons in the atom of molybdenum would appear to be bound in equivalent orbits of the 5_1 type.

From the considerations that have been presented in regard to the atoms and the spectra of chromium and manganese some deductions can be made regarding the spectrum and stationary orbits of the unknown element of atomic number 43. Its arc spectrum, and probably that of its singly charged positive ion too, will likely consist of triplet series. Its spectrum will also very likely include a set of multiplets, and its two outer electrons will probably be found in equivalent 5_1 orbits. Although some considerations recently put forward by Lande[34] and by Back[35] may lead to modifications in the views expressed above, the possibility of making these deductions constitutes a rather remarkable testimony to the power of the methods that are being at present applied in unravelling the mysteries of atomic structure and of the origin of radiations.

An interesting point in connection with the Kossel-Sommerfeld Displacement Law arises in connection with the magnetic properties of the neutral atoms of argon, of the singly-charged positive atom ions of potassium, and of the singly-charged negative atom ions of chlorine. Recent work by W. L. Bragg[36] and Davey,[37] as well as a report by Herzfeld,[38] go to show that the ions referred to and the atom of argon have practically the same dimensions, with a radius of about 1.56×10^{-8} cm. It appears also from the work of Königsberger,[39]

33 Catalan, *C.R.*, April 16, 1923.
34 Lande, *Zeit. für Phys.*, vol. 15, p. 189, 1923.
35 Back, *Zeit. für Phys.*, vol. 15, p. 206, 1923.
36 W. L. Bragg, *Phil. Mag.*, vol. xl., p. 187, 1920.
37 Davey, *Phys. Rev.*, vol. xviii., p. 103, 1921.
38 Herzfeld, *Jahr. der Rad. und Elek.*, Bd. 19, p. 259, 1922.
39 Königsberger, *Ann. der Phys.*, vol. 66, p. 713, 1898.

St. Meyer,[40] Curie,[41] and Soné[42] that the atom ions of potassium and chlorine and the atoms of argon are diamagnetic.

Since these ions and the atoms of argon contain the same number of electrons, and since the electrons in all three are supposed to be bound in orbits of the same type and of the same area, one would expect them to show identical diamagnetic properties. The experimental results, however, do not appear to support this view. While the specific magnetic susceptibility of argon has been shown by Soné to have the value 5.86×10^{-6}, that of the singly-charged negative atom ions of chlorine and of the singly-charged positive atom ions of potassium have been found from observations on the magnetic properties of potassium chloride to be equal approximately to 0.55×10^{-6}, *i.e.* the diamagnetic susceptibility of argon is about ten times that of the ions of potassium and chlorine. As Pauli[43] has shown that this high value of the diamagnetic susceptibility of argon leads on certain simple assumptions to a value for the moment of inertia of the atoms of argon about ten times too great, it would appear that the discrepancy arises in connection with the evaluation of the diamagnetic susceptibility of argon. Although all the experimental work involved appears to have been carefully done, it is evident that the investigation of the diamagnetic properties of these elements will have to be carried further before the matter is finally cleared up.

Quantisation in Space.

One of the most surprising and interesting developments of the quantum theory is that which shows that quantum numbers determine not only the size and form of the electronic Keplerian orbits in atoms, but also the orientation of these orbits in space with regard to a favoured direction such as that provided by an intra-atomic or by an external magnetic or electric field of force. For any arbitrary value of the azimuthal quantum number k, the simple theory shows that there are exactly $k+1$ quantum positions of the orbital plane characterised by whole numbers. For example, if $k=1$ the normal to the orbit may be either parallel to the direction of the controlling field or at right angles to it. If $k=2$ the normal to the orbit may take up in addition to these two positions a third one, in which the normal to the orbit makes an angle of 60° with the field. For higher values of the quantum number k, the possible orientations of the corresponding orbits become regularly more numerous.

A striking confirmation of this theory is afforded by the very beautiful experiments of Gerlach and Stern.[44] In these a stream of atoms of vaporised silver was allowed to flow past a wedge-shaped pole of an electromagnet which provided a radial non-uniform magnetic

[40] St. Meyer, *Ann. der Phys.*, vol. 69, p. 239, 1899.

[41] Curie, *Jl. de Phys.*, 3, S. 4, p. 204, 1895.

[42] Soné, *Tôhoku Univ. Sc. Rep.*, vol. 8, pp. 115-167, Dec. 1919, and *Phil. Mag.*, vol. 39, p. 305, March 1920.

[43] Pauli, *Zeit. für Phys.*, Bd. Heft 2, p. 201, 1920.

[44] Gerlach and Stern, *Zeit. für Phys.*, vol. 7, p. 249, 1921: vol. 8, p. 110, 1921; vol. 9, p. 349 and p. 353, 1922.

field. The atoms were caught on a glass plate placed immediately behind the pole, and it was found that they were deposited in two distinct sharply defined layers, indicating that the atoms were sorted out into two distinct and separate beams. The positions of the bands on the plate showed that one of the beams was attracted by the pole and the other repelled by it, the attraction being slightly the greater in intensity. No evidence was obtained of an undeflected beam. From these results it was concluded that all the silver atoms in the stream of vapour possessed a definite magnetic moment, and that while the atoms were passing through the magnetic field their magnetic axes had two distinct orientations in space.

By assuming the correctness of this interpretation, Gerlach and Stern found from measurements on the various magnitudes involved in the phenomenon that within the limits of error of their experiments the magnetic moment of the normal atom of silver in the gaseous state was that of one Bohr magneton.

Bohr, also, has drawn attention to another possible illustration of the principle of the quantisation of orbits in space. It is known that all the rare gases do not exhibit the property of paramagnetism. From this fact the conclusion has been drawn that the atoms of these gases in their normal condition do not possess any angular momentum. According to the quantum theory, however, this conclusion may not be warranted, for we have seen that for an atom which has a finite angular momentum and, consequently, possesses a magnetic moment, the theory prescribes certain definite directions for the axis of momentum relative to a magnetic field in which the atom may be situated. If we assume that the atoms of the rare gases in a magnetic field can place themselves with their momentum axes perpendicular to the magnetic field, it follows that they could appear to be diamagnetic, and all indication of paramagnetism on their part would be absent. In this connection I may point out that Bohr has made the suggestion that evidence in support of the validity of this view is derivable from the results of an analysis, on the basis of the quantum theory, of the anomalous Zeeman effect shown by the rare gases.

One point that may be worthy of notice in dealing with phenomena associated with the principle of space quantisation is that the permitted orientations depend only on the values of the quantum number involved, and not on the magnitude of the magnetic field applied.

Orbits characterised by certain definite values of the quantum number should take up their permitted orientations in weak magnetic fields as well as in strong ones, provided the time allowed for the process to take place was ample, and provided suitable pressures were used and disturbances arising from the presence of contaminating gases were eliminated. Such conditions as these have recently been realised by Gerlach and Schutz,[45] and they have been able to obtain with sodium vapour at low pressures in the absence of foreign gases remarkably striking manifestations of the magnetic rotation of the plane of

[45] Gerlach and Schutz, *Die Naturwissenschaften*, vol. 11, Heft 28, p. 638, 1923.

polarisation of the light passing through the vapour with magnetic fields as low as a few tenths of a gauss.

This idea of space quantisation may perhaps throw some light on the interesting and suggestive experiments of R. W. Wood and A. Ellett [46] on the polarisation of the resonance light emitted by mercury and sodium vapours. In their experiments, it will be recalled, strong polarisation of the resonance light from mercury or sodium vapours could be produced by weak magnetic fields properly orientated. Moreover, they found that the polarisation of the resonance light emitted by these vapours in the presence of the earth's magnetic field could be destroyed by applying a magnetic field of less than one gauss provided it was suitably orientated. It is highly desirable that the experiments of Wood and Ellett should be followed up in order that sufficient information may be gained to enable us to elucidate the principles underlying the modifications in the polarisation of the resonance light observed by them.

It seems clear that atoms of sodium, for example, when excited by the absorption of resonance radiation would tend during the period of excitation to take up definite and characteristic orientations even in weak magnetic fields that would result in the polarisation of the resonance radiation emitted being different from that of the radiation emitted from atoms of the vapour situated in space in which absolutely no magnetic field existed. It should be remembered, too, that in the normal atom of sodium the orbit in which the valency electron is bound has the value 1 for its characteristic azimuthal quantum number k. When the atom is excited by the absorption of resonance radiation the azimuthal quantum number of the orbit, in which the valency electron becomes bound for a time, takes on the value 2. It seems clear then that the electronic orbit of the valency electron may be subject to different orientations relative to the rest of the atom when the atom is in the excited state from what it would be with the atom in its normal state. These relative orientations, moreover, would again be different in the presence of even a weak external magnetic field from what they would be in the complete absence of such a field. It is, therefore, quite conceivable that changes in orientation of electron orbits may be able to account for the phenomena observed by Wood and Ellett, but at present the whole matter appears to be rather involved and rather difficult to clear up with the information as yet available.

Quantum Theory and the Zeeman Effect.

Among the most fruitful of the principles utilised by Bohr in the development of his theory of radiation is the Adiabatic Hypothesis enunciated by Ehrenfest.[47] To this hypothesis Bohr has given the name the Principle of Mechanical Transformability. Numerous examples of the application of this principle might be cited, but the one that concerns us most here is that which deals with the effect of the establishment of a magnetic field on the electronic orbits in atoms. It

[46] **Wood and Ellett,** *Proc. Roy. Soc.*, **A, June 1923, p. 396.**

[47] Ehrenfest, *Die Naturwissenschaften*, vol. 11, Heft 27, July 6, 1923, p. 543.

is well known that Larmor has shown that one result of the establishment of such a field is to endow an electronic orbit with a uniform rotation about the direction of the magnetic field, the angular velocity being given by $\omega = \frac{1}{2} \frac{e}{m} \frac{H}{c}$. Langevin has also pointed out that the size and form of the electronic orbit remain unaffected by the magnetic field. Ehrenfest's hypothesis asserts that if the magnetic field be established slowly the energy of the electron in its orbital motion and the frequency of its revolution in the orbit may be changed, but the *number* of quanta defining its energy undergoes no modification. With the adoption of these principles it is an easy matter to show that when we quantise the angular momentum about the direction of the magnetic field the normal Zeeman components are exactly the same as those provided by the older classical theory of Lorentz. The singular beauty and simplicity of this method of explaining the normal Zeeman effect constitute one of the finest achievements placed to the credit of the quantum theory.

Efforts to explain the abnormal Zeeman effect have not as yet met with the same success. Among the contributions made to this subject perhaps that of Heisenberg [48] is the most stimulating and suggestive. In addition to offering an explanation of the abnormal Zeeman effect it constitutes an attempt to account for the doublet and triplet structure of series spectra.

Taking for example the case of an alkali element, Heisenberg postulates that through magnetic coupling a movement of rotation within an atom of these elements involves simultaneously the valency electron and the core of the atom as well. According to the theory it is supposed that in the various stationary states there is a partition of the angular momentum between the two, one-half an azimuthal quantum being assigned to the core and $k-\frac{1}{2}$ azimuthal quanta to the electron. The author supposes further that through space quantisation the two axes of rotation are in the same direction, and that the rotation of the core and that of the electron may take place either in the same sense or in opposite senses. As far as the radial quanta for the electronic orbits are concerned, it is assumed that they are given by $n'+\frac{1}{2}$ where n' has integral values. This device leads to the result that the total quantum number characterising the orbit of the electron is an integer n that is equal to the sum $k+n'$. In this way the author is enabled, at the same time, to characterise the spectral terms in the Rydberg series formulæ by integral quantum numbers.

This scheme, it will be noted, provides for the binding of the valency electron in one or other of two energy levels and reduces the frequency difference characterising the members of the doublet series of the spectra of the alkali elements to a manifestation of what is practically a Zeeman effect produced by an internal atomic magnetic field. To account for the triplet structure of series spectra such as we obtain with the alkaline earth elements, Heisenberg supposes the magnetic coupling

[48] Heisenberg, *Zeit. für Phys.*, No. 8, p. 257 and p. 273, 1922.

to involve not only the core of the atom but the two outer valency electrons as well. It is shown when the theory is extended to take account of an external magnetic field in addition to the internal one, that the Zeeman separations of the magnetic components of doublet and triplet lines are in exact agreement with the laws formulated by Preston and Runge.

When the external magnetic field is high compared with the internal one, the theory shows that for doublets and triplets the final result is a normal Zeeman triplet in complete accordance with the observations of Paschen and Back.[49]

To illustrate the validity of the theory Heisenberg used his formulæ to evaluate the magnitude of the internal magnetic field of the atoms of lithium, and found that it led to a value of 0.32cm^{-1} for the frequency difference characterising the doublets of the second subordinate series in the spectrum of this element. As the experimental value found by Kent[50] is 0.34cm^{-1}, it will be seen that the agreement is good.

Again, in connection with the matter of triplet series the theory shows that in the case of the p terms the ratio of the triplet frequency differences should be as 2:1, for the d terms it should be as 3:2, and for the f terms as 4:3. These deductions find ample verification in the measurements made on the frequency differences of triplet series in the spectra of such elements as magnesium, calcium, strontium, barium, zinc and cadmium.

To say the least, the theory outlined above is extremely suggestive. It leads, however, to rather surprising results. If we are to account for doublet separations generally as being due to Zeeman separations produced by intra-atomic magnetic fields, it follows that with some atoms these must be exceedingly high. Taking the doublet separations of the second subordinate series in the spectra of the alkali elements, we find the following values for the internal magnetic fields of the different atoms:—

Element	$\Delta\nu_p$	H_i
Lithium	0·34 cm^{-1}	7,173 Gauss
Sodium	17·18 ,,	366,744 ,,
Potassium	57·71 ,,	1,231,945 ,,
Rubidium	237·6 ,,	5,072,090 ,,
Cæsium	554·0 ,,	11,826,330 ,,

If it should turn out that magnetic fields so high as those given above are present in atoms of elements such as those in the alkali group, the results obtained by Wood and Ellett would be easily explained.

Whether the existence of a magnetic coupling between the valency electron and the atomic core justifies Heisenberg in adopting the artifice of partitioning the quanta of rotation between the electron and the atomic core is a debatable point.

It does not appear to be permissible to adopt the value $\frac{1}{2}$ for the azimuthal quantum number in defining the stationary orbits of a heavy atom such as that of uranium. In a recent paper by Rosseland,[51] in

[49] Paschen and Back, *Ann. der Phys.*, vol. 39, p. 897, 1912; vol. 40, p. 960, 1913.

[50] Kent, *Ast. Phys. Jl.*, vol. 40, p. 343, 1914.

[51] Rosseland, *Nature*, March 17, p. 357, 1923.

which a suggestion is put forward that the phenomenon of radioactivity exhibited by the heavier atoms may be due to some interaction between the nuclear and the external electrons in these atoms, he finds that the nearest approach of an electron to the nucleus in the atom of uranium according to Bohr's scheme of orbits is 16×10^{-12} cm. If the electronic orbit closest to the nucleus in the atom of uranium had $\frac{1}{2}$ for the value of its azimuthal quantum number, it would mean that the shortest distance of approach to the nucleus would be equal to 4×10^{-12} cm. As the radius of the nucleus of the atom of uranium has been shown to be 6.5×10^{-12} cm. it is evident that such an orbit could not exist. For reasons of this character we are practically precluded from assigning to k, the azimuthal quantum number, a value less than 1 in defining the electronic orbits in atoms.

In this paper an attempt has been made to outline some of the leading features of the quantum theory as it is being used to solve the problems of atomic structure as well as of those connected with the origin of radiations emitted by atoms. Other illustrations of special interest might have been drawn from the treatment of problems that have arisen in a study of band spectra[52] and of fluorescence phenomena.[53] The recent work of Cabrera,[54] Epstein,[55] and Dauvillier,[56] on paramagnetism, too, has a most interesting connection with the development of inner systems of electronic orbits in atoms in Bohr's scheme of the genesis of atoms.

I venture to think, however, that the few illustrations presented may serve, in a measure, to indicate the power and also the beauty of the methods being put forward to elucidate the problem of the origin of radiation.

[52] Kratzer, *Die Naturwissenschaften*, vol. 11, Heft 27, p. 577, 1923.

[53] Franck and Pringsheim, *Die Naturwissenschaften*, Heft 27, vol. 11, July 6, p. 559, 1923.

[54] Cabrera, *Jl. de Phys.*, t. 6, p. 443, 1922.

[55] Epstein, *Science*, vol. lvii., No. 1479, p. 532, 1923.

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SOME ASPECTS OF THE PHYSICAL CHEMISTRY OF INTERFACES.

ADDRESS TO SECTION B (CHEMISTRY) BY

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It was at the last meeting at Liverpool, in 1896, that I first had the honour of attending a gathering of the British Association. On that occasion Dr. Ludwig Mond, F.R.S., was President of Section B, and I shall never forget the interest and pleasure I felt in listening to the Address of that great master of science and scientific method. Little did I dream that in 1923 I should have the honour and privilege of occupying the Chair of Section B at Liverpool.

Looking back on the Liverpool Meeting of 1896, one can say now that it came at the dawn of a new era in the development of physico-chemical science. The X-rays had just been discovered by Röntgen. Perrin had proved experimentally (1895) that a negative electric charge was associated with the cathode rays and had surmised that these so-called 'rays' were constituted by electricity in motion, thus corroborating Crookes' brilliant views of a decade earlier and demonstrating that Lenard was wrong. Sir J. J. Thomson had just begun that splendid series of researches which resulted not only in the complete elucidation of the nature of the cathode 'rays,' but also in the discovery of the negative electron as a constant, universal, and fundamental constituent of all matter.

The discovery of the chemically inert elementary gases by Rayleigh and Ramsay had begun in 1894, and the series of investigations which finally led to the recognition of the radio-active transformations of atoms and to the discovery of the nature and constitution of the atom itself, were just beginning. During the last twenty-five years the influence of these discoveries on chemical science has been enormous. There has come about a fresh reunion of physics and chemistry, somewhat analogous to that which occurred in the days of Volta and Davy. During the two decades preceding 1896, physical science had been largely concerned with the phenomena of the 'ether,' with electric and magnetic fields, electromagnetic waves, and the identification of light and other forms of radiant energy as electromagnetic phenomena. Now that the physicists have brought physical science back to the close and intimate study of matter, physics and chemistry have come together again, and the old and homogeneous science of 'natural philosophy' has been reconstituted. It is time that the walls which divide our chemical and physical laboratories were broken down, and that the young men and women who come to our Universities to study physics *or* chemistry, should study the facts and principles of a fundamental science which includes both.

Since the last meeting of our Section a number of eminent men of science have passed away. It is with great sorrow that I record the deaths of Professor Sir James Dewar, F.R.S., in our own country, and of Professors E. Beckmann, J. P. Kuenen, G. Lemoine, L. Vignon, and J. D. van der Waals on the Continent. Limits of time and space forbid me to attempt here any account of the great services to science rendered by these eminent men. As the successor of Tyndall, Sir James Dewar worked for over forty years at the Royal Institution, and by his investigations on the liquefaction of gases and the physical and chemicial behaviour of substances at low temperatures, upheld the famous tradition of the Royal Institution as a home of pioneer research in science. Beckmann's name is well known for his researches on the effect of dissolved substances on the boiling- and freezing-points of solvents, and for the convenient form which he gave to the 'variable zero' thermometer. He also devised useful and convenient forms of apparatus required in spectroscopic work. Lemoine was one of the pioneers in the study of chemical reaction velocities and equilibria in France, whilst Vignon was well known for his researches in organic chemistry. Kuenen was at one time Professor of Physics at Dundee, although at the time of his death he had been for many years one of the Professors of Physics at Leiden. He was particularly noted for his investigations on the equilibria occurring in the evaporation and condensation of liquid mixtures. His death at a comparatively early age is a very heavy loss to science in general, and to Holland in particular. In van der Waals there passes away one of the very greatest men of science. He was one of that group of Dutch men of science, including Cohen, Lorentz, Kamerlingh Onnes, van't Hoff, Roozeboom, Schreinemakers, and Zeeman, who have made Holland so famous as a centre of physical and chemical research during the last thirty or forty years. Van der Waals was the great mathematical and physical interpreter of the work begun by Thomas Andrews.

In recent years a great deal of attention has been paid by chemists, physicists and physiologists to the phenomena which occur at the surfaces or interfaces which separate different sorts of matter in bulk. During the last quarter of the nineteenth century, both J. Willard Gibbs and J. J. Thomson had shown clearly, though in different ways, the peculiar nature of these interfacial or transitional layers. It was evident that things could happen in these regions which did not occur in the more homogeneous and uniform regions well inside the volume of matter in bulk. Such happenings might, if they could be investigated, reveal molecular or atomic peculiarities which would be undetectable in the jostling throng of individuals inside. A surface or surface layer represents a sort of thin cross section which can be probed and examined much more readily than any part of the inside bulk. It is indeed only within comparatively recent years that the X-rays have provided a sufficiently fine probe for examining this bulk in the case of crystalline matter.

The living organisms of plants and animals are full of surfaces and membranes. What can happen at surfaces is therefore a matter of great importance for the science of living things. We are bound to hold as long as possible to the assumption that the physico-chemical manifestations of life can be explained in terms of the potentialities of action inherent in electrons, atoms, and molecules. The drilled and disciplined soldiers of an army behave very differently from an undisciplined and disordered mob of the same men. Thus the modes of action of ordered arrays and marshallings of atoms and molecules are of extreme interest, since such modes of action will constitute phenomena non-existent in a disordered multitude of the same atoms and molecules with exactly the same individual powers and potentialities These phenomena may be intimately connected with the phenomena of living matter, and as the latter evidently require the existence of surfaces and membranes, the idea naturally suggests itself that the special arraying or ordering of individuals occurs at, and may start from, such surfaces.

An essential characteristic of this ordering or arraying may consist in *special orientation*. In the chemical and physical actions occurring in a volume of liquid whose bulk is large compared with its surface, the molecules or atoms probably move towards each other with every sort of orientation, no special type being privileged or distinguished. Should, however, some special orientation be characteristic of interfaces, then it is clear that such interfaces will exhibit new phenomena due to this special sort of arraying. Moreover, if we are dealing with molecules which are ionised into electrically polar constituents, or which, if not actually dissociated, can be treated as electrically bi-polar, it follows that, if orientation occurs at interfaces and surfaces, then electrical double layers and electrical potential differences may be set up at such boundaries.

In the theories of Laplace, Gauss, and Poisson the field of force surrounding an attracting element or molecule was regarded as essentially uniform in its spatial relations, *i.e.* the equipotential surfaces were regarded as concentric spheres with the molecule as a small element at the centre. The only way in which the molecule could show its character was in affecting the intensity of this central force at a given distance and the rate at which the force falls off with increasing distance. The molecules were thought of as possessing what one might call a very rounded and somewhat monotonous 'physical' personality or character as regards their fields of force. In recent years our views on such matters have undergone a somewhat radical transformation. The field of force surrounding a molecule may in reality be very 'irregular,' and may be specially localised around certain active or 'polar' groups Its region of sensible magnitude may be very variable and relatively small compared with molecular dimensions. The chemical constitution of the molecule is now regarded as determining the varying nature of the field of force surrounding it, so that parts of the molecule possessing high ' residual chemical affinity ' give rise to specially powerful regions of force. In this way the older ' physical ' theories of cohesion according to central forces with uniform orientation have been to some extent replaced, or at all events supplemented, by ' chemical ' theories according to which the attractive force-fields are highly localised round active chemical groups and atoms, are relatively minute in range, and can be saturated or ' neutralised ' by the atoms or groups of neighbouring or juxtaposed molecules.

Dr. W. B. Hardy has been the chief pioneer in the development of these newer theories, having been led thereto by his researches on surface tension, surface films, composite liquid surfaces and static friction and lubrication. As the matter is one of great importance, I shall take the liberty of giving two quotations from Hardy's scientific papers.

' The corpuscular theory of matter traces all material forces to the attraction or repulsion of foci of strain of two opposite types. All systems of these foci which have been considered would possess an unsymmetrical stray field—equipotential surfaces would not be disposed about the system in concentric shells. If the stray field of a molecule, that is of a complex of these atomic systems, be unsymmetrical, the surface layer of fluids and solids, which are close-packed states of matter, must differ from the interior mass in the orientation of the axes of the fields with respect to the normal to the surface, and so form a skin on the surface of a pure substance having all the molecules oriented in the same way instead of purely in random ways. The result would be the polarisation of the surface, and the surface of two different fluids would attract or repel one another according to the sign of their surfaces.' (Hardy, 1912.)

These ideas are even more clearly expressed in the following passage. ' If the field of force about a molecule be not symmetrical, that is to say, if the equipotential surfaces do not form spheres about the centre of mass, the arrangement of the molecules of a pure fluid must be different at the surface from the purely random distribution which obtains on the average in the interior. The inwardly directed attractive force along the normal to the surface will orientate the molecules there. The surface film must therefore have a characteristic molecular architecture, and the condition of minimal potential involves two terms—one relating to the variation in density, the other to the orientation of the fields of force.' (Hardy, 1913.)

Hardy thus bases the notion of molecular orientation at the surface on the existence of unsymmetrical fields of force surrounding the molecule; in other words, the parts of the molecule possessing the most powerful stray fields will be attracted inwards towards the bulk and thus cause a definite orientation of the whole molecule at the surface.

If γ_A be the surface tension of a liquid A, γ_B that of another practically immiscible liquid B, and γ_{AB} the interfacial tension at the interface A/B, then the quantity $W = \gamma_A + \gamma_B - \gamma_{AB}$ represents the decrease of free surface energy, and therefore the maximum work gained, when a surface of A is allowed to approach normally and touch a surface of B at constant temperature. Comparing different liquids A with water as a constant liquid B, Hardy has shown that the quantity W is extremely dependent on the chemical constitution of A, and is especially high when A contains the atomic groups characteristic of alcohols, acids, and esters. Thus, for such saturated substances as octane, cyclohexane, CS_2 and CCl_4, the values of W at ordinary room temperature lie between 21 and 24. Compare with these values the following:—

(*a*) Introduction of a hydroxyl group:—

Octyl Alcohol	46
Cyclohexanol	51.4

(*b*) Introduction of a carboxyl group:—

n—Caprylic acid . . .	46.4
Oleic acid	44.7

The natural inference from results such as these is that the cohesional forces are essentially chemical in origin and that they depend in large measure on the presence of ' active ' atoms or groups of atoms, namely those possessing strong fields of ' residual chemical affinity '; in other words, powerful and highly localised stray fields of electrical or electromagnetic force (or of both types). The existence of such atoms or atomic groups is strong presumptive evidence of the unsymmetrical fields of force postulated by Hardy and therefore of the molecular orientation at surfaces.

The conclusions drawn by Hardy have been amply confirmed by W. D. Harkins, and his collaborators, who in a long series of accurate measurements of surface and interfacial tensions have found that in the case of very many organic liquids the ' adhesional work ' towards water is greatly increased by the presence of oxygen atoms (as in alcohols, acids, and aldehydes). They find that the very symmetrical halogen derivatives CCl_4 and $C_2H_4Br_2$ (which possess specially high values for their own cohesional work) give markedly low values for their adhesional work towards water, and that in the case of unsymmetrical molecules, the adhesional work towards water is determined by the presence of certain active atoms or atomic groups.

In his work on static friction and lubrication, Hardy has found that the influence of chemical constitution and the effects of active atomic groups are very pronounced. This, comparing aliphatic or open chain compounds, the co-efficient of static friction falls (and the lubricating power increases) as we pass through the series hydrocarbon—alcohol—acid. The corresponding ester is in this case a much worse lubricant than the related acid or alcohol. These results suggest, as Hardy has indicated, that friction is caused by the molecular cohesion of surfaces, and that in the action of such lubricants the molecules are oriented with their long axes normal to the surface, whereby the active atomic groups play an important part in ' taking up ' or saturating a portion of the stray force-fields of the molecules of the solid surfaces, and in orienting and anchoring the lubricant molecules to these surfaces. Many facts lend strong support to Hardy's views. Thus it is true, I believe, that the addition of aliphatic esters improves the lubricating value of hydrocarbon oils, whilst H. Wells and W. Southcomb have demonstrated the marked improvement due to a small addition of a fatty acid. In this connection it is interesting to note that W. E. Garner and S. S. Bhatnagar have recently shown in my laboratory that the interfacial tension between mercury and B.P. paraffin oil is markedly lowered by small additions of oleic acid. The oleic acid molecules are therefore absorbed or concentrated at the mercury-oil interface, an action which may well be due in part to the fixation and orientation of these molecules at the metal-oil interface.

This question of the orientation of molecules at the surfaces of liquids has been greatly extended in recent years by a detailed study of the extremely thin and invisible films formed by the primary spreading of oily substances on the surface of water. In a continuation and development of the work of Miss Pockels, the late Lord Rayleigh showed many years ago that when olive oil forms one of these invisible films on water, there is no fall in surface tension until the surface concentration reaches a certain very small value. He made the highly interesting and important suggestion that this concentration marks the point where there is formed a continuous layer just one molecule thick. In the case of olive oil, he found this critical thickness to be 10^{-7} cm., and concluded that this number represented the order of magnitude of the diameter of a molecule of the oil. Increase in surface concentration beyond this point causes the surface tension to fall, until a second point is reached, after which no further fall in surface tension occurs. Lord Rayleigh assumed that at the second point a layer two molecules thick is formed. This pioneer work of Lord Rayleigh was repeated and extended by H. Devaux and A. Marcelin, who showed the correctness of his first suggestion, namely that the primary film consists of a *unimolecular* layer. It appears, however, that the fall in surface tension which he ascribed to the building up of a bimolecular layer, must be ascribed to the closer packing of the molecules of the unimolecular layer, and that the second point occurs when these molecules are packed as tightly as possible.

Instead of varying the surface concentration by adding more and more of the oily substance to a definite surface, we may attain the same end by means of a moving boundary and a variable surface, and study the relation between the force of surface-compression (difference between the surface tension of pure water and that of the contaminated surface) and the surface concentration. This method was greatly developed by Devaux. Although these researches had firmly established the theory of the formation of a unimolecular surface layer and therefore of the existence of a *new 'two dimensional'* phase of matter, we owe it to I. Langmuir to have made a very important advance by connecting this conception with the ideas of chemically active groups and molecular orientation. Influenced, no doubt, by the ideas of Hardy, Langmuir reasoned that the formation of these primary unimolecular films must be due to the presence of active groups in the molecules, which are attracted inwards towards the water and thus cause the long open chain molecules of the fatty acids to be oriented on the water surface with their long hydrocarbon axes vertical and side by side.

Working by means of the method of Devaux, Langmuir put these ideas to the test of experiment, and determined the internal molecular dimensions of a unimolecular layer. The following is an excerpt from the results which he published in 1917:—

—	Molecular Cross Section (S) (sq. cms.)	$\sqrt{S}$	Molecular Length (cms.)	Length per C atom (cms.)
Palmitic Acid . .	21×10^{-16}	$4{\cdot}6\times10^{-8}$	$24{\cdot}0\times10^{-8}$	$1{\cdot}5\times10^{-8}$
Stearic Acid . . .	22×10^{-16}	$4{\cdot}7\times10^{-8}$	$25{\cdot}0\times10^{-8}$	$1{\cdot}4\times10^{-8}$
Cerotic Acid . . .	25×10^{-16}	$5{\cdot}0\times10^{-8}$	$31{\cdot}0\times10^{-8}$	$1{\cdot}2\times10^{-8}$

It is at once evident that these results agree in a wonderful manner both with the idea of a unimolecular layer and with that of molecular orientation. The molecular cross section is practically constant, as we should expect, since it must represent the cross section either of a carboxyl or CH_3 group. Since the molecular length is determined from the thickness of the layer, and is found to be five or six times the value of $\sqrt{S}$ (molecular 'thickness'), we perceive here the first actual experimental proof of the theory of molecular orientation. Another fact of great significance emerges from these results. If we calculate the average distance between two adjacent carbon atoms in the three acids, we obtain a value of 1.4×10^{-8} cm. Now this distance must be of the order of magnitude of the distance between the centres of the carbon atoms in the crystal structure of a diamond. This latter distance is known to be 1.52×10^{-8} cm. The agreement is striking.

These regularly oriented and unimolecular surface films on water have been recently investigated in a very detailed and careful manner by N. K. Adam, who has improved the method employed by Devaux and Langmuir. From a closer analysis of the relationship between the force of surface compression and the surface concentration (expressed as area occupied per molecule) he has shown that a distinction must be made between the close packing of the polar or active end groups (head groups) of the molecules and the subsequent close packing of the hydrocarbon chains. The following table contains a few of Adam's results for the higher aliphatic acids:—

—	No. of C atoms	Cross Section (sq. cms.) $\times10^{16}$		Approx. Length (cms.) $\times10^{8}$
		Chain	Head	
Myristic Acid . .	14	21·0	25·1	21·1
Pentadecylic Acid . .	15	21·0	25·1	22·4
Stearic Acid . . .	18	21·0	25·1	26·2
Behenic Acid . .	22	21·0	25·1	31·4

Although these results must be considered as more accurate and detailed than those of Langmuir, they provide an ample confirmation of the theory of unimolecular films of juxtaposed and oriented molecules. If we calculate the average distance between two carbon atoms for the four acids, we obtain the following results:—

	Distance (cms.) $\times 10^8$
Myristic Acid	1·6
Pentadecylic Acid	1·6
Stearic Acid	1·5
Behenic Acid	1·5

As pointed out before, these values do not deviate much from the value for the distance between the carbon atom centres in the diamond (1.52×10^{-8} cm.). Too much stress cannot, however, be laid on this point, since in calculating the lengths of the oriented carbon chains an assumption has to be made regarding the density of the film, because only its area and mass are given directly by experiment.

Concerning this point some very interesting results have been recently obtained in Sir William Bragg's laboratory by Dr. A. Müller. In these experiments layers of crystallised fatty acids on glass plates have been examined by an X-ray photographic method. From these results it appears that the unit cell is a long prism, the cross section of which remains constant for the substances investigated, whilst the length of the prism increases linearly with the number of carbon atoms in the molecule. The increase in length of the unit prism per carbon atom in the molecule is found to be 2.0×10^{-8} cm. Since it appears likely that there are *two* molecules arranged along the long axis of each unit cell (prism), it would follow that the increase in the length of the molecule per carbon atom added is 1.0×10^{-8} cm. Comparing this result with the value for the distance between the carbon centres in the diamond lattice, it would appear that the carbon atoms in the long hydrocarbon chains of the higher saturated fatty acids are arranged in a zig-zag, or more probably in a spiral or helix. If this be the case, the closer packing or compression of the juxtaposed molecules in the unimolecular films, as revealed in the investigations of Devaux, Langmuir, and Adam, may be to some extent explained by the straightening out of these zig-zags, or perhaps by the 'elastic compression' of the helices.

As pointed out by Langmuir, the question of the formation of unimolecular surface films can be attacked in a different manner. It is known that gases or vapours can be condensed or adsorbed by solid and liquid surfaces. The question then arises, does the formation of primary unimolecular films ever occur in such cases? It will be recollected that Hardy made the suggestion that the formation of the primary unimolecular film in the spreading of oily substances on water might be due to adsorption from the vapour. In order to examine this question, Mr. T. Iredale has recently measured in my laboratory the fall in the surface tension of mercury caused by exposing a fresh mercury surface to vapours of increasing partial pressure. The excess surface concentration q of the adsorbed vapour can then be calculated by means of Gibbs' formula

$$q = -\rho \frac{d\gamma}{dp}$$

where γ = surface tension, and ρ and p denote the density and partial pressure of the vapour respectively. Working with the vapour of methyl acetate, Iredale found in this way that at a temperature of 26° C. and a partial pressure of 62 mm. of mercury, $q = 4.5 \times 10^{-8}$ grm. per square centimetre of surface. From this result we can readily calculate that there are 0.37×10^{15} molecules of methyl acetate adsorbed per square cm., and that the area per molecule is 27×10^{-16} sq. cm. As under the conditions corresponding to this calculation the molecular surface layer was probably not quite saturated (in the unimolecular sense), we may expect the value found to be of the same order of magnitude but somewhat greater than the values found by Adam for the cross section of the head group of the higher saturated fatty acids (25×10^{-16}) and of the esters (22×10^{-16} for ethyl palmitate and ethyl behenate). We may, therefore, say that Iredale's results appear to indicate the formation of a primary unimolecular layer built up by adsorption from the vapour phase.

Langmuir has measured the adsorption of a number of gases at low temperatures and pressures on measured surfaces of mica and glass, and has arrived at the conclusion that the maximum quantities adsorbed are always somewhat less than the amounts to be expected in unimolecular surface layer. E. K. Carver, who has measured the adsorption of toluene vapour on known glass surfaces, has arrived at a similar conclusion. The view that the *maximum* adsorption from the gas phase cannot exceed a unimolecular layer has, however, been much criticised. Thus, for example, M. E. Evans and H. J. George, on the basis of their own measurements on the adsorption of gases on a known surface of glass wool, combined with the data obtained by Mülfarth, have concluded that the adsorption layer may be several (and in some cases many) molecules thick. It may well be that the formation of a unimolecular 'saturation' layer only occurs in the case of molecules with relatively very active atoms or atomic groups, whose strong localised fields of force suffice to produce powerful attraction and orientation and an almost complete saturation of the 'stray' fields of the surface molecules of the adsorbing surface, especially when the thermal temperature agitation is sufficiently small. In the case of molecules with weaker or more symmetrical fields of force, there may be relatively little orientation, and an extension of the attraction field of the adsorbent through layers of the adsorbate many molecules thick. It would be rash to theorise too much on this subject until more data are accumulated, but it may be pointed out that in his investigations on the spreading of surface films and on the theory of lubrication, Hardy has been led to distinguish between primary spreading (primary unimolecular films) and secondary spreading (secondary relatively thick sheets).

Let us now consider another type of formation of surface layers at the surfaces of liquids—namely, the case where a substance dissolved in a liquid concentrates preferentially at the liquid-air or liquid-vapour interface. Gibbs, and later J. J. Thomson, have shown that if a dissolved substance (in relatively dilute solution) lowers the surface tension, it will concentrate at the surface. That such a phenomenon actually occurs has been qualitatively demonstrated in the experiments of D. H. Hall, J. von Zawidski, and F. B. Kenrick and C. Benson, by the analysis of foams and froths. In 1908 S. R. Milner used the same method in the case of aqueous solutions of sodium oleate, and arrived at a mean value of 1.2×10^{-10} gram mols. excess concentration per sq. cm. of surface. Now, in the case of dilute solution, we can calculate q, the amount concentrated or 'adsorbed' in the surface per sq. cm. (excess surface concentration) by making use of the equation of Gibbs,

$$q= -\frac{d\gamma}{d\mu}$$

where γ =surface tension and μ=chemical potential of the adsorbed substance in the bulk of the solution. Writing $\mu = \text{RT} \log a + k$, where a='activity' of the solute, and k is a quantity dependent only on the temperature and nature of the solute and solvent, $d\mu$=R T d log a, and so Gibbs' equation can be written in the form

$$q= -\frac{1}{\text{RT}}\frac{d\gamma}{d \log a}.$$

If for very dilute solutions (or for so-called 'ideal' solutions) we put $a=c$, we can write

$$q= -\frac{1}{\text{RT}}\frac{d\gamma}{d \log c}= -\frac{c}{\text{RT}}\frac{d\gamma}{dc}.$$

In this way Milner has calculated from Whatmough's data for aqueous solutions of acetic acid that the 'saturation' value of q is 3.3×10^{-10} mols. per sq. cm., from which it follows that the area per molecule in the surface is 50×10^{-16} sq. cm. In a similar manner, Langmuir has calculated from B. de Szyszkowski's data for aqueous solutions of propionic, butyric, valeric, and caproic acids that the surface area per molecule adsorbed in the saturated layer is equal to 31×10^{-16} sq. cm., whilst Harkins has arrived from his own measurements for butyric acid at the value 36×10^{-16} sq. cm.

In 1911 Dr. J. T. Barker and myself made a direct determination of q for a solution of nonylic acid in water. For a practically saturated surface layer it was found that q was about 1.0×10^{-7} grm. per sq. cm., or 3.1×10^{14} molecules per sq. cm. From this result it follows that the surface area per molecule is 26×10^{-16} sq. cm.

If we consider these various values, it will be at once evident that they are not very different from the values found by Langmuir and by Adam for the oriented unimolecular layers of practically insoluble fatty acids resting on the surface of water. That in the present case some of the values are larger might easily be explained on the ground that these adsorption layers are partially, or completely, in the state of 'surface vapours.' For Adam and Marcelin have recently made the important discovery that the unimolecular surface films investigated by them may pass rapidly on increase of temperature from the state of 'solid' or 'liquid' surface films to the state of 'vaporised' surface films, in which the juxtaposed molecules become detached from each other and move about with a Brownian or quasi-molecular motion, probably communicated to them by the thermal agitation of the water molecules to which they are attached.

It is, indeed, highly probable that the molecules which are concentrated in the surface from the state of solution in the liquid phase are not in quite the same situation as the molecules of practically insoluble substances which are placed *on* the surface. In the former case the molecules are still 'dissolved,' so that they will be more subject to thermal agitation and less able to form a juxtaposed unimolecular layer. They may also be 'hydrated.' The difference between the two cases is rendered very evident from the fact that in the production of surface layers from dissolved molecules of the fatty acids (and other 'surface active' substances) there is a very marked fall of surface tension, whilst the uncompressed unimolecular surface films placed on the surface from outside do not affect the surface tension of the water. Thus the molecules of the surface-active substance in the former case are in much closer relation to the solvent molecules, and are in kinetic equilibrium with the molecules of both solvent and solute in the bulk of the liquid. Nevertheless, the agreement as regards order of magnitude in the values of the surface area per molecule in the two types of case is certainly very suggestive and significant. Moreover, the experiments of Mr. Iredale show that molecules which are adsorbed on the surface from the vapour phase lower the surface tension, and are therefore from this point of view comparable with molecules concentrated in the surface from the bulk of the liquid phase.

The question as to whether the simplified form of Gibbs' equation yields a sufficiently accurate value for the excess surface concentration can scarcely be decided without more experimental data. In the experiments made by Dr. Barker and myself, the values calculated from the surface tension-concentration curve were 1.3×10^{-7} and 0.6×10^{-7} grm. per sq. cm., according as the value of the van't Hoff factor i for the very dilute solutions of nonylic acid was taken as 1 or 2 respectively; whilst the corresponding directly determined value was about 1.0×10^{-7} grm. per sq. cm. This discrepancy was probably well within the experimental error of our measurements.

Let me now direct your attention to another very interesting phenomenon relating to the surfaces of liquids and solutions—namely, the existence of an electrical potential gradient or potential difference in the surface layer. These interfacial potential differences are of great importance, and play a fundamental rôle in determining the stability or instability of many colloidal states of matter. The liquid-gas interface offers the simplest case of such interfaces, and so the investigation of the potential differences which may exist at this interface is a matter of fundamental interest. In 1896 F. B. Kenrick developed, on the basis of earlier experiments of Bichat and Blondlot, an electrometric condenser method for the comparative determination of the gas-liquid P.D.'s. The results which he obtained show that substances (such as the aliphatic alcohols and acids) which concentrate at the surface produce a very great change in the surface P.D., whilst highly dissociated univalent inorganic salts, such as KCl, do not. The results obtained by Kenrick have been much extended by an investigation carried out with the same type of apparatus by Professor Thorbergur Thorwaldson in my laboratory. The general result of these experiments can be described in the following terms:—

Consider the system:

Aqueous Solution of KCl (conc. $=c$) A	Air	Aqueous Solution of KCl (conc. $=c$) B

The positive potential of A will be equal to that of B. If we now add to the solution B a small quantity of a substance S (generally a non-electrolyte or weak electrolyte) which has a strong tendency to concentrate at the air-B interface, it is found that the positive potential of A rises markedly above that of B, the value of the quantity, positive potential of A minus that of B, varying with the concentration of S in the way that is characteristic of adsorption phenomena. What is the interpretation of this phenomenon? If we were to assume that there was practically no P.D. at the interface A-air, it would follow that the effect of S is to make the positive potential of the bulk of B markedly below that of the air. The same result would follow if we were to assume that at the interface A-air there exists a P.D. which makes the positive potential of the bulk of A markedly below that of the air outside. Both these assumptions would lead to the conclusion that in the surface layer of the solution at the A-air interface there must exist either no electrical double layer, or else one with its *positive* half oriented towards the air side. Now Quincke has shown that a bubble of air in water placed in an electrical potential gradient travels towards the anode—*i.e.* the bubble behaves as if it were negatively charged. From this it would follow that the P.D. at the air-water interface is such that the *negative* half lies towards the air side. As an electrolyte such as KCl is negatively adsorbed at an air-liquid surface, it is probable that a P.D. of the character indicated by Quincke's experiment exists at the A-air interface. If we accept this conclusion, it follows that the effect of S is markedly to *reduce* this P.D. (or to reverse it). Now the P.D. at the air-water interface is probably due to the existence of a double layer containing hydroxyl ions on the outside and hydrogen ions on the inside, or to oriented water molecules regarded as electrical bi-poles. If S is a non-electrolyte (or a substance which possesses little self-ionisation), we can understand why its concentration at the surface could result in the reduction of this P.D.

The experiments of Thorwaldson show that a substance such as the hydrochloride of methyl violet has a powerful effect on the P.D. at the air-water interface. It is probable that in this case the complex basic dye cation is drawn into, or 'adsorbed' in, the outside layer next to the air, the result of this being a reduction or possibly reversal of the original potential difference.

Kenrick found that if gases such as hydrogen and coal gas be substituted for air, there is no effect on the surface P.D.

Within the last few years H. A. McTaggart has made a number of experiments on the electric cataphoresis of gas bubbles in aqueous solutions and other liquids. He finds that aliphatic acids and alcohols in aqueous solution reduce the surface P.D. and that this effect runs parallel with their influence on the surface tension of water. He also finds that acids reduce the P.D. These results may be regarded as a corroboration of those obtained by Kenrick. McTaggart has found that the nitrates of tri- and tetravalent cations have a powerful effect in not only reducing but reversing the P.D. (*i.e.* the bubble becomes positively charged). His experiments also show that polyvalent negative ions, such as the ferrocyanide ion, act in the opposite direction to the polyvalent cations—*i.e.* they increase the negative charge on the bubble or diminish a previously existing positive one. These results are of great interest, inasmuch as they show the powerful effects produced by polyvalent ions on the P.D. existing in the surface layer of an aqueous solution. As we shall see presently, very similar results have been obtained at liquid-liquid and solid-liquid interfaces. But it is of great importance to know what happens at the air-liquid interface, since we can largely discount the chemical and physical influence of the gas phase.

Although the electrometric method employed by Kenrick and Thorwaldson only gives comparative results (since two interfaces must always be simultaneously used), whilst the cataphoresis method gives results for a single interface, it is necessary to observe that the electrometric method measures the *total* fall of potential from the bulk of one phase to the bulk of another. The cataphoresis method measures what Freundlich has called the 'electrokinetic' P.D.—that is to say, the potential drop between the limiting surface of the 'fixed' part of the double layer and the rest of the liquid. The two values need not necessarily coincide.

When liquids are sprayed or splashed, or when gases are bubbled through liquids, it is known that the gas often acquires an electrical charge, whilst the liquid acquires an opposite one (so-called 'waterfall' electrification). Since the pioneer work of Elster, Lenard, J. J. Thomson, Kelvin, Maclean, and Galt, very many investigators have dealt with this subject (Eve, Christiansen, Bloch, de Broglie, Zwaardemakers, Coehn, &c.). Originally, Lenard thought that the effect was due to a 'contact electrical' action between the gas and the liquid, whilst J. J. Thomson was inclined to ascribe it to a sort of partial chemical action between them. It is known that there are produced in the air or gas relatively slow-moving carriers, both positive and negative. Lenard has quite recently changed his views, and ascribes the origin of these carriers to the tearing off of very small portions of the outside layer of the electrical double layer existing in the surface of the liquid. It may be mentioned that Kenrick, Thorwaldson, and McTaggart came to the conclusion that the surface P.D.'s measured by them were not connected, or at all events not connected in any simple manner, with the phenomena of waterfall electrification.

We may say, therefore, that if there be a relation between these two types of phenomena, it is a complicated and still largely obscure one.

The subjects which I have been discussing have an interesting bearing on the formation and stability of foams and froths. If air be violently churned up with water, only comparatively large bubbles are produced, and these quickly rise to the surface and burst. If now a very small quantity of a substance which concentrates at the air-water interface be added, an almost milk-white 'air emulsion' of small bubbles is produced, which rise to the surface and produce a relatively durable froth. These phenomena were discussed by the late Lord Rayleigh in a very interesting Royal Institution lecture on 'Foam.' It is clear that the diminution in interfacial tension facilitates the subdivision or dispersal of the air. The existence of the surface layer will also confer a certain amount of stability on the resultant froth, since it will give rise to forces which resist the thinning of a bubble wall. Any sudden increase in the surface will produce a momentary diminution in the concentration or 'thickness' of the surface layer, and hence a rise in surface tension, which will persist until the normal thickness or concentration is readjusted by diffusion of molecules from the inside volume—a process which in very dilute solution will occupy a perceptible time. That this explanation (due to the late Lord Rayleigh) is the correct one can be seen from the fact that very often stronger solutions of the same surface-active substance scarcely foam at all. In this case the readjustment of the equilibrium thickness or concentration of the surface layer occurs with such rapidity (owing to the greater concentration of the molecules in the inside volume) that practically no rise in surface tension, and hence no counteracting force, comes into play. These effects will be the more pronounced—other things being equal—the greater the mass and hence the smaller the motion of the solute units, as in the case of large molecules or colloidal micelles. It is probable, however, that the explanation of the stability of very durable forms, as, for example, those produced by the sea at the sea coast, by beer and stout, by aqueous solutions of soap or saponin, &c., is often more complex, and that we must seek it in the formation of very viscous or semi-rigid or gel-like membranes at the interface. Moreover, small solid particles may contribute to the stabilisation of a froth, as in the case of the 'mineralised froths' of the ore flotation process; and the preferential aggregation of small particles in the interface between two phases has been demonstrated in the experiments of W. Reinders, F. B. Hofmann, and many others.

Let us now inquire how far the phenomena which we have seen to be characteristic of a gas-liquid interface occur also at the interface between two immiscible or partially miscible liquids. Many years ago it was shown by Gad and by Quincke that a fatty oil (such as olive oil) is very readily dispersed in the form of an emulsion by a dilute solution of caustic soda. Some experiments which I once made showed that a neutral hydrocarbon oil could be similarly emulsified in a dilute aqueous solution of alkali if one of the higher fatty acids was dissolved in it, whilst the lower fatty acids do not produce a similar action. It was shown that the action runs parallel to the lowering of interfacial tension and must be ascribed to the formation of a soap, which lowers the interfacial tension and concentrates at the interface. These phenomena have have been further investigated by S. A. Shorter and S. Ellingsworth, by H. Hartridge and R. A. Peters, and by others.

If a substance which is dissolved in one liquid A, and which is practically insoluble in another liquid B, is found to have, in very dilute solutions, a strong effect in lowering the tension at the interface A-B, the following interesting questions arise:—

(1) What is the amount of the surface concentration or adsorption per sq. cm. of interface?

(2) Can it be calculated by means of the simplified Gibbs equation?

(3) How does the surface adsorption vary with the concentration?

(4) Does the 'saturation' value correspond to the formation of a unimolecular layer?

Some of these questions were experimentally investigated in my laboratory by W. C. McC. Lewis. For the liquid A water was chosen, and for B a neutral hydrocarbon oil. Working with sodium glycocholate as the surface-active subtance, it was found that the experimentally measured surface adsorption q was much greater than that calculated by means of the equation

$$q = -\frac{c}{RT}\frac{d\gamma}{dc}.$$

For example, a 0.2 per cent. aqueous solution at 16° C. gave a directly measured value of $q = 5 \times 10^{-6}$ grm. per sq. cm., whilst the calculated value was 5×10^{-8} grm. per sq. cm., practically a hundred times smaller. A similar type of discrepancy was found in the cases of Congo Red and methyl orange. If we calculate from the experimentally found surface adsorption of sodium glycocholate the value of the surface area per molecule, we obtain about 0.9×10^{-16} sq. cm. A similar calculation in the case of Congo Red gives a correspondingly low figure. Now if we compare these values with those previously obtained for the air-liquid surface, it is clear that in the present case we are not dealing with simple unimolecular layers, but with adsorption layers or films many molecules thick. On the other hand, if we calculate from Lewis' results the surface area per molecule as deduced from the surface tension measurements by the simplified Gibbs formula, we arrive at values of the order of 90×10^{-16} (sodium glycocholate) and 100×10^{-16} (Congo Red). These are values which are consistent with the gradual building up of a unimolecular layer (of possibly heavily hydrated molecules or micelles). It is possible, therefore, that the Gibbs equation gives the surface concentration of the primary unimolecular 'two dimensional' surface phase, and that any building up of further concentrations beyond this layer does not affect the surface tension. It is true that in the case of substances such as sodium glycocholate, and especially Congo Red, in aqueous solution, there is a considerable amount of uncertainty as to the nature and molecular weight of these substances as they exist, not only in the bulk of the solution, but especially in the surface phase. In a later investigation Lewis determined the surface adsorption of aniline at the interface mercury-aqueous alcoholic solution, and found in this case a very fair agreement between the observed and calculated results. This case is more favourable, since we can be in little doubt concerning the molecular weight of the solute units. The mean observed value for the surface adsorption was

2.7×10^{-8} grm. per sq. cm. Hence the number of molecules per sq. cm. of interface

$$=\frac{2{\cdot}7}{93}\times 10^{-8}\times 6{\cdot}06\times 10^{23}=0{\cdot}17\times 10^{15},$$

and the surface area per molecule $=58 \times 10^{-16}$ sq. cm. Langmuir's calculation from Worley's measurements of the surface tensions of aqueous solutions of aniline gives at the air-water surface the value 34×10^{-16} sq. cm. for the area per molecule of aniline. We may conclude, therefore, that Lewis' measurements in this case point to the building up of a primary unimolecular layer, unaccompanied by any further concentration or 'condensation' of molecules or colloidal micelles.

The relation between surface adsorption and fall of interfacial tension at a mercury-water interface was further investigated by W. A. Patrick, who concluded that, although there was a correspondence between the two phenomena, the surface adsorption could not be calculated from the simplified Gibbs equation. If we were to accept this conclusion as correct, we might find an explanation either in the suggestion made above, or in the possible invalidity of conclusions drawn from the use of the simplified Gibbs equation; either because the simplifications introduced are not justified, or because the existence of electrical or other factors requires an extension or elaboration of the original equation. This matter has been discussed by Lewis, by A. W. Porter, and by various investigators of electro-capillary phenomena.

From very accurate measurements of the interfacial tensions of the aqueous solution-mercury interface, W. D. Harkins has calculated (by means of the simple Gibbs equation) that when the interface is saturated as regards butyric acid molecules coming from the aqueous solution, the surface area per molecule is 36×10^{-16} sq. cm.

Here, again, we see that a calculation by means of the Gibbs equation seems to point to the formation of a primary unimolecular layer. Experiments similar to those of Lewis have been very recently made by E. L. Griffin, who has measured directly the adsorption of soaps from aqueous solutions at a mineral oil-water interface. The results obtained are as follows:—

Substance	Average Surface per Molecule adsorbed
Sodium Oleate	48×10^{-16} sq. cm.
Potassium Stearate	27×10^{-16} sq. cm.
Potassium Palmitate	30×10^{-16} sq. cm.

These figures are very interesting, for they would appear to indicate the formation of unimolecular surface layers. It may be mentioned here that T. R. Briggs has investigated the adsorption of sodium oleate at a benzene-water interface, and finds that the amount of soap adsorbed at the interface increases rapidly at first with small increases in the concentration of the solution, and then remains very nearly constant while the concentration of the solution undergoes great increase. This is just what one would expect from the building up of a saturated surface or surface layer (whether unimolecular or otherwise).

We have seen that in the case of the air-water surface there exists an electrical separation or potential difference in the surface layer, and that certain substances can produce pronounced variations, or even reversals in sign, of this electrical double layer. It becomes a matter, therefore, of great interest to inquire whether similar phenomena occur at the interface between two immiscible liquids, and, if so, to ascertain whether such electrical charges or double layers bear any relation to the 'stability' of pure emulsions, or fine dispersions of one liquid in another. It is well known that those disperse or finely heterogeneous states of matter known as colloidal solutions depend in part for their stability on the existence of such electrical potential differences. We might expect, therefore, that an investigation of these emulsion systems would throw some light on the general theory of what are called 'suspensoid' or 'lyophobic' colloidal states. Investigations with these objects in view were carried out some years ago in my laboratory by R. Ellis and F. Powis. The method employed was to measure directly by means of a microscope the motion of minute globules (suspended in water) under the influence of a known electric field. This procedure may be regarded as an extension and development of the work of Quincke. From the measured velocity and potential gradient the interfacial P.D. and the electrical charge can be calculated from the theories of Helmholtz, Lamb, and Stokes. The microscopic method has the advantage that the P.D. between the aqueous solution and the glass wall (cover glass or object glass) can be simultaneously determined It is a remarkable fact that the P.D. between various types of hydrocarbon oils (purified from acid as far as possible) and water was found to be 0.045—0.053 volt, the oil being negative—that is to say, the oil droplet moving towards the anode. If we compare this with the value recently calculated by McTaggart for the P.D. between an air-bubble and water (deduced from a precisely similar type of measurement), namely 0.055 volt, we can draw the conclusion that the potential difference is due to an electric double layer residing in *the surface layer of the water*. The oil droplet moves, therefore, with an attached negative layer or surface sheet, probably determined by hydroxyl ions, this being balanced by a positive layer whose charge is determined by hydrogen ions. If hydrochloric acid be added to the water the interface P.D. rapidly falls, and appears asymptotically to approach zero. If, on the other hand, caustic potash be added, the P.D. at first rises, reaches a maximum at a concentration of about one thousandth molar, and then falls with increasing concentration, but nothing like so sharply as in the case of the acid. Similar results hold good for the glass-water interface. From the results recently obtained by H. R. Kruyt (by means of the stream method) it is probable that at very low concentrations of acid there also occurs an initial increase in the interfacial P.D. The influence of salts is very remarkable. Thus at low concentrations potassium chloride and potassium ferrocyanide increase the P.D., whilst at higher concentrations they reduce it, just as in the case of the acid and the alkali. The initial increase caused by potassium ferrocyanide is markedly greater than that caused by potassium chloride. The effect of the valency of the salt cation is very pronounced. Thus barium chloride at very low concentrations probably causes a very small rise of the P.D., but at quite low concentrations its effect is to reduce it, and this effect increases rapidly with rising concentration, and is much more marked than in the case of potassium chloride. The lowering effect of aluminium chloride at low concentrations on the P.D. is much more pronounced than in the case of barium chloride, and this effect becomes still greater with thorium chloride. Both aluminium chloride and thorium chloride at low concentrations *reverse the sign* of the P.D., the oil side of the double layer becoming positive. In these cases the positive charge of the oil droplet reaches a maximum with increasing concentration of the salt, and then appears to fall slowly towards zero. No second reversal of sign has ever been observed. So far as the solid-liquid interface is concerned, these results have been in general confirmed by the electroendosmotic experiments of G. v. Elissafoff (carried out in Freundlich's laboratory) and by the stream-potential measurements of Kruyt. It may also be remarked that Loeb has recently obtained similar results in the case of collodion particles, using the micro-cataphoresis method. Perhaps the most remarkable result which has emerged from these electrical investigations of oil suspensions is the relation between the stability of the emulsion and the potential difference of the interfacial double layer. The minute oil globules are in constant Brownian motion and must frequently collide. Why do the forces of cohesion not produce agglomeration or coalescence (coagulation or clearing of the emulsion)? We should expect that under determinate conditions a certain fraction of these collisions would give rise to coherence. Is there any other factor besides orientation of path and kinetic energy which affects the probability of coherence following an encounter? At distances great in comparison with their own dimensions the electric double layers will act practically as closed systems. But when two oil drops approach sufficiently near each other the conditions will be different, since we must expect a repulsive force when two similarly charged outer layers just begin to interpenetrate each other. Hence the answer to the question asked above is that the third factor is the potential difference or electric density of the interfacial double layer. Other things being equal, the probability P of an encounter leading to coherence will be a diminishing function of the electric intensity π of the similarly constituted double layers, *i.e.* $\frac{dP}{d\pi}$ will be negative. Hence of the total number of encounters in a given small period of time the number which lead to coherence should be a maximum at the point of zero potential difference (iso-electric point of Hardy).

Now the experiments of Powis brought out the very important fact that when the interfacial P.D. (whether positive or negative) is above a certain value, which was about 0.03 volt for his conditions, the rate of coagulation or coherence of the oil drops is relatively small, but rapidly increases when the P.D. falls inside the zone -0.03 to $+0.03$ volt. Under definite conditions there exist, therefore, what we may, speaking broadly, call a *critical potential* and a *critical potential zone.* When the P.D. is outside this zone the emulsion is comparatively very 'stable.' Very small concentrations of electrolytes, which, as we have seen, increase the P.D., increase this stability. As soon as the concentration of any electrolyte is sufficient to bring the P.D. into the critical zone, the stability of the emulsion undergoes a sudden and very marked decrease, and relatively rapid coagulation occurs. Take, for example, the case of thorium chloride. On increasing the concentration we find that the interfacial P.D. traverses successively the following regions:—

(1) Above the critical value (and negative).
(2) Inside the critical zone (negative and positive).
(3) Above the critical value (and positive).
(4) Below the critical value (and positive).

In exact correspondence with this series we find that the emulsion goes through the following states:—

(1) Stable (oil particles 'negative').
(2) Unstable and flocculating (oil particles negative or positive).
(3) Stable (oil particles positive).
(4) Unstable and flocculating (oil particles positive).

Here we see a very striking analogue and explanation of the phenomena observed by Joly in studying the effect of aluminium salts on the sedimentation of clays, and of the numerous examples of the so-called 'irregular series' observed in the flocculation of suspensoid hydrosols by salts with polyvalent cations.

As Linder and Picton showed, when two suspensoid hydrosols, one negative and the other positive, are mixed, then, depending on the ratio, a stable hydrosol (either positive or negative) can be obtained. In continuation of this work, W. Biltz demonstrated the existence in such cases of a 'zone of coagulation,' *i.e.* a zone of concentration ratios leading to coagulation. A study of the mutual behaviour of a negative oil emulsion and the positively charged ferric oxide hydrosol provides a complete explanation of this curious phenomenon. When increasing amounts of the iron oxide hydrosol are added to the oil emulsion it is found that the interfacial P.D. falls to zero, and then reverses its sign, becoming increasingly positive—an action which is due to the adsorption of the positively charged micelles at the oil-water interface. When the P.D. is above a certain value (positive or negative) the system is stable. But within the critical zone a rapid and relatively complete mutual coagulation takes place.

These studies of oil emulsions (and of the glass-water interface), by means of the micro-cataphoresis method, have thrown a great deal of light on many previously ill-understood points in the theory of colloids. If, for example, the P.D. between the particles of a suspensoid hydrosol and the aqueous fluid is not above the critical potential, coagulation will occur. But very small concentrations of certain electrolytes can raise the P.D. and stabilise the hydrosol. This is the explanation of the well-known 'peptising' action. Higher concentrations of even the same electrolytes will reduce the P.D. below the critical potential, and produce flocculation. We see also that rapid coagulation will occur before the P.D. becomes zero. This was proved for arsenic sulphide hydrosol by Powis. Later experiments of Kruyt have confirmed these conclusions. It is obvious, therefore, that coagulation of a lyophobic hydrosol will occur before the iso-electric point is reached, and that Hardy's famous rule requires revision.

The following table contains the concentrations (in millimols per litre) of certain electrolytes required to reduce the potential of a certain hydrocarbon oil emulsion from its 'natural' value (against pure water) of 0.046 volt to the critical value, 0.03 volt:—

—	Concentrations	Ratios of Concentrations
KCl . . .	51	2500
$BaCl_2$ . . .	1·9	95
$AlCl_3$ . . .	0·020	1
$ThCl_4$ . . .	0·0070	0·35

These results show the enormous influence of the valency of the cation in a series of salts with the same univalent anion, and explain in a striking manner the analogous effects in the coagulation of lyophobic hydrosols. The exact value of the critical potential and the range of the critical zone will depend, of course, on the experimental definition of 'rapid coagulation,' and on the concentration, nature, and degree of dispersion of the hydrosol. It is not to be supposed, therefore, that these critical values are constants except under very definite conditions. The fundamental fact is that under given conditions the rate of coagulation of the particles of an oil suspension or of a lyophobic hydrosol undergoes a relatively sudden and very great increase when the interfacial P.D. falls below a certain finite value (positive or negative).

There is not time or space at my disposal to enter into the much discussed question as to the inner mechanism of the action whereby ions (and electrically charged micelles) set up or vary the potential difference in the interfacial layer. According to Freundlich's original theory we must ascribe an independent effect to each ion, which will depend on the sign of its charge, its specific adsorbability, and electrovalency and the nature of the already existing double layer. A different theory was proposed by Freundlich in order to explain the results obtained in the electroendosmotic experiments of Elissafoff. According to this point of view, the 'solid' surface acts chemically (as an acid, base, ampholyte, or salt), whereby it may dissociate off an ion or ions, and itself become an ionised surface. Invading foreign ions may then alter this ionisation equilibrium; or they may simply combine with the ionised surface and form neutral insoluble spots (compare the views of Freundlich, Gyemant, and Kolthoff). J. N. Mukherjee has suggested that ions are attached to the surface by chemical forces, and has attempted to work out an electro-kinetic theory of ion adsorption. It is probable that surfaces very often do act ionically or chemically, and that specific actions of this sort must often be taken into account in dealing with the great variety of material presented in the study of surface actions. Nevertheless, in the case of the hydrocarbon oil droplets studied by Ellis and Powis, or the gas-liquid interface studied by Kenrick, Thorwaldson, and McTaggart, any *specific* chemical activity or ionisation of the oil or gas would seem improbable. Any theory which attempts a general treatment of the problem must be prepared to deal with cases such as these.

Many measurements have been made of the potential differences between solids and liquids, or between pairs of immiscible (or partly miscible) liquids, using electrometric methods. Thus Haber and Klemensiewicz determined the potential difference at a glass-water solution interface, and found the glass to act like a hydrogen electrode. Their results have been recently confirmed by W. S. Hughes. It will be at once obvious that these results are not in agreement with those obtained by cataphoretic and electroendosmotic methods. A somewhat similar type of discordance has been observed in the electrometric measurements of the potential difference between solid paraffin and an aqueous solution made by G. Borelius, and of the P.D.'s between pairs of liquids made by R. Beutner, E. Baur, and others. Freundlich and Gyemant have drawn attention to the fact that in all such electrometric measurements, where in the process of the measurement an electric current must pass from one phase to the other, we measure the total or 'thermodynamic' potential difference between the phases in bulk, whereas in determinations by the methods of electroendosmose and cataphoresis, we measure only a portion of this total potential difference. These 'electro-kinetic' P.D.'s, although of fundamental importance in relation to the stability of suspensoid (lyophobic) systems, need not, and in general will not, coincide in value with the total (thermodynamic) potential differences. It will be recollected that I drew attention to a quite analogous difference in discussing the measurements of the potential differences at gas-water interfaces made by Kenrick and by McTaggart.

We may illustrate this point by considering the P.D. between two immiscible phases, L_1 and L_2, in equilibrium with each other, and each of which contains dissolved in it the electrolyte KA. If ε denote the positive potential of L_2 above L_1, and F the quantity of electricity associated with an ionic gram equivalent, then by a virtual variation of the equilibrium system it follows that

$$(\mu_K)_1 - (\mu_K)_2 = F\varepsilon = (\mu_A)_2 - (\mu_A)_1$$

where the subscripts refer to the cation or anion and to the phases L_1 or L_2, and the μ's denote the chemical potentials per gram equivalent (partial equivalent free energies) of the ionic constituents in the bulk of the two phases. Whatever may be the 'electro-adsorption' or ion adsorption of K and A at the interface $L_1 - L_2$, it is clear that ε depends only on the 'bulk' values of the respective chemical potentials, which likewise determine the surface concentrations. If the phases L_1 and L_2 be not in equilibrium, then velocity or diffusional terms will enter into the equations, and the potential difference will be partly or wholly a 'diffusional potential.' These relationships were clearly established many years ago by R. Luther.

In discussing the 'stabilities' of hydrocarbon oil emulsions, it must not be forgotten that I was dealing with very dilute *suspensions* of oil in water, produced by mechanical agitation without the addition of any 'emulsifier.' I pointed out that in the emulsification of oils in water by means of soap, the soap lowers the interfacial tension and concentrates at the interface. When we wish to produce oil emulsions in the ordinary sense of the term we must use some such emulsifying agent, and for this purpose many substances are employed, such as soap, gum acacia, gelatine, casein, starch, &c., &c. All these substances concentrate or condense on the surfaces of the oil globules. If we may regard these surface films as very mobile from the molecular-kinetic point of view, it is clear that they will confer an increased degree of stability on the emulsion. For any sudden decrease of interface (caused, for example, by coalescence or partial coalescence of two adjacent globules) will produce a momentary increase in the surface concentration or thickness of the adsorption layer, and so a decrease in the interfacial tension, if the surface layer is not saturated. It may require a perceptible time for the molecular-kinetic motion (especially in the case of large molecules or hydrated micelles) to readjust the equilibrium between the surface layer and the bulk.

It is probable, however, that the stability of the emulsion is in many cases due to the fact that the surface films possess a very viscous, quasi-rigid, or gel-like character, so that a more mechanical explanation is necessary. As S. U. Pickering showed, oils may be emulsified in water by the gels of certain basic salts; and A. U. M. Schlaepfer has shown that emulsions of water in kerosene oil may be obtained by means of finely divided 'carbon.' Nevertheless, even in cases where an emulsifier is used, we may hope to succeed in obtaining a more precise physical analysis of the system. It is interesting in this connection to note that Mr. W. Pohl has recently found in my laboratory that when a neutral hydrocarbon oil is emulsified in water by means of sodium oleate, the electrical potential difference at the oil-water interface is almost doubled, and that the effects of alkalies and salts on this potential difference are very similar to those found in the case where no emulsifier is employed.

I cannot conclude this account of certain aspects of surface actions and properties without making a passing, though all too brief, reference to the beautiful investigations of Sir George Beilby on the amorphous layer. He has shown that when the surface of crystalline matter is subjected to shearing stress there is produced a surface layer of a vitreous or amorphous character—a 'flowed' surface—in which the particular ordered arrangement of the molecules or atoms which is characteristic of the crystalline matter largely disappears. Working at University College, London, Dr. Travers and Mr. R. C. Ray have recently obtained a very interesting confirmation of the Beilby Effect. The heats of solution (in kilogram calories per gram mol) of vitreous silica and silver sand (silica as crystalline quartz) in aqueous hydrofluoric acid were found to be 37.24 and 30.29 respectively. After grinding for fifteen hours the corresponding values were 36.95 and 32.46 respectively. If we assume that the internal energy of the amorphous phase produced by grinding is the same as that of the vitreous silica (silica glass), we can calculate from these results that about 31 per cent. of the crystalline silica has been converted by grinding into 'amorphous' silica. The densities of silica glass and silver sand were found to be 2.208 and 2.638 respectively. After fifteen hours' grinding the density of the latter was lowered to 2·528. On the same assumption as before, it follows that about 26 per cent. of the quartz has been converted into the vitreous condition. The difference between the figures 31 and 26 is doubtless due to the approximate character of the assumption underlying the calculations and to experimental errors. There seems little doubt, however, about the soundness of the main conclusion—namely, that the mechanical action of shearing stress on crystalline matter is to produce a random molecular or atomic distribution in the surface layers.

This discussion, necessarily brief and limited, of certain aspects of the properties of surfaces—molecular orientation, surface concentration or adsorption, electrical or ionic polarisation—has dealt very largely with states of thermodynamic equilibrium. The chief interest of such studies has always appeared to me to lie in their possible ultimate bearing on the phenomena of life. We must remember, however, that the activities, and indeed the very existence, of a living organism depend on its continuous utilisation of an environment that is not in thermodynamic equilibrium. A living organism is a consumer and transformer of external free energy, and environmental equilibrium means non-activity, and eventual death.

It is probable, therefore, that along and across 'living surfaces' there is a continual flux of activity. Does the very existence of these surfaces depend on some special sort of activity? Questions such as these must make us cautious as regards any premature generalisation from simple physico-chemical results. But there is encouragement if we may assume that the physico-chemical manifestations of life are functions of the same powers and potentialities of electrons, atoms, ions, and molecules that we find in what we call inanimate environments. Life would then be simply a new functional relationship of very old parameters, at all events in so far as its various physico-chemical 'mechanisms' are concerned.

In the totality of its activities and relationships, however, a living organism is an individual, and to arrive gradually at an understanding of this 'individualisation' it will be necessary to study very carefully the laws pertaining to the intimate and particlar modes of action of simpler individuals. The actions of an individual are conceived by science as determined by its internal state and by its relation to its environment. As we pass from certain peculiar atomic states, where the actions appear to have no relation to environment, to molecules, colloidal micelles, and living cells, the effects of the environment in determining activity seem to become more and more pronounced.

The internal state of a living cell or organism may arrive from time to time at 'critical' points and 'critical' transformations. Whatever may be the relation of such possible critical states to the previous cell-environment reactions, the resulting events will be immediately determined by the special internal nature and activity of the cell itself. Is this 'special internal nature and activity' simply a special type of organisation or arrangement of the positions, shapes, sizes, orientations and motions of electrons, atoms, ions, and molecules? To this oft-put question the answer of physico-chemical science is still in the affirmative. More complex individuals are not cloaked in any mysterious 'law of complexity.'

Probably future progress will depend more on the investigation of the special nature, situation, and action of individuals than on the statistical thermodynamic treatment of the average behaviour of the 'crowd.'

EVOLUTIONAL PALÆONTOLOGY IN RELATION TO THE LOWER PALÆOZOIC ROCKS.

ADDRESS TO SECTION C (GEOLOGY) BY

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PRESIDENT OF THE SECTION.

It is just twenty-seven years since the British Association last met in Liverpool, and in casting my mind back over the intervening years and thinking how our Science stands to-day with regard to its position then, it has appeared to me that one at any rate of the most important lines along which progress has been achieved is due to the growth of what may be termed the genetic principle. This would seem to be equally true both as regards Petrology and Palæontology, for it is becoming increasingly evident that conceptions and classifications, whether they be of rocks or of fossils, if they are to be natural, must be based fundamentally upon origin and descent. Therefore, situated as we are here in Liverpool, almost within sight of the Welsh Hills on the one hand and the Lake District Fells on the other, both classic areas so far as the Lower Palæozoic rocks are concerned, it may perhaps be appropriate to see how far this principle may be applied to the elucidation of problems connected with these Lower Palæozoic rocks, to note what has been achieved in this respect, and how much yet remains to be done. The subject, therefore, of my address to you to-day is 'Evolutional Palæontology in Relation to the Lower Palæozoic Rocks.'

Problems of the Older Rocks.

As I interpret the facts, the chief problems still awaiting solution are both fundamentally stratigraphical: on the one hand there are problems relating to classification, that is, of subdivisions of the formations on a basis that shall be of wide application, and render possible correlation of beds in areas far removed from one another; on the other, there is the actual structural relationship existing between these beds as seen in the field, which, when rightly interpreted, makes evident the nature and extent of those deformational strains that have from time to time so profoundly affected the rocks of the Earth's crust. With regard to classification, the problems are of different degrees of magnitude; there are, for example, those larger difficulties relating to the satisfactory determination of the upper and lower limits of the formations; there are also those connected with the correlation of all those smaller local subdivisions of formations with which Stratigraphical Geology is becoming increasingly overburdened without any prospect of compensation unless a fresh principle be introduced.

Moreover, the interpretations of structural details must to a large extent depend upon the satisfactory elucidation of these problems of classification, so that the solutions of the two really go together. It is my firm conviction that the most satisfactory solution of the first, and therefore also of the second, of these problems will be found in the application of the principles of evolutional Palæontology.

Variation in Shallow-water Fauna.

As regards the more fundamental of the two problems, a general principle seems to be involved, demanding the recognition of the relative values of faunal changes in shallower and deeper waters respectively. The faunas of the shallow seas must of necessity be subject to far greater degrees of physical change than those of the deeper waters, and, thanks to the excellent work done at the Danish Biological Station[1] in carrying out investigations on the bottom faunas of different Danish waters, we now know a good deal as to the extent to which the distribution of modern faunas is governed by physical conditions. Some of the more important conclusions reached by the Danish investigators may be summarised as follows:—

1. That certain *characteristic* animal communities undoubtedly exist under certain physical conditions, and when these conditions remain constant even over wide areas the same community will be found, but each community is bounded by those physical conditions.

2. That change in physical conditions brings about a change in the *characteristic* animal community, though certain organisms may be found in more than one community.

3. The physical changes to be correlated with the change in community are those of temperature, salinity, and clearness of the water; depth as depth seems to be less important than *the factors which go with depth*, such as temperature, amount of light, character of the sea bottom, and quietness of the water. Thus along a section in the N. Kattegat at depths varying only between 7 and 50 metres, five different animal communities have been recognised:—

Community	Depth	Character of Bottom	Temp.
1. Echinocardium Community .	7 metres	Fine sand	—
2. Echinocardium - Turritella Community	12·19 metres	Dark sand with fine detritus	—
3. Brissopsis - Turritella - Echinocardium Community (transition)	24.5 metres	Fine sand with fine particles	14° C.
4. Brissopsis - Turritella Community	35 metres	Grey Kattegat Clay	13.4° C.
5. Brissopsis-Nucula Community	50-52 metres	Light Kattegat Clay	8°—6° C.

[1] 1913, Petersen, C. G. J Report of the Danish Biological Station.

That depth is not the determining factor is clearly indicated by another section taken in the Sams ø Belt:—

Community	Depth	Character of Bottom	Temp.
1. Macoma Community (No Echinoderms)	8 metres	Pure sand	18.5° C.
2. Calcarea Community . .	18 metres	Light mixed clay and sand	10.1° C.
3. Rich Modiola Echinoderm Community	18 metres	Coarse gravel with sand, clay, pebbles	10.3° C.

This Macoma community is very well known, as it occurs in all the more sheltered waters of the Danish Fjords, and can be directly observed and examined at low-water. It is seen to present many facies, and to vary greatly according to whether the bottom is sandy, stony, muddy, or soft, and according to whether it is exposed to the action of currents and to varying conditions of temperature and salinity. The fauna in bulk, apart from those characteristic species which belong to the community as a whole, varies considerably in different localities, and, as the author of the Report expresses it, 'the real matter for wonder is that there are some species common to all these localities and different conditions.'

The difference between the *characteristic* animals of the communities living in waters of different depth is so great that none of the animals are common to both. This does not mean that no species are common to shallower and deeper waters, but that no *characteristic* species as such.

Now the interest for the geologist in all this lies in the fact, as Petersen has pointed out, that these 'characteristic animals' are closely akin to the 'characteristic fossils' of the geologist, and we may ask ourselves whether the variations which can be seen to exist in the contemporaneous shallow-water fossil assemblages of past ages may not be recognised as brought about by the same factors as those that can be seen operating to-day.

Our ancient Lower Palæozoic faunas were composed in the main of trilobites, brachiopods, and corals, both solitary and reef-building. The distribution of coral reefs at the present day is governed by three cardinal factors [2]:—

(1) Uniformly warm waters, the temperature of which does not fall below 22° C. on an average throughout the year;

(2) A depth not exceeding 14 fathoms;

(3) Clear waters, *i.e.* those free from mud in suspension;

and there is every reason to believe that formations containing the remains of coral reefs were laid down under very similar conditions to these; hence reef-building corals might be expected to have flourished

[2] 1923, Potts, F. A. 'The Distribution of Coral Reefs.' *School Science Review*, Feb. 1923.

best in clear, warm seas of moderate depth, and such trilobites and brachiopods as occur abundantly associated with them might be presumed to have flourished also under these conditions; other brachiopods and trilobites would appear to have attained their greatest development on sandy shores, whilst others, again, seem to have lived in greatest numbers in muddy waters, no great change in depth being necessitated. Unfavourable conditions seem to be indicated by the dwarfing of a fauna as a whole, the extreme of such conditions being attained when salinity of the waters resulting from desiccation reached such a pitch that abnormally distorted forms predominate. Moreover, in the case of faunas inhabiting the actual coastal region, it is obvious that even slight changes in the relative levels of sea and land will be very effectively felt, since these may be sufficient to bring about permanent submergence or emergence, and thus induce a total change of environment; also since shore lines tend more particularly to be the lines along which migrations take place between the faunas of one area and another a further factor contributing to heterogeneity may thereby be introduced.

It is therefore obvious that there are many factors tending to give different aspects to shallow-water faunas in different places, hence a certain amount of *Lateral Variation* or lack of uniformity is only to be expected amongst those of the same age when seen in different localities. There may also be considerable *Vertical Variation* in the type of shallow-water fauna of successive ages, either in response to changes in the physical conditions of one and the same area, or as the result of migration; and if the surroundings are variable it may happen that two faunas separated in time may bear a greater degree of resemblance to each other than two successive faunas, the similarity being induced by a return to similar conditions. *Vertical Variation* has long been recognised and understood in principle by geologists, but I do not think the same can be said of *Lateral Variation*.

Since then a greater or lesser degree of variation is to be expected even in ancient shallow-water faunas that are contemporaneous, it is in their case too the resemblances that should be considered remarkable rather than the differences, since close resemblance would seem to indicate one of two things, either a wonderful degree of uniformity of conditions over a wide area, or else the occurrence of a large proportion of those fossils that I have elsewhere [3] called 'successful types,' these possessing amongst other characteristics the property of being, in some cases at any rate, less susceptible to differences of physical condition. Thus in comparing the contemporaneous shallow-water faunas of the past in different areas it would seem that all we are entitled to expect is a *general* resemblance rather than a *particular*, and this at best will probably show itself in generic rather than specific agreement, a fact well illustrated by the trilobite faunas of the Keisley and Chair of Kildare Limestones of Ashgillian age; the general aspect of these faunas is really far closer than any fossil list would indicate, since the species are often different, though the faunas agree in the

[3] 1922, Elles, G. L. 'The Graptolite Faunas of the British Isles.' *Proc. Geol. Ass.*, 1922, vol. xxxiii.

occurrence of numerous Cheirurids, Lichads, and Remopleurids. In many cases, therefore, where there is considerable lateral variation in faunas, and also where the fragmentary condition of the specimens renders specific determination impossible, or where the assemblage is insufficient to determine the horizon, the recognition of the evolutional stage reached by an organism may prove to be of greater significance than specific determination, in that it is essentially independent of any nomenclature, however much such a nomenclature may in the past have been forced upon it.

Moreover, since all shallow-water faunas will be liable to be affected to a greater or lesser extent by the different factors enumerated above, difficulties in correlation are bound to occur; these may be obviated in two ways, either by studying the faunas from the evolutional standpoint, and noting the stage reached, or by determining where possible the relation of each separate fauna to its deeper-water equivalent; for it is obvious that the faunas of the deeper-water areas where conditions are more uniform should furnish the standard for purposes of classification. Since the physical conditions in such areas are far more constant, and the sediments of more uniform type, any change in the character of the fauna that does take place is almost bound to be of real significance, and probably in many cases indicates the attainment of an important stage in the evolution of the group or groups of organisms concerned. Every modern classification of strata should surely take these data into account. It is not that I undervalue the importance of local changes—they have their own significance—but just because they are bound to be more or less entirely local they are useless for purposes of international correlation.

Principles of the Modern Classification of Strata.

It can hardly be doubted at the present day that the most efficient classification of strata is that based upon the palæontological principle of the coming in of new forms, but if the classification is to be of wide application and to be depended upon, this coming in of new forms must not be directly connected with changes in the character of the sedimentation. Physical causes which induce changes in the nature of the sediments are no doubt important, and probably give great impetus to evolutionary development, but to be depended upon they must be reflected in those faunas of the deeper parts of the epicontinental seas where sedimentation continues apparently unaltered; in other words, where the change in the fauna shows primarily as an advance in the evolutional stage. The factors that have to be considered render the international classification of our great formations a matter of considerable difficulty. This is well illustrated by the differences of opinion that exist as to where the upper limit of the Silurian should be placed, and in spite of all that has been urged by Stamp,[4] I am not yet convinced that his claim that the boundary should be shifted to the base

[4] Stamp, L. D. { 1920. *Geol. Mag.*, vol. lvii, p. 164.
1922. *Bull. Soc. Belge de Géologie*, vol. xxxi, p. 87.
1923. *Geol. Mag.*, vol. lx, p. 92 and p. 276. }

of the Downtonian rests upon a satisfactory basis. Towards the close of the Silurian, as is perfectly well known, far-reaching changes in physical conditions took place, necessarily involving changes in the character of the shallow-water fauna whenever and wherever these occurred, and the coming in of fishes appears to be directly connected with them. That these changes took place simultaneously over wide areas is in the highest degree improbable, and having had some experience of the behaviour of these rocks in the field I have felt that the evidence at times so strongly suggested that the Downtonian was essentially a *facies* formation that the possibility of its horizon being eventually found to be almost as inconstant as that of the Millstone Grit was far from improbable. That there may appear to be a similar change of conditions in parts of Britain and France at about the same time is not really the point; it is not the succession of shallow-water marine faunas that is important from the point of view of classification, but how far these are really of the same age in different places, and how much change is reflected in the fauna of the more stable deeper-water beds. The author may be perfectly right in his contention, only up to the present as I see the problem he has not proved his case.

So, too, at the lower limit of the same Silurian formation; at present the top of the Ashgillian needs clearer demarcation, and I have endeavoured to show elsewhere that on palæontological grounds the most satisfactory place at which to draw the line is at the horizon where Monograptus makes its first appearance in force in the deeper-water sediments of the period, a well-defined faunal change indicative of the attainment of an important evolutional stage, of world-wide significance, and independent so far as can be determined of any change in the nature of the sedimentation. This appears also to be the horizon of the entrance in force of the true Pentamerids (*Barrandella*) amongst the faunas of shallow-water type.

With regard to these general principles of modern classification, there would appear also to be only one really effective way of rescuing our Science from the increasing burden of local nomenclature; this has had its uses undeniably in indicating the exact nature of local successions and developments, and at present cannot be avoided in unfossiliferous rocks such as those of Pre-Cambrian age, but for the rest of our Lower Palæozoic rocks surely the time is coming, if, indeed, it has not already come, when there may be detected emerging from all this wealth of local detail a general palæontological sequence that may be of wide and possibly even of international application.

There will, no doubt, be those who will object on the grounds that in adopting such a classification the geological world might be at the mercy of the whims of a few palæontologists; this should not be the case if the evolutionary principle be adopted, for the choice of fossil indices should then be limited to those fossils that are of the nature of stable or successful types, for these are likely to be the only forms with a sufficiently wide distribution in space to be really useful, whilst in widely remote areas, should these fail, corresponding forms at a similar general stage of evolution should be utilised in their stead.

The most reliable classification for shallow-water beds would then be that based upon the evolutional sequence of the members of one or more species-groups [5] belonging to genera possessing considerable possibilities of variation (variation gradient) so long as such members continue to be important and characteristic members of the fauna; when they fail in this respect they should be replaced by the members of another species-group that succeeds in importance. Thus, as will be shown in the sequel, the evolutional series comprised within the species-group of *Calymene cambrensis* might well be adopted for classifying the lower part of the Ordovician in our own country, whilst in the upper part members of the species-group of *C. blumenbachi* might be utilised. It may prove advisable in some cases to choose genera belonging to two distinct phyla to serve as a check upon each other such as, in the case of certain of the Lower Palæozoic rocks, might be afforded by Trilobita and Brachiopoda; in other cases species-groups of either of these phyla might prove sufficient.

Deeper-water Faunas of the Lower Palæozoic.

We must now pass on to the consideration of some Lower Palæozoic Faunas, and see what has been achieved by regarding them from the evolutional standpoint; and since, for reasons already given, it would seem that the faunas of the deeper waters must be taken as the standard for purposes of classification, these will be considered first.

Throughout the greater part of Lower Palæozoic time the Graptolite Shales constitute the typical deposit of the deeper waters of our epicontinental seas, the factors controlling their accumulation being not depth as such, but rather the factors that are closely associated with depth, especially quietness of the water, and absence of coarse sediment. Strictly speaking, I suppose the graptolite fauna does not belong to the Black Shale, since it is in all probability pseudo-planktonic; but owing to similar conditions governing its distribution the two are almost invariably associated and may be taken in that sense to belong; in any case, its occurrence is independent of those factors which make for heterogeneity in the faunas of the shallower waters, so that the Graptolite Shales furnish the standard sequence for purposes of classification. As regards the study of this highly interesting group of organisms, it is as well to note at the outset their extraordinarily favourable position from the evolutionary standpoint; for though we may not know the complete story of the whole class of the Graptolithina, since at present its actual beginning is uncertain, we do appear, at any rate, to have a more or less complete history of the more important order, the *Graptoloidea*, comprised within the rocks of Lower Palæozoic age; so that here, if anywhere, we ought to be able to study the various forms in their true relationship to each other. To a large extent this can be done, and the honour of its first conception belongs to Nicholson and

[5] *Species-group* or gens may be considered to be the aggregate of all the species which possess in common a large number of essential properties and are continuously related in space or time. Vaughan, *Q.J.G.S.*, 1905, vol. lxi, p. 183.

Marr, who in 1895[6] pointed out the evolutional importance of the simplification of branching; the work is still far from complete, though more lines of evolutional importance have been added to that of Nicholson and Marr. At the present day we can study the lines along which general development took place, see how different species-groups arose, reached their acme, and diminished in importance as they were succeeded by those of the next evolutional stage; and we can note the horizons at which the more important of these evolutional stages were reached.

Looked at purely from the evolutional standpoint there seem to be at least three main lines along which the graptolites evolved as a whole:—

1. Change in direction of growth.
2. Simplification in branching.
3. Elaboration of cell type.

The first of these brings about a change from the primitive pendent or hanging form to the scandent or climbing position, and appears to be brought about by the necessity for the better protection of the nema or attachment organ, and would, therefore, seem to arise in direct response to environment.

The second line of development eventually results in reduction of the total number of stipes or branches of the rhabdosoma to one; the earliest attempt in this direction, where the tendency to reduction outdistances that of change in position of growth, appears to be unsuccessful, since the forms are all 'dead ends' undergoing apparently no further development of any kind (*Azygograptus*). The later attempt is combined with further change in the position of growth, so that the forms which result are scandent one-branched graptolites with a well-protected nema; these are obviously highly successful, undergoing a rapid development in many different directions.

This simplification in branching may, as suggested by Nicholson and Marr, be the impression of the struggle for an adequate food supply.

The third line also occurs in what may be termed two episodes, and is of a somewhat different nature each time; the earliest elaboration affects the cell as a whole, whereby the cell with a bend or sigmoid curve in it is gradually evolved from a straight tubular cell, the curvature eventually becoming so pronounced that there is torsion of the whole apertural region. Since the development of a cell of this type would allow of closer packing, its evolution, like that of the simplification in branching, may be the impression of the struggle for food; if so this type of cell elaboration may result in response to conditions of environment.

In the second episode the elaboration is of a totally different nature, and seemingly results as the expression of two definite tendencies or trends within the organism, one a trend towards *lobation*, the other a trend towards *isolation*.

So it comes about that the broad outline of the Graptolite History is found to be comprised within four chapters, all dealing with different

[6] 1895, Nicholson and Marr, 'Phylogeny of the Graptolites.' *Geol. Mag.*, dec. 4, vol. ii.

evolutional stages, each chapter being capable of further divisions into sections and sub-sections.

The four chapters of the story may be summarised as follows:—

1. General simplification of branching coupled with change in direction of growth. Attainment of unsuccessful one-branched form, which undergoes no further development. Characteristic of Arenigian and Llanvirnian beds.

2. Commencement of elaboration of cell type (first episode) Characteristic of Llandilian beds.

3. Widespread attainment of the scandent position by two-branched forms. Characteristic of Caradocian and Ashgillian beds.

4. Widespread attainment of one-branched stage by scandent forms which undergo conspicuous elaboration of cell type (second episode). Characteristic of the whole of the Silurian.

The first chapter deals mainly with the many-branched graptolites, of which the best known is the 8-branched form *Dichograptus*, and the most obvious changes shown are those tending in the direction of the reduction of number of stipes or branches. Thus the 32-stiped forms are gradually succeeded in time by those with 16 stipes (*Loganograptus*), the 16-stiped by those with 8 (*Dichograptus*), the 8 by 4 (*Tetragraptus*), and the 4 by 2-branched forms (*Didymograptus*). Thus the simpler forms succeed the more complex, and *at the same time* there is a gradual change from the pendent through the horizontal to the scandent position of growth; by the time this is attained the number of stipes is reduced to four, so that such forms are essentially scandent or climbing forms of *Tetragraptus*, though they are more familiar under the name of *Phyllograptus*.

This, the first attainment of the scandent position of growth, is an evolutional stage of considerable significance, and differentiates the upper part of this first or Dichograptid fauna from the lower containing the many-branched graptolites; the 2-branched horizontal *Didymograpti* become abundant at the same horizon (*zone of D. extensus*), so that it is easy of recognition without any knowledge of graptolite species. The *Phyllograptus* stage is short; there is a certain degree of elaboration, and then further reduction in the number of stipes to two follows on, and the place of *Phyllograptus* is gradually taken by *Glossograptus*, a graptolite common for the first time in the Llanvirn rocks, and often a conspicuous element in the faunal assemblages of that age. The structure of the proximal end of these two graptolites is so peculiar and so alike that there can be no doubt of their relationship; moreover, I regard the septal spines of *Glossograptus* as possibly representing the last vestiges of the thecæ of the third and fourth stipes of *Phyllograptus*. Structural resemblances of such a kind may naturally be made out in the laboratory or museum, but the realisation of the true connection between them and their proper place in the evolutional line only becomes obvious when they are seen gradually replacing each other in the field with all the intermediate stages.

If now simplification in branching be accepted as a line of evolution, how does it come about that many-branched graptolites are often found occurring on the same slabs of rock as those with four or even with only two branches? Field evidence supplies the answer to this very natural query. Whilst the earliest graptolite with which we are acquainted was a pendent form, there very quickly followed other graptolites in which a horizontal direction of growth replaced the earlier pendent direction, though both occur side by side in rocks of the same age; the horizontal growing forms we term *Clonograptus*, the pendent *Bryograptus*. Now it is perfectly obvious from observation in the field that as regards simplification of branching the same plan of evolution was followed in both these groups, though there is always a tendency for development to lag behind and go slower in the pendent line, whereas development is so rapid in the horizontal line that many *Clonograpti* persist alongside the 8-branched *Dichograpti*, though when *Dichograpti* persist alongside the 4-branched *Tetragrapti* they are most commonly those in which a certain amount of simplification has already taken place, since they are, as a rule, forms with only six or five stipes instead of eight; owing, however, to the unequal rate of development in the two groups there is a characteristic association of *pendent* 4-branched graptolites with *horizontal* 2-branched forms of the type of *D. extensus*, whilst *horizontal* 4-branched forms have become rare.

The apparent anomaly is thus clear when followed out step by step. This greater rapidity of development in one group seems to indicate that these horizontal-growing forms were the more successful of the two; and it is, therefore, perhaps only to be expected that almost all the later graptolites are developed from ancestors within that group, the exceptions being those whose ancestry is at present obscure, but there is no indication that these arose from any member of the pendent group; I have so far been utterly unable to find any graptolites in later beds which seem to be connected with these. If I am right in supposing that the change in direction of growth of the rhabdosoma was connected with the protection of the hollow thread-like nema (*virgula auctorum*), which is the attachment organ so vitally necessary to the colonial organism, the forms belonging to the pendent group may be regarded as unsuccessful because they fail utterly to secure this necessary protection, and, therefore, the members of this group come entirely to an end at the top of the Llanvirnian. Within the other group protection is better achieved, since in many cases at any rate the horizontal-growing stipes appear to have been plastered on to foreign bodies or suspended therefrom by short threads, and the nema would, therefore, in most cases have been short. Within this horizontal group the goal in simplification would seem to have been reached early in the one-stiped *Azygograptus* of the Middle Arenig; this type is repeated more than once at slightly higher horizons, but appears to be in no case a successful form; individuals are very commonly broken in the region of the sicula, which is in itself suggestive, and they, like the pendent *Didymograpti*, appear to be 'dead ends.' The successful one-stiped form is attained much later by very devious routes through the scandent or climbing graptolites, and in all of them the attachment organ is very perfectly protected, partly by being buried within the rhabdosoma for the whole of its initial region, and partly by the development of a special encasing tube or sheath.

Practically all the graptolites referred to above, which are the predominating element in the fauna, are characterised by simple cells—*i.e.* at most a reproduction of the embryonic sicula slightly modified in respect of relative length and breadth—and they follow what I have called elsewhere the Dichograptus plan of development; they may, therefore, be regarded as constituting the first or Dichograptid Fauna, which is pre-eminently characteristic of the rocks of Arenigian or Llanvirnian age. Without any special knowledge of species or genera, the horizon of this fauna may be recognised by the presence of branched graptolites with simple thecæ, the presence of scandent forms being indicative of the higher beds.

In all the earlier graptolites, as has been shown, the cell type is simple, but soon after the two-stiped horizontal *Didymograpti* have developed a slight change begins to be apparent in the thecæ of some forms; this shows itself in a drawn-out curvature of the cell wall and a turning in of the apertural margin, which gives a most striking and characteristic appearance to the cell after compression. This is first apparent in the thecæ in the region of the sicula, and becomes less conspicuous as the stipe grows in length; for it may be noted at this point that all progressive development (anagenesis) is first indicated in the proximal and, therefore, youthful region of the rhabdosoma, and when retrogression (catagenesis) occurs, it is in this same proximal region that signs of former elaboration are retained.

Throughout the earlier rocks of Llandilian age the great majority of the graptolites have cells of this slightly elaborated type and two stipes only, which are reclined or reflexed in their position of growth; but gradually in some forms an increasing degree of curvature of the walls of the cells becomes apparent, and the incurving of the apertural region is accompanied by a degree of torsion that after compression causes a very different appearance according to whether the rhabdosoma is viewed from the front (obverse) or back (reverse). This is the *Dicellograptus* stage, and so distinct is the appearance of this graptolite from any *Didymograptus* that it would never be considered related if the successive stages had not been followed step by step. It may be noted, too, that whilst this cell elaboration is in progress evolution along other lines seems to be temporarily arrested, but is resumed when the elaboration has reached its acme, especially towards the attainment of the scandent position of growth; this is at first only partial, as in *Dicranograptus*, but is eventually complete, as in the closely related *Climacograpti*, which are scandent throughout. The relationship of *Climacograptus* is clearly with *Dicranograptus* and *Dicellograptus* rather than with *Diplograptus*, with which up to the present it has been invariably grouped. The only connection it really has with *Diplograptus* is that, being a biserial scandent form, it is at *a similar evolutional stage*.

Since the simpler type of thecal elaboration is characteristic of the graptolite *Leptograptus*, the various forms in which this type of theca is found may suitably be regarded as constituting the second or Leptograptid Fauna, and its occurrence, whether in simpler or more complex forms, may be taken as indicating rocks of Llandilian or Caradocian age. As will be shown later, other features more particularly characteristic of the Caradocian will serve readily as a guide to discriminate between these two, whilst the degree of elaboration shown will afford some indication as to whether the lower or upper part of the Llandilian is indicated.

There is no new element definitely to be associated with the third chapter of the graptolite story, and yet perhaps the opening paragraphs are as striking as anything in the whole narrative. A feature that cannot fail to arrest the attention of every field worker is surely that extraordinary development of large *Diplograpti* and *Climacograpti* that characterises the junction of the Llandilian and Caradocian rocks. So far as can be determined from field evidence this swarm of *Diplograpti*, particularly of *Orthograptus* type, is due to development along at least two lines reaching their acme at approximately the same time, and when these meet the *Climacograptus* lines the result is bound to be very striking; moreover, since most of these are clearly highly successful forms, giving origin to numerous varietal modifications, the predominance of the scandent biserial graptolites is pre-eminently the distinctive feature of the rocks at this horizon. Hence the various associated graptolites may be regarded as belonging to the third or DIPLOGRAPTID FAUNA.

In the lower beds belonging to this fauna the complex-celled *Dicellograpti* and *Dicranograpti* still persist, but the association of the large *Orthograpti* is sufficient to differentiate the horizon from the Llandilian. This is the association characteristic of the Caradocian.

So far as the graptolite faunas are concerned there is obviously a close connection between the Caradocian and the Ashgillian, the predominance of the *Orthograpti* continuing to be a characteristic feature; in the lower beds regarded as Ashgillian there is some evidence of retrogression as respects the *Dicellograpti* and *Climacograpti*, both showing a return to the simpler type of cell; the stages of this, however, have not as yet been completely worked out. The highest beds, which from the point of view of their graptolites should logically be grouped with this third fauna, include some at present very generally grouped with the Silurian. In these *Diplograpti* (*Orthograpti*) and *Climacograpti* are still predominant, though the *Dicellograpti* have disappeared.

The next striking feature is the coming in of *Monograptus*, or, if expressed evolutionally, the uniserial (one stiped) scandent graptolite, a very important and easily recognised evolutional stage. This marks the successful attainment of the end along two lines of development: simplification in branching, and change in direction of growth. It is pre-eminently characteristic of Silurian rocks.

In the earliest graptolites reaching this stage there is nothing new as respects the cells; all are 'old-fashioned' types seen previously in *Diplograptus*, *Climacograptus*, *Leptograptus*, or *Dicellograptus*; but with the attainment of the uniserial scandent form the organism seems to have had its energies set free to follow further trends, these being in the main in the direction either of lobation or isolation, but they do not keep quite apart; a certain degree of lobation creeps into the line of isolation, and a certain amount of isolation is clearly discernible in the lobate line; nevertheless, one or other trend is always the more conspicuous and the more definitely followed. In both these lines the trend continues to the point where, as Lang[7] has so ably described it, 'their exaggeration puts the organism so much out of harmony with its environment as to cause extinction'; the lobation is developed till the aperture of the cell is practically closed (*Monog. lobiferus*), and isolation is carried to such a pitch that the cells seem readily to have fallen apart from each other altogether, so extremely slender is the connecting portion (*Rastrites maximus*). The hooked variant of the lobate line, however, fares much better, and can be seen to work steadily up to its acme (*M. priodon*), and as steadily decline until the cell-form is seen to have returned to the point from which it started.

These are the general facts concerning the evolution of the group as a whole. We may now see the way this works out along a few particular lines.

1. *Bryograptus to Didymog. indentus.*
2. *Clonograptus to Didymog. hirundo.*
3. *Monog. cyphus to Monog. tumescens.*

In the first of these lines the evolution is purely in the direction of simplification in branching, the thecæ being practically identical throughout and the pendent position of growth unchanged. Thus we pass successively from *Bryograptus kjerulfi* to *Tetragraptus pendens* by failure of branching, and thence to the two-branched *Didymog. nanus*, which by slight modification seems to pass into the form known as *D. indentus*; this is really only a late mutation[8] of *D. nanus*. In the second case there is simplification of branching combined with change in direction of growth and some increase in the size of the thecæ. The first conspicuous change is the change in position of growth from pendent to horizontal, resulting in *Clonograptus flexilis*, a 32-stiped graptolite, thence by gradual stages to *Loganograptus logani*, a 16-branched form, and by further reduction in the number of branches to 12, 11, 10, and 9 an important stage is reached in the well-known 8-branched form *Dichograptus octobrachiatus*. This passes successively through what may be termed septad, hexad, and pentad stages before attaining another important stage, that of the 4-branched form *Tetragraptus quadribrachiatus*, a horizontal form with perfect symmetry. It may be noted that the commoner and more widespread forms are always those in which there is symmetry. Now such a form as *T. quadribrachiatus* has two obvious lines of variation: it may continue the process of simplification in branching or it may change its position of growth. It appears to do both, and so two lines diverge at this point with very far-reaching results.

(*a*) follows the tendency for change in position of growth, and passing through the reclined forms *Tetrag. amii* and *T. serra* leads into that scandent *Tetragraptus* which we know better as *Phyllograptus*, the earliest scandent graptolite, and a very important form indeed; for

[7] 1923, Lang. 'Evolution; a Resultant.' *Proc. Geol. Ass.*, 1923, vol. xxxiv, p. 11.

[8] Mutation.—This term is used throughout in Waagen's sense and not in that of De Vries.

simplification in branching follows whereby the stipes are reduced to two, and an entirely new factor supervening in localisation of thickening in the graptolite wall, the line diverges in one direction and leads into the Retiolitidæ, a quite distinct species-group.

(*b*) follows the tendency to simplification, and passes into the two-stiped form *Didymog. extensus*, and thence to an unsuccessful one-stiped graptolite *Azygog. eivionicus*. The two-stiped form undergoes also various modifications in the packing of the cells, and passes through *Didymog. nitidus*, a very variable graptolite, into *D. hirundo*, a more stable form, which is, however, apparently a dead end. In others of this *Didymog. extensus* type an actual modification of the cell structure supervenes as an entirely new factor, so that the cell, instead of being a simple tube, is gradually bent and twisted and its aperture turned in. The details of this have yet to be worked out completely, but the general plan is perfectly clear, and leads first into the *Leptograpti*, and thence into the *Dicellograpti*, *Dicranograpti*, and *Climacograpti* in turn.

Lastly, we may study the elaboration of the cell as seen in the second episode, the evolution of the hooked variant of the apertural lobe. Here, starting from *Monog. cyphus*, which has the old-fashioned Dichograptus type of cell, we find the first traces of a hook in the closely related *M. revolutus*, and can trace its gradual development in the proximal region of the rhabdosoma in *M. difformis* and *M. argenteus*, in which, though the hook is well developed proximally, the distal thecæ are still simple; gradually the hook-form invades the whole rhabdosoma (*M. clingani* and *M. sedgwicki*), and taking on its most distinctive features in *M. marri*, reaches its acme in *M. priodon*, perhaps one of the best-known graptolites all over the world. Thereafter retrogression sets in, the hook becomes less pronounced in *M. flemingii* s.s., and a small, highly characteristic variety is seen occurring side by side with the larger form; this smaller variety gradually gives way to *Monog. colonus*, in which only the proximal thecæ retain any signs of their former elaboration, and *M. colonus* itself is replaced by *Monog. tumescens*, where all thecæ are once more of the unhooked type just as in *Monog. cyphus*, though the form of the rhabdosoma of *M. colonus* is retained. This is one of the latest graptolites with which we are acquainted.

Shallow-water Faunas of the Lower Palæozoic.

The case of the shallow-water faunas of Lower Palæozoic age must now be considered; and here, in spite of a vast amount of work that has already been accomplished, much remains to be done, but from a different standpoint and along very different lines. There exists already a great mass of more or less purely descriptive literature, accompanied in general by illustrations of varying degrees of merit. All this has a value of its own; it provides descriptions which aid identification of fossils, and in many cases gives an excellent idea of the variety of the brachiopods, trilobites, or corals represented in a certain bed or set of beds; but, looked at broadly, is not its value to a great extent purely numerical, giving an idea mainly of the relative abundance of certain fossils at certain horizons and their relative scarcity at others? Since such work has too often unfortunately been carried out in the museum or laboratory by workers unacquainted with the fossils in their natural environment, it is liable to fail to take note of peculiarities of preservation and condition that may be significant, and new names have in the past been sometimes given to the same fossil in different conditions of preservation, or to other forms which owe their apparent peculiarities to the deformation of the rocks in which they lie. As is perfectly well known, the older rocks of this country have almost always suffered more or less considerably in this respect, though in the case of some rocks, such as mudstones, it is exceedingly difficult to estimate the degree of such deformation in hand specimens removed from their proper surroundings. So, too, the relative sizes of fossils may take on a totally new aspect when seen in the field. In such a connection we may note the characters of the Caradocian faunas of Shropshire and North Wales respectively. Similar fossils from the two areas differ so much in size that the existence of small Welsh varieties is inevitably suggested, until it is realised when the faunas are seen in the field that the *whole* Welsh fauna is of smaller size though otherwise very similar, therefore obviously we are here dealing not with any true varieties but rather with a whole fauna living under less favourable conditions.

The pity of it is that, in spite of all the labour and skill that has been expended, we are still left so largely in ignorance of the crucial facts that in these days we want to know. There is a very real need at the present time for the co-ordination of these descriptions so far as possible on genetic lines. The difference between the past and future palæontological work appears to me to be just this: the older type of work is too dead, whilst the palæontology of the future must be essentially alive; it must vitalise fossil organisms, and regard them as parts of once-living entities possessing definite ancestors and descendants, developing along definite lines which are the result partly of internal and partly of external forces.[9] The biologist will find his interest in the degree of relationship between species-group and species-group, or in the precise relationship between ancestor and descendants within the species-group, but the value of the work to the geologist will lie rather in the determination of the definite lines along which evolution takes place and the horizons at which important and easily recognised evolutional stages are reached.

It may perhaps be argued that the geological record is so imperfect that our story can at the best be of little value, because it will be so incomplete; to that I would reply that such features as have been sufficiently permanent in any organism to impress themselves upon the hard parts that are all that remain to us are likely to be those of enduring significance, and therefore particularly reliable so far as they go. We may miss detail, but the main facts of the story should be beyond question. Up to the present time resemblances and differences existing between certain fossils have often been noticed as points to render identification more accurate, but their true significance has too

[9] Lang, *loc. cit.*

often been missed. Classifications have also been given claiming to be genetic, but too often all that has been done has been the placing in the same group or class, forms that have reached *a parallel evolutional stage*, and since many of the more conspicuous evolutional stages appear to be reached at approximately the same time, even though along different lines, such a classification is chronological rather than biological. From the geological standpoint a chronological classification is valuable, but the biological side must not be ignored. Thus we have seen in the classification of the Graptoloidea, *Climacograptus* and *Diplograptus* are both included in the family of the *Diplograptidæ*, presumably because they are both biserial and have both attained the scandent position of growth; they have no other connection and appear to have totally different lines of descent. The same is to a large extent true of Pompeckj's classification of the Calymenes.[10] Thus Pompeckj divides the Calymenes proper into two sub-genera, *Pharostoma and Calymene*. The forms included under the s.g. *Pharostoma* are stated to be characterised by the presence of long genal spines and the termination of the facial suture at the posterior margin. These two are closely connected, for the presence of genal spines seems to inhibit the facial suture coming out at the genal angle as in the s.g. Calymene; hence if, as Pompeckj himself suggests, the possession of spines is a primitive character, it carries with it a notable stage in the development of the facial suture, since until the spines have disappeared the facial suture cannot come out at the genal angle. Hence the rounding of the angle and the position of the termination of the facial suture together mark an evolutional stage that is regarded as characteristic of the s.g. *Calymene*. He also places *Calymenes* of the *tristani* type in a totally different section from the *Calymenes* of the type of *C. cambrensis* (*Calymene* s.s.), for he holds that the lobing of the glabella is so different that 'relationship is not to be thought of,' whereas I hope to be able to show that, looked at evolutionally, these forms may be regarded as belonging to different points along a special trend line, that of evolution of the glabella lobes, and the appearance of bifurcation in the glabella furrows upon which he lays such stress as a feature of importance in classification appears to me to be a necessary stage in the lobal evolution, and therefore only highly developed at a certain stage.

On the other hand, *Calymene caractaci*, which he places in the same group as *C. cambrensis*, apparently chiefly on the grounds of the course of the facial suture and number of glabella lobes, does not appear to me to be so closely related from the genetic point of view, since these two differ markedly in other characters that must, I think, be considered 'essential,' and therefore belong more likely to different species-groups.

A glance at the table given at the end of his paper will serve to show how largely this classification is chronological. It is probably true that the greater number of our fossil 'genera' at the present day are polyphyletic, and cut across true lines of evolution, as can be demonstrated

[10] 1898, Pompeckj, J. F. 'On Calymene Brongniarti.' *Jahrb. f. Mineral., Geol. & Pal.*, vol. i, p. 187.

in the case of the Corals, Trilobites, and Graptolites. The true relationship existing between individual fossils and fossil-groups will probably only become manifest after searching examination in the field, and whilst many of the species previously established will no doubt stand, others will probably be found to be more truly related to certain central forms as space or time variants (mutations), and may or may not be worth specific rank. So that the evolutional work that is required must be carried out primarily in the field, though supplementary work will have to be carried out in the museum or laboratory; but the value of different features can, I believe, be only truly estimated when they are seen making their first appearance, gradually coming to their acme, and then dying away to be replaced by others. Thus we may study in the field all the stages between fossil A and fossil B, whose relationship to A would probably otherwise never have been suspected, so different do the two extreme types appear. It was indeed truly said by your President three years ago[11] 'that not until we have linked species into lineages can we group them into genera, not until we have unravelled the strands by which genus is connected with genus can we draw the limits of families, not until that has been accomplished can we see how lines of descent diverge or converge so as to warrant the establishment of orders.' This is equally applicable to shallow- and deeper-water faunas alike, but the time and space variants are best seen in shallow-water faunas, where the variation gradient being spread out over thicker deposits is less steep than it is in the deeper-water faunas, where it is often so steep that the time-variants tend to become absorbed in genera.

The facts just dealt with concern the more purely biological side of the question, but for the geologist there is more in the evolutional method of work than this. Bearing in mind that Palæontology fulfils one of its chief functions as the handmaid or helper of Stratigraphy, we may ask how far evolutional work will accomplish that object. The answer is clear and definite. The Lower Palæozoic faunas, as has already been stated, are essentially Brachiopod-Trilobite faunas together with Corals where the seas were sufficiently clear to permit of their growth and development.

As regards the Corals, the kind of work required is that initiated by Vaughan, and most ably extended by Dixon, Carruthers, Stanley Smith, and others. Lang[12] has recently performed splendid service in the cause of evolutional palæontology in putting forward his Doctrine of Trends, and showing how Carboniferous Corals follow what he terms *Programme Evolution*, since coral stocks continually developed along parallel lines so that different lineages may go through the same sequence of changes. We may hope that some such trends may be discernible amongst the corals of Lower Palæozoic age, and Carruthers[13] has shown us how best to obtain the knowledge we require. In

[11] 1920, Bather, F. A. Pres. Address to Section C., Cardiff.

[12] 1923, Lang, W. D. 'Trends in British Carbonif. Corals.' *Proc. Geol. Ass.*, vol. xxxiv, pt. 2, p. 120.

[13] 1910, Carruthers, R. G. 'Evolution of *Zaphrentis delanouei*.' *Q.J.G.S.*, vol. lxvi, p. 523, &c.

his most admirable account of the evolution of *Zaphrentis delanouei* Carruthers has shown the importance of cutting serial sections, for the stages seen in the adult of early forms are often characteristic of adolescence in forms at higher horizons. Thus in *Z. delanouei* evolutionary stages are confined to the shape of the cardinal fossula and the length of the major septa, and different time-variants (mutations, Waagen) show striking differences between these.

In *Z. delanouei* s.s., which occurs in the Cementstone Group 300-400 ft. below the base of the Fells Sandstone, the transverse sections show septa meeting in the centre of the corallum and a large cardinal fossula expanded towards the inner end; together with this form there occur others which agree with *Z. delanouei* in their adolescent stage, but in the adult a stage is reached in which *the walls of the fossula become parallel* and finally show a tendency to constriction at the inner end. Since this mutation marks an important evolutional change as regards the fossula, it is termed *Z. parallela.*

At a considerably higher horizon, in the Lower Limestone Group, the cutting of sections of a fresh mutation foreshadowed in the Cementstones reveals no trace remaining of what may be termed the *delanouei stage;* but the *parallela stage* is distinct, and with growth the inner end of the fossula narrows, whilst in sections of the adult stage the constriction becomes very pronounced, the septa being, however, still joined together in the centre of the corallum. Again, on account of a further change in the character of the fossula this mutation may be distinguished as *Z. constricta.* Within the Lower Limestone Group are also found forms representing a further change; these do not pass through the *parallela stage*, but start at the *constricta stage*, and on further growth the septa shorten until they separate at the centre of the corallum. This again is an important and easily recognised stage (*Z. disjuncta*), and this mutation is said by Carruthers to show amplexoid characters (=amplexoid trend, Lang). The geological value of these changes lies mainly in the fact that they are continuous in time and characteristic of different stratigraphical horizons, apart from whether they are progressive or retrogressive, but it is clear that careful discrimination may at times have to be made between these.

At the mere thought of coping with the many evolutional problems connected with the Lower Palæozoic Brachiopods the heart of the most vigorous palæontologist amongst us might well fail him. I suppose that there is no single worker on the Lower Palæozoic rocks who has not at one time or another realised the stupendous nature of the problem that awaits us here. We have, I feel sure, all been conscious of the fact that many of the so-called long-ranged species are not really quite the same, but show certain differences at different horizons with which in the course of our field-work we have become familiar and can recognise, so that for the sake of our own convenience we have often given them the field-names; but when we try to analyse these differences palæontologically each character seems so slight as to be trivial and unimportant; nevertheless, in bulk they may be important and the two extremes quite distinct. This may well be illustrated by the case of the Dalmanellas as represented by the species *D. elegantula*, a name which as at present used does not define a species but an important *species-group*, the earliest members of which occurring low down in the Ordovician are certainly markedly different even as regards the external ribbing of the shell from those occurring at the base of the Silurian, though all have been included in the same diagnosis. Up to the present all we can do in naming such a fossil is to term it, in despair, *Dalmanella of elegantula* type.

This work can and must be tackled group by group; it will demand an amount of careful field-collecting, in the first place, of specimens showing internal as well as external characters, for these last are by no means to be neglected, since they often reflect changes in internal characters, though they do not do so invariably; hence it will be necessary to distinguish between those possessing different internal and external characters and those which differing in their internal characters yet may have the same external characters.

Field palæontology, when it has a definite aim of this sort in view, becomes a fascinating and absorbing study, and a fresh zest is given to the somewhat monotonous task of mere fossil-collecting.

Kiaer, in his classic memoir on the Silurian Rocks of the Christiania Basin,[14] has indicated to us how this work may be carried on. He was fortunate in that the rocks in the area where he did his work are but slightly inclined and are affected only by faulting and not by folding, so that there can be no doubt as to the order of succession of the various beds. To a large extent Kiaer has applied the principles of evolutional palæontology with great success; he notes the appearance of early mutations and their gradual evolution at successive horizons up to and beyond the development of the typical form. Thus he utilises the evolution of the septum in the Pentamerids of the species group of *P. oblongus*; he notes how this septum is short in *Barrandella undata*, the earliest of the true Pentamerids, and shows how this gives place upward to another mutation, *P. borealis*, with a septum which, though rather longer, is nevertheless shorter than that of *P. oblongus* s.s., which is next developed. At a still definitely higher horizon is found *P. gotlandicus*, probably to be regarded as a late mutation of *P. oblongus*, in which the septum is still further developed.

Having arranged these Pentamerids in order, Kiaer is able to throw light on the development and relation of the Stricklandinias, among which there has been and still is much confusion in this country. He shows that *Stricklandinia lens* makes its appearance in the Christiania Basin with the *borealis* mutation of *P. oblongus*, and is followed at a slightly higher horizon by a mutation of its own, whereas *S. lirata* does not occur till the horizon of the *galeatus* mutation.

For purposes of correlation, however, Kiaer notes the position of the beds containing the fossils in relation to the deeper-water Graptolite Shales. Thus, for example, beneath his zone of *Barrandella undata* he recognises the zone of *Cl. normalis*, the equivalent of our British zone of *Diplog. acuminatus*, and some little way above his zone of *Pentamerus oblongus* he notes the graptolite zone of *Cyrtog. Murchisoni*,

[14] 1908, Kiaer, J. 'Das Obersilur im Kristianiagebiet.'

and taking that rightly as representing the base of the Wenlock, he concludes that all the zones of 'shelly' beds in between must belong to the Valentian.

In the course of work amongst the rocks of Ordovician age I have been struck with distinct evolutional trends amongst some of the commoner trilobites, the stages of which have proved valuable as indices of age. In illustration of this I may quote two:—

1. The evolution of the glabella lobes in a species-group of *Calymene*.
2. The relation between the segments of the side lobes and axis in the pygidia of *Encrinurus*.

With regard to the first of these, the evolution of the lobe, two things have to be noted:—

(*a*) The number of the lobes.

(*b*) Their character—*i.e.* the degree of rounding off into a real lobe.

The number of lobes appears to increase steadily in proceeding from older to newer beds; thus, for example, Silurian forms in general have more lobes than those of Ordovician age. The actual character of the lobe is to a large extent determined by the state of development, both as regards depth and breadth, of the curved glabella furrows. Primarily the lobation seems to arise as the necessary result of the development of such curvature; the glabella furrows appear to develop gradually in width from above downwards, and at the same time increase in breadth; the lobation of the basal lobe, for example, is complete when the downward curvature of the first furrow cuts into the upward curvature of the neck furrow, and the furrow is deep and broad throughout its extent; but before this stage is attained there are many degrees in the development from an incompletely developed furrow through one where, though more or less complete, it is still so shallow for a part of its course that the lobe is not cut off, but appears definitely attached to the rest of the glabella by a 'neck' or bridge.

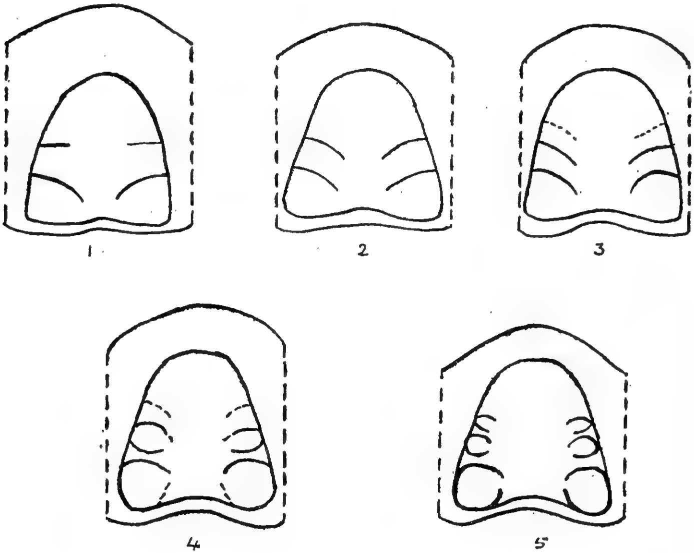
The Calymenidæ appear in part at any rate to be derived from the Olenidæ, and starting with the earliest known *Calymene* occurring in our British rocks of Ordovician age we may note that the general form of the glabella is still definitely oval or parabolic in outline, the neck furrow incompletely developed, and the two glabella furrows fairly deep but short and oblique, giving more the idea of indenting the general outline of the glabella than of cutting off a lobe; the outer edge of the segment too, being still that of the outline of the glabella, is straight; there is, moreover, at this stage no very conspicuous difference in size between the two segments, though there is a tendency for the posterior pair to be slightly the larger of the two. This is the form known as *Calymene tristani*, which is characteristic of the trilobitic beds immediately below and associated with the graptolite zone of *Didymog. extensus*. At a slightly higher horizon, that of the graptolite zone of *Didymog. hirundo*, there is found a similar form hardly to be distinguished from *C. tristani* except for the *greater distinction of the basal lobe* and the curvature of the second pair of glabella furrows (*C. parvifrons*), whilst another type with a less parabolic glabella more truncated in front makes its first appearance (var. *Murchisoni*). Within the Ordovician up to this horizon, despite various descriptions hinting the contrary, I have never observed any *Calymene* which had any indication of more than two glabella segments, but in higher beds the equivalents of the zone of *Didymog. bifidus* there may be detected in some forms, otherwise very closely allied to the *C. parvifrons* of the horizon of the zone of *Didymog. hirundo*, the occasional presence of a third glabella furrow; this is, however, always obscure, and its presence is generally accompanied by a very definite difference in size in the glabella segments, largely induced by the increase in breadth of the furrows, the basal segment at this stage being very decidedly the larger. By the time the horizon of the Llandilo Limestone is reached (zone of *Didymog. Murchisoni*) this third lobe, minute though it be, is constant and perfectly definite in form; also the proximal pair of glabella furrows are now curved to such an extent that the basal segment may be regarded as constituting a pair of basal lobes; the curved furrow is, however, so shallow for part of its course in the middle that there is still a distinct 'neck of attachment.' The so-called bifurcation of the glabella furrow, to which much importance has been attached in classification, seems to arise as a direct consequence of this tendency to lobation; the lobation of the basal segment is not, however, yet complete; there is still some angularity on the outer side, the oval parabolic outline of the glabella as a whole being still obvious.

This stage, the development of a basal lobe and the presence of a third segment, seems to mark a definite advance and to constitute a very successful form, for this *Calymene*, *C. cambrensis*, is very stable in its characters in many different kinds of sediment, and has a wide distribution in space. In our own country it is one of the few trilobites found in both the Scotch and Welsh types of the Llandilian.

All the *Calymenes* hitherto dealt with are characterised by the possession of a broad frontal region, which has, however, steadily decreased in size relatively to the glabella, but at this horizon there appear to be two forms to both of which the name *C. cambrensis* seems to have been applied, in one of which there is a far more conspicuous diminution in breadth of the margin than in the other, though both are at the same stage of evolution as respects their glabella lobes. This suggests that the marginal development is going to be a factor of importance, and from what happens later it is clear that this is the case, and when it takes place some retardation may be expected on the older line, either as regards the number of the lobes or as regards the perfection of their development.

In *Calymene planimarginata*, the common Caradocian form which retains its broad margin, further development on the old lines takes place; the third lobe, though still small, becomes more definite; there is marked disparity in size as between segments 1 and 2, both of which are distinctly more lobate in character, having lost to a large extent the angularity of the outer margin, though those specimens characteristic of the lower part of the Caradocian (*alternata beds*) are distinctly less perfectly lobate than those of the higher *chasmops beds*; in the lower beds the third segment, though definite, is not lobate at all, whilst at the higher horizon it is lobate but with a definite neck of attachment. Both these forms of *C. planimarginata* are characteristic of the horizon of the graptolite zone of *Dicranog. clingani*, but others also occur showing that the line has begun to branch in various directions leading into different species-groups, the details of which have still to be worked out. It is, however, clear, I think, that the state of evolution of the glabella lobes may afford a valuable index of the age of the beds in which it occurs.

Further investigation is required to show how far this parallel evolution takes place at approximately the same time in remote areas in different species-groups. So far as I have investigated the problem it would appear to be broadly true in the case of the deeper-water



1. Calymene tristani. (Zone of D. extensus.)

2. Calymene parvifrons. (Zone of D. hirundo.)

3. Calymene parvifrons mut. (Zone of D. bifidus.)

4. Calymene cambrensis. (Zone of D. Murchisoni.)

5. Calymene planimarginata. (Zone of Dicranog. clingani.)

faunas, for so far as the graptolites are concerned the outstanding stages in evolution are reached in the majority of cases at approximately the same time along many different routes, though there are some exceptions, for which the reason is, however, usually obvious. So far as the *Calymenes* are concerned it is of great interest to note that those of Bohemia, though constituting a different species-group from those found in this country, undergo a precisely similar evolution at the same time; thus *C. arago* of D.1. γ shows a very slight and faint indication of a third lobe with a straight outer edge to the glabella, a precisely similar stage to that of *C. parvifrons* in this country; so, too, *C. parvula* of D.d.2. is at a stage of development similar to that of *C. cambrensis*, as is also *C. pulchra* at the same horizon in yet another species-group.

It would, I believe, be perfectly possible to adopt a classification of the whole of the Ordovician based upon the evolutional sequence of the various *Calymenes*.

All these facts illustrate that even from the purely palæontological standpoint much field knowledge is essential if a right conception is to be gained of the true relationship existing between species and species. It appears to be also in the highest degree necessary to view a succession of forms like those I have quoted in order to determine what characters are really of importance in the recognition of species.

Also, when lines of evolution result in the attainment of successful forms, not only do these appear to be numerically abundant, but it would seem also that they have a wide distribution in space.

So much, then, for a possible line of evolution in the head of a trilobite; we may next consider the evolution of the pygidium in a very different form. An interesting study of this appears to be afforded by the species-group of *Encrinurus punctatus*. As is well known in the commonest type of this trilobite occurring in the Wenlock Limestone of Dudley, the axis of the pygidium shows a far greater degree of segmentation than do the lateral lobes; this may be interpreted as implying that numerous segments have been incorporated into the tail with a greater degree of fusion in the side lobes than in the axis. The species, moreover, is commonly recognised as possessing two well-marked varieties, var. *arenaceus* and var. *calcareus*, differing chiefly from each other in the possession of a definite mucro in var. *calcareus*, which has been interpreted as being connected with the supply of calcareous matter available, but, viewing the species-group as a whole, it would seem rather to be the natural culmination or acme of a definite tendency to fusion which is developed with increasing persistence throughout its history in time so far as I have been able to study it.

The earliest forms which I have examined are to be found at the horizon of the Stinchar Limestone in Scotland and the Derfel Limestone of Wales. The graptolite shales associated with these limestones prove their age to be Llandilian. At this horizon the relation between the segments of the axis and the lateral lobes of the pygidium never exceeds 2:1, whilst in the two earliest segments the proportion is very clearly 1:1; in the Caradocian the proportion rises to 3:1 for segments 5 and 6, whilst the Ashgillian forms (*multisegmentatus* stage) show 2:1 for segment 2 and still 3:1 for segments 5 and 6. In the Lower Valentian segment 4 has risen to 3:1, whilst in the Upper Valentian it is commonly the third, though there is some variation, since in some cases all that it is possible to make out is that there are five segments in the axis compared with two (2 and 3) in the lateral lobes. In the succeeding Wenlock forms the culmination is reached with 3:1 for segments 2-5, and 4:1 at the sixth; in all these later forms there is a tendency to fusion of the later lateral lobes with the axis, partially, as in the case of 7 and 8, throughout their length, and more definitely at their terminations.

FUSION OF SEGMENTS OF TAIL IN SPECIES-GROUP OF ENCRINURUS PUNCTATUS.

—		Llandilian			Caradocian	Ashgillian			Valentian								Salopian	
Segments on side lobes of pygidium		Derfel Lst.	Stinchar Lst.	Stinchar Lst.	Middle Bala Dent	Slade Beds, Haverfordwest	Slade Beds, Haverfordwest	Drummock Beds, Thraive Glen	Ritton Castle, Shelve	Tortworth	Skelgill	Mulloch Hill Beds, Rough Neuk	Saugh Hill Beds, Woodland Point	Saugh Hill Beds, Newlands	Camregan Beds, Camregan	Up. Llandovery, Penlan	Wenlock Lst., Dudley	Gothland Lst., Sweden
I.	I.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
II.	I.	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	3	3
III.	I.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3?	3	3
IV.	I.	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3
V.	I.	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3
VI.	I.	?	2	2	3	3	3	?	3	3	?	?	3	3	3	3	4	4
VII.	I.	?	2	?	?	?	?	?	?	?	?	?	?	3	?	?	?	?
VIII.	I.	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?

The species-group of *Encrinurus sexcostatus* would appear to show a similar evolutional stage at similar horizons, though in this the line at present is incomplete.

Facts such as I have enumerated in the different groups of fossils with which we have mainly to deal in Lower Palæozoic rocks show that, if viewed from the evolutional standpoint, even the most meagre fauna may yet in many cases be made to yield a considerable amount of information as to the age of the beds containing it, for the evolutional succession, once established, can be applied anywhere, and the explanation of any apparent anomalies will be more correctly sought in the mutual relations of the rocks than in the faunas they contain.

Moreover, as regards the varying shallow-water faunas, even those which have a generally similar aspect may be shown definitely to be of different ages when one as a whole contains fossils at a different stage of evolution from the other, and the apparent similarity, so striking upon superficial examination, will then be regarded as determined by physical conditions and not by contemporaneity. Working on lines such as these we shall be enabled to visualise more definitely the conditions which governed the distribution of the different faunas in the remote past, and thereby acquire a more accurate conception of the changes in physical geography that must have taken place with the progress of time.

MODERN ZOOLOGY:

SOME OF ITS DEVELOPMENTS AND ITS BEARINGS ON HUMAN WELFARE.

ADDRESS TO SECTION D (ZOOLOGY) BY

PROFESSOR J. H. ASHWORTH, D.Sc., F.R.S.,

PRESIDENT OF THE SECTION.

Zoology has far outgrown its early boundaries when it could be defined simply as a part of natural history, and at no period has its growth been more rapid or more productive in results of scientific and practical importance than in the interval since our last meeting in this city. It is however impossible, even if time permitted, for any one observer to survey the many lines of activity in zoology or to record its contributions to knowledge in this fruitful period. I have thought it might be profitable to endeavour to take in retrospective glance the broad outlines of development of zoology during the last two or three decades, and then to limit our further consideration more especially to some of the relations of zoology to human welfare. The period under review has witnessed a growth of our knowledge of the living organism of the same order of importance as the progress in our knowledge of the atom. Never have investigators probed so deeply or with so much insight into the fundamental problems of the living animal; the means for observation and recording have become more delicate, and technique of all kinds more perfect, so that we can perceive details of structure and follow manifestations of activity of the organism which escaped our predecessors.

At the time of the last Liverpool Meeting and for some few years previously, a distrust of the morphological method as applied to the study of evolution had been expressed by a number of zoologists. At that meeting Professor MacBride put forward an able defence of morphology while recognising that the morphological method had its limitations, which must be observed if the conclusions are to rest on safe ground. Through undue zeal of some of its devotees morphology had been pushed too far on arid and unproductive lines, and rash speculation based on unsound morphology brought discredit on this branch of our science. It is now fully recognised that the observed resemblances between animals are due, some of them to genetic relationships, and others to convergent evolution, and therefore that the conclusions drawn from the study of morphology are to be interpreted with the greatest circumspection. There are some groups of animals, *e.g.* the earthworms, in regard to the evolutionary history of which we can never hope to receive help from palæontology; we must perforce make the best use we can of the morphological method applied, be it understood, with wide knowledge and deep insight. That careful systematic work, coupled with the skilful application of sound morphological principles, is capable of yielding results of specific and general importance is well illustrated by the researches of Michaelsen and of Stephenson on Indian Oligochætes; these authors have been able to trace the lines of evolution of the members of the family Megascolecidæ so completely that we know their history as well as we know that of the Equidæ. Again, to take an example from a different category, the fine morphological work on the cell and on the nucleus and its chromosomes which we owe to Hertwig, Flemming, Boveri, van Beneden, Wilson and others, made possible the modern researches and conceptions in regard to inheritance and sex. The danger that morphology will be pushed to excess is long past; the peril seems to me to be rather in the opposite direction, *i.e.* that some of our students before passing on to research receive too little of that training and discipline in exact morphology by which alone they can be brought to appreciate how the components of the living organism are related to one another and to those of allied species or genera, and how they afford, with proper handling, many data for the evolutionist. I plead, therefore, for the retention of a sound and adequate basis of morphology in our zoological courses.

No one who engages in the study of morphological problems can proceed far without meeting questions which stimulate enquiry of a physiological nature, and, where means are available, resort to experimental procedure is the natural mode of arriving at the answer. That morphology is detrimental to or excludes experimental or physiological methods is entirely contrary to present day experience, and indeed the fruitfulness of the combination of morphology and physiology could have been amply illustrated any time during the last eighty years simply by reference to the work of Johannes Müller. The structure of an organism must be known before its co-ordinated movements can be adequately appreciated—morphology must be the forerunner of physiology.

Another of the basal supports of our science an appreciation of which, or better still a training in some branch of which, we must encourage is the systematic or taxonomic aspect. The student or graduate who is proceeding to specialise in experimental zoology or in genetics particularly requires a sound appreciation of the fact that the accurate determination of the genus and species under investigation is a primary requisite for all critical work—it is part of the fundamental data of the experiment and is essential, if for nothing else, to permit subsequent observers to repeat and perhaps to extend any given series of observations. Moreover, the systematic position of an animal is an expression of the final summary of its morphology and its genetic relationships, and it is from such summaries that we have to attempt in many cases—as, for example, in the Oligochætes already cited—to discover in a restricted group or order the probable course of evolution, though the method of evolution may not be ascertainable. From these summaries prepared by systematists issue problems for the experimental evolutionist and the geneticist. As Mr. Bateson has pointed out, it is from the systematist who has never lost the longing for the truth about evolution that the raw materials for genetical researches are to be drawn, and the separation of the laboratory men from the systematists imperils the work and the outlook of both.

Among the notable features of zoological activity during the last twenty-five years the amount of work on the physiology of organisms other than mammals must attract early notice in any general survey of the period. Eighty years ago Johannes Müller's physiological work was largely from the comparative standpoint, but for some years after his death the comparative method fell into disuse, and the science of physiology was concerned chiefly with the mode of action of the organs of man or of animals closely related to man, the results of which have been of outstanding importance from their bearing on medicine. Interest in the more general applications of physiology was revived by Claude Bernard (' Leçons sur les phénomènes de la vie,' 1878), and the appearance of Max Verworn's ' General Physiology,' in 1894, was in no inconsiderable measure responsible for the rapid extension of physiological methods of enquiry to the lower organisms—a development which has led to advances of fundamental importance. Many marine and freshwater organisms lend themselves more readily than the higher vertebrates to experimentation on the effects of alterations in the surrounding medium, on changes in metabolic activity, on the problems of fertilisation and early development, on the chemistry of growth and decline, and to the direct observation of the functioning of the individual organs and of the effects thereon of different kinds of stimuli. The study of these phenomena has greatly modified our interpretation of the responses of animals and has given a new impetus to the investigation of the biology and habits of animals, *i.e.* animal behaviour. This line of work—represented in the past by notable contributions such as those by Darwin on earthworms, and by Lubbock on ants, bees and wasps—has assumed during the last two or three decades a more intensive form, and has afforded a more adequate idea of the living organism as a working entity, and revealed the delicacy of balance which exists between structure, activity and environment. This closer correlation of form, function and reaction is of the greatest value to the teacher of zoology, enabling him to emphasise in his teaching that for the adequate appreciation of animal structure a clear insight into the activities of the organism as a living thing is essential.

The penetrating light of modern investigation is being directed into the organism from its earliest stage. During the summer of 1897 Morgan discovered that the eggs of sea-urchins when placed in a two per cent. solution of sodium chloride in sea-water and then transferred to ordinary sea-water would undergo cleavage and give rise to larvæ, and J. Loeb's investigations in this field are familiar to all students of zoology. Artificial parthenogenesis is not restricted to the eggs of invertebrates, for Loeb and others have shown that the eggs of frogs may be made to develop by pricking them with a needle, and from such eggs frogs have been reared until they were fourteen months old. The application of the methods of microdissection to the eggs of sea-urchins is leading to a fuller knowledge of the constitution of the egg, of the method of penetration of the sperm, and of the nuclear and cytoplasmic phenomena accompanying maturation and fertilisation, and will no doubt be pursued with the object of arriving at a still closer analysis of the details of fertilisation.

The desire for more minute examination of developing embryos led to the more careful study of the egg-cleavage, so that in cases suitable for this method of investigation each blastomere and its products were followed throughout development, and thus the individual share of the blastomere in the cellular genesis of the various parts of the body was traced. This method had been introduced by Whitman in his thesis on Clepsine (1878), but it was not until after the classical papers of Boveri on Ascaris (1892) and E. B. Wilson on Nereis (1892) that it came into extensive use. About the time of our last meeting here, and for the next twelve or fifteen years, elaborate studies on cell-lineage formed a feature of zoological literature and afforded precise evidence on the mode of origin of the organs and tissues, especially of worms, molluscs and ascidians. A further result of the intensive study of egg-cleavage has been to bring into prominence the distinction between soma-cells and germ-cells, which in some animals is recognisable at a very early stage, *e.g.* in Miastor at the eight-cell stage. The evidence from this and other animals exhibiting early segregation of germ-cells supports the view that there is a germ-path and a continuity of germ-cells, but the advocates of this view are constrained to admit there are many cases in which up to the present an indication of the early differentiation of the germ-cells has not been forthcoming on investigation, and that the principle cannot be held to be generally established.

A cognate line of progress which, during the period under review, has issued from the intensive study of the egg and its development is experimental embryology—devoted to the experimental investigation of the physical and chemical conditions which underlie the transformation of the egg into embryo and adult. By altering first one and then another condition our knowledge of development has been greatly extended, by artificial separation of the blastomeres the power of adjustment and regulation during development has been investigated, and by further exploration of the nature of the egg the presence of substances foreshadowing the relative proportions and positions of future organs has been revealed in certain cases, the most striking of which is the egg of the Ascidian *Cynthia partita* (Conklin, 1905). Still further intensive study of the cytoplasm and nuclei of eggs and cleavage stages is required to throw light on the many problems which remain unsolved in this domain.

Progress in investigation of the egg has been paralleled by increase in our knowledge of the germ-cells, especially during their maturation into eggs and sperms, the utmost refinements of technique and observation having been brought to bear on these and on other cells. During the last thirty years, and especially during the latter half of this period, cytology has developed so rapidly that it has become one of the most important branches of modern biology. One of the landmarks in its progress was the appearance, at the end of 1896, of E. B. Wilson's book on 'The Cell,' and we look forward with great expectations to the new edition which, it is understood, is in an advanced stage of preparation. A great stimulus to cytological work resulted from the rediscovery in 1900 of the principle of heredity published by Mendel in 1865, which showed that a relatively simple conception was sufficient to explain the method of inheritance in the examples chosen for his experiments, for in 1902 Sutton pointed out that an application of the facts then known as to the behaviour of the chromosomes would provide an explanation of the observed facts of Mendelian inheritance. In the same year McClung suggested that the accessory chromosome in the male germ-cells is a sex-determinant. These two papers may be taken as the starting-point of that vast series of researches which have gone far toward the elucidation of two of the great problems of biology—the structural basis of heredity and the nuclear mechanism correlated with sex. The evidence put forward by Morgan and his colleagues, resulting from their work on Drosophila, would seem to permit little possibility of doubt that factors or genes are carried in the chromosomes of the gametes, and that the behaviour of the chromosomes during maturation of the germ-cells and in fertilisation offers a valid explanation of the mode of inheritance of characters. The solution of this great riddle of biology has been arrived at through persistent observation and experiment and by critical analysis of the results from the point of view of the morphologist, the systematist, the cytologist, and the geneticist.

Among other important developments in the period, reference may be made to the great activity in investigation of the finer structure of the nerve-cell and its processes. By 1891 the general anatomical relations of nerve-cells and nerve-fibres had been cleared up largely through the brilliant work of Golgi and Cajal on the brain and spinal cord, and of von Lenhossék, Retzius, and others on the nervous system of annelids and other invertebrates. In these latter had been recognised the receptor cells, the motor or effector cells, and intermediary or internunciary cells interpolated between the receptors and effectors. In June 1891 Waldeyer put forward the neurone theory, the essence of which is that the nerve-cells are independent and that the processes of one cell, though coming into contiguous relation and interlacing with those of another cell, do not pass over into continuity. He founded his views partly upon evidence from embryological researches by His, but chiefly on results obtained from Golgi preparations and from anatomical investigations by Cajal. The neurone theory aroused sharp controversy, and this stimulus turned many acute observers—zoologists and histologists—to the intimate study of the nerve-cell. First among the able opponents of the theory was Apáthy, whose well-known paper, published in 1897, on the conducting element of the nervous system and its topographical relations to the cells, first made known to us the presence of the neurofibrillar network in the body of the nerve-cell and the neurofibrils in the cell-processes. Apáthy held that the neurofibrillar system formed a continuous network in the central nervous system, and he propounded a new theory of the constitution of the latter, and was supported in his opposition to the neurone theory by Bethe, Nissl, and others. The controversy swung to and fro for some years, but the neurone theory—with certain modifications—seems now to have established itself as a working doctrine. The theory first enunciated as the result of morphological studies receives support from the experimental proof of a slight arrest of the nerve-impulse at the synapse between two neurones, which causes a measurable delay in the transmission. The latest development in morphological work on nerve-elements is the investigation of the neuromotor system in the Protozoa. Sharp (1914), Yocom (1918), and Taylor (1920), working in Kofoid's laboratory, have examined this mechanism in the ciliates Diplodinium and Euplotes and they describe and figure a mass—the neuromotorium—from which fibrils pass to the motor organs, to the sensory lip, and, in Diplodinium, to a ring round the œsophagus. The function of the apparatus is apparently not supporting or contractile, but conducting. By the application of the finest methods of micro-dissection specimens of Euplotes have been operated upon while they were observed under an oil-immersion objective. Severance of the fibres destroyed co-ordination between the membranelles and the cirri, but other incisions of similar extent made without injuring the fibrillar apparatus did not impair co-ordination, and experiments on Paramæcium by Rees (1922) have yielded similar results. While the experimental evidence is as yet less conclusive than the morphological, it supports the latter in the view that the fibrils have a conducting, co-ordinating function. Progress in our knowledge of the nervous system is but one of many lines of advance in our understanding of the correlation and regulation of the component parts of the animal organism.

The ciliate protozoa have been the subject during the last twenty years of a series of investigations of great interest, conducted with the purpose of ascertaining whether decline and death depend on inherent factors or on external conditions. While these researches have been in progress we have come to realise more fully that ciliates are by no means simple cells, and that some of them are organisms of highly complex structure. Twenty years ago Calkins succeeded in maintaining a strain of Paramæcium for twenty-three months, during which there were 742 successive divisions or generations, but the strain, which had exhibited signs of depression at intervals of about three months, finally died out, apparently from exhaustion. From this work, and the previous work of Maupas and Hertwig, the opinion became general that ciliates are able to pass through only a limited number of divisions, after which the animals weaken, become abnormal and die, and it was believed that the only way by which death could be averted was by a process of mating or conjugation involving an interchange of nuclear material between the two conjugants and resulting in a complete reorganisation of the nuclear apparatus. Jennings has shown that conjugation is not necessarily beneficial, that the ex-conjugants vary greatly in vitality and reproductive power, and that in most cases the division rate is less than before conjugation. Woodruff has since May 1, 1907, kept under constant conditions in culture a race of Paramæcium. During the sixteen years there have been some ten thousand generations, and there seems no likelihood of or reason for the death of the race so long as proper conditions are maintained. The possibility of conjugation has been precluded by isolation of the products of division in the main line of the culture, and the conclusion is justifiable that conjugation is not necessary for the continued life of the organism. The criticism that Woodruff's stock might be a non-conjugating race was met by placing the Paramæcia, left over from the direct line of culture under other conditions when conjugation was found to occur. Later observations by Erdmann and Woodruff show that a reorganisation of the nuclear apparatus of Paramæcium takes place about every twenty-five to thirty days (forty to fifty generations). This process, termed endomixis (in contrast to amphimixis), seems to be a normal event in the several races of Paramæcium which Erdmann and Woodruff have examined, and it is proved to coincide with the low points or depressions in the rhythm exhibited by Paramæcium. The occurrence of endomixis raises the question, to which at present there is no answer, as to whether this process is necessary for the continued health of the nuclear apparatus and of the cytoplasm of Paramæcium.

Enriques (1916) maintained a ciliate—*Glaucoma pyriformis*—through 2,701 generations without conjugation, and almost certainly without endomixis. From a single 'wild' specimen he raised a large number and found that conjugating pairs were abundant, so that the objection could not be made that this was a non-conjugating race. Enriques then began his culture with one individual, and examined the descendants morning and evening, removing each time a specimen for the succeeding culture. The number of divisions per day varied from nine to thirteen, and as there was no break in the regularity and rapidity of division, and no sort of depression, Enriques concluded that neither endomixis nor conjugation could have occurred, for these processes take some time and would have considerably reduced the rate of division. These results, especially if they are confirmed by cytological study of preserved examples, show that for Glaucoma neither conjugation nor endomixis is necessary for continued healthy existence. Hartmann's observations (1917) on the flagellate *Eudorina elegans* extend the conclusion to another class of Protozoa. He followed this flagellate through 550 generations in two and a-half years. The mode of reproduction was purely asexual, and there was no depression and no nuclear reorganisation other than that following fission. The evidence seems sufficient to confirm the view that certain Protozoa, if kept under favourable conditions, can maintain their vigour and divide indefinitely, without either amphimixis or endomixis.

Child (1915) states as the result of his experiments that the rate of metabolism is highest in Paramæcium and other ciliates immediately after fission—'in other words, after fission the animals are physiologically younger than before fission.' This view, that rejuvenescence occurs with each fission, derives support from the observations of Enriques and Hartmann, for no other process was found to be taking place and yet the vigour of their organisms in culture was unimpaired. If, then, fission is sufficiently frequent—that is, if the conditions for growth remain favourable—the protoplasm maintains its vigour. If through changes in the external conditions the division rate falls, the rejuvenescence at each fission may not be sufficient to balance the deterioration taking place between the less frequent divisions. Under such conditions endomixis or conjugation may occur with beneficial results in some cases, but if these processes are precluded there is apparently nothing to arrest the progressive decline or 'ageing' observed by Maupas and others. But further investigations are required on the physiology and morphology of decline in the protozoan individual.

The culture of tissues outside the body is throwing new light on the conditions requisite for the multiplication and differentiation of cells. R. G. Harrison (1907) was the first to devise a successful method by which the growth of somatic cells in culture could be followed under the microscope, and he was able to demonstrate the outgrowth of nerve-fibres from the central nervous tissue of the frog. Burrows (1911), after modifying the technique, cultivated nervous tissue, heart-cells, and mesenchymatous tissue of the chick in blood-plasma and embryonic extract, and this method has become a well-established means of investigation of cell-growth, tissues from the dog, cat, rat, guinea-pig, and man having been successfully grown. One strain of connective tissue-cells (fibroblasts) from the chick has been maintained in culture in vigorous condition for more than ten years, that is for probably some years longer than would have been the normal length of life of the cells in the fowl. Heart-cells may be grown generation after generation—all traces of the original fragment of tissue having disappeared—the cells forming a thin, rapidly growing, pulsating sheet. Drew (1922) has recently used instead of coagulated plasma a fluid medium containing calcium salts in a colloidal condition, and has obtained successful growth of various tissues from the mouse. He finds that epithelial cells when growing alone remain undifferentiated, but on the addition of connective tissue differentiation soon sets in, squamous epithelium producing keratin, mammary epithelium giving rise to acinous branching structures, and when heart-cells grow in proximity to connective tissue they exhibit typical myofibrillæ, but if the heart-cells grow apart from the connective tissue they form spindle-shaped cells without myofibrillæ. This study of the conditions which determine the growth and differentiation of cells is only at the beginning, but it is evident that a new line of investigation of great promise has been opened up which should lead also to a knowledge of the factors which determine slowing down of the division-rate and the cessation of division, and finally the complete decline of the cell.

For many lines of work in modern zoology biochemical methods are obviously essential, and the applications of physics to biology are likewise highly important—*e.g.* in studies of the form and development of organisms and of skeletal structures. Without entering into the vexed question as to whether all responses to stimuli are capable of explanation in terms of chemistry and physics, it is very evident that modern developments have led to the increasing application of chemical and physical methods to biological investigation, and consequently to a closer union between biology, chemistry, and physics. It is clear also that the association of zoology with medicine is in more than one respect becoming progressively closer—comparative anatomy and embryology, cytology, neurology, genetics, entomology, and parasitology, all have their bearing on human welfare.

Some Bearings of Zoology on Human Welfare.

The bearings of zoology on human welfare—as illustrated by the relation of insects, protozoa and helminthes to the spread or causation of disease in man—have become increasingly evident in these later years and are familiar to every student of zoology or of medicine. At the time of our last meeting in Liverpool, insects were suspected of acting as transmitters of certain pathogenic organisms to man, but these cases were few and in no single instance had the life-cycle of the organism been worked out and the mode of its transmission from insect to man ascertained. The late Sir Patrick Manson, working in Amoy, had shown (1878) that the larvæ of *Filaria bancrofti* undergo growth and metamorphosis in mosquitoes, but the mode of transference of the metamorphosed larvæ was not determined until 1900. Nearly two years after our last meeting here the part played by the mosquito as host and transmitter of the parasite of malaria was made known by Ross. In addition to these two cases at least eight important examples can now be cited of arthropods proved to act as carriers of pathogenic organisms to man—*e.g.* Stegomyia—yellow fever, Phlebotomus—sandfly fever, tsetse-flies—sleeping sickness, Conorhinus—South American trypanosomiasis (Chagas' Disease), Chrysops—*Filaria* (*Loa*) *loa*, the flea *Xenopsylla cheopis*—plague, the body-louse—trench fever, relapsing fever and typhus, and the tick Ornithodorus—African relapsing fever. In selecting examples for brief consideration I propose to deal very shortly with malaria, although it is the most important of the insect-carried diseases, because the essential relations between the Anopheles mosquito and the parasite are known to everyone here. There still remain lacunæ in our knowledge of the malarial organisms. Ross and Thomson (1910), working in this city, showed that asexual forms of the parasite tend to persist in small numbers between relapses, and suggested that infection is maintained by these asexual stages. Such explanation elucidates those cases in which relapses occur after short intervals, but the recurrence of the attacks of fever after long intervals can only be explained by assuming that the parasites lie dormant in the body—and we know neither in what part of the body nor in what stage or condition they persist. Nevertheless, the cardinal points about the organism are established, and preventive measures and methods of attack based on a knowledge of the habits and bionomics of Anopheles have been fruitful in beneficial results in many parts of the world.

If we desire an illustration of the vast difference to human well-being between knowing and not knowing how a disease-germ is transmitted to man, we may turn to the case of yellow fever. When this pestilence came from the unknown, and no one knew how to check it, its appearance in a community gave rise to extreme despair and in many cases was the signal for wholesale migration of those inhabitants who could leave the place. But with the discovery that Stegomyia was the transmitting agent all this was changed. The municipality or district took steps to organise its preventive defences against a now tangible enemy, and the successful issue of these efforts, with the consequent great saving of life and reduction of human suffering in the Southern United States, in Panama, in Havana and in other places, is common knowledge. It is a striking fact that during 1922 Central America, the West Indies, and all but one country of South America were free from yellow fever, which has ravaged these regions for nearly two centuries. The campaign against Stegomyia is resulting, as a recent Rockefeller report points out, in yellow fever being restricted to rapidly diminishing, isolated areas, and this disease seems to be one which by persistent effort can be brought completely under control.

In 1895 Bruce went to Zululand to investigate the tsetse-fly disease which had made large tracts of Africa uninhabitable for stock, and near the end of the same year he issued his preliminary report in which he showed that the disease was not caused by some poison elaborated by the fly—as had been formerly believed—but was due to a minute flagellate organism, a trypanosome, conveyed from affected to healthy animals by a tsetse-fly (*Glossina morsitans*). In 1901 Forde noticed an active organism in the blood of an Englishman in Gambia suffering from irregularly intermittent fever, and Dutton (1902) recognised it as a trypanosome, which he named *Trypanosoma gambiense*. In 1902 Castellani found trypanosomes in the blood and cerebro-spinal fluid of natives with sleeping sickness in Uganda, and suggested that the trypanosome was the causal organism of the disease. The Sleeping Sickness Commission (Bruce and his colleagues) confirmed this view, and showed that a tsetse-fly, *Glossina palpalis*, was the transmitter. Since then much has been learnt regarding the multiplication of the trypansosome in the fly and its transference to man. For some years this was believed to take place by the direct method, but in 1908 Kleine demonstrated 'cyclical' transmission, and this was shown later to be the principal means of transference of *T. gambiense*. In 1910 Stephens and Fantham described from an Englishman, who had become infected in Rhodesia, a trypanosome which, from its morphological characters and greater virulence, they regarded as a new species, *T. rhodesiense*, and its 'cyclical' transmission by *Glossina morsitans* was proved by Kinghorn and Yorke. Recent reports by Duke and Swynnerton (1923) of investigations in Tanganyika Territory suggest that direct rather than cyclical transmission by a new species of Glossina is there mainly responsible for the spread of a trypanosome of the *rhodesiense* type. The impossibility of distinguishing by their morphology what are considered to be different species of trypanosomes, and the difficulty of attacking the fly, are handicaps to progress in the campaign against sleeping sickness, which presents some of the most subtle problems in present day entomology and protozoology. Here also we come upon perplexing conditions due apparently to the different virulence of separate strains of the same species of trypanosome and the varying tolerance of individual hosts—on which subjects much further work is required.

The relation of fleas to plague provides one of the best and most recent illustrations of the necessity for careful work on the systematics and on the structure and bionomics of insects concerned in carrying pathogenic organisms. Plague was introduced into Bombay in autumn 1896, and during the next two years extended over the greater part of Bombay Presidency and was carried to distant provinces. The Indian Government requested that a Commission should be sent out to investigate the conditions. This Commission, which visited India in 1898-99, came to the conclusion (1901) that rats spread plague and that infection of man took place through the skin, but—and this is amazing to us at the present day—'that suctorial insects do not come under consideration in connection with the spread of plague.' Further observations, however, soon showed this conclusion to be erroneous. Liston found in Bombay in 1903 that the common rat-flea was *Pulex* (*Xenopsylla*) *cheopis*, that it was present in houses in which rats had died of plague and in which some of the residents had become infected, that the plague-bacillus could multiply in the stomach of this flea, and that the flea would —in the absence of its usual host—attack man. These observations pointed to the importance of this flea in the dissemination of plague, and the Second Plague Commission, which was appointed and began work in 1905, definitely proved that *Xenopsylla cheopis* is the transmitter of the plague-organism from rat to rat and from rat to man. The mechanism of transmission of the plague-bacillus was worked out by Bacot and Martin in 1913. They showed that in a proportion of these fleas fed on the blood of septicæmic mice the plague-bacilli multiply in the proventriculus—which is provided with chitinous processes that act as a valve to prevent regurgitation of the blood from the stomach—and a mass of bacilli is formed which blocks the proventriculus and may extend forward into the œsophagus. Fleas in this condition are not prevented from sucking blood because the pharynx is the suctorial organ, but their attempts to obtain blood result only in distending the œsophagus. The blood drawn into the œsophagus is repeatedly forced backwards into contact with the mass of plague-bacilli and on the sucking action ceasing some of this infected blood is expelled into the wound. The transmission of plague depends on the peculiar structure of the proventriculus of the flea and on the extent to which, in certain examples, the plague-bacilli multiply in the proventriculus. Such 'blocked' fleas being unable to take blood into the stomach are in a starved condition, and make repeated attempts to feed, and hence are particularly dangerous.

Until 1913 it was believed that all the fleas of the genus Xenopsylla found on rats in India belonged to one species—*cheopis*, but in that year L. F. Hirst reported that the rat-flea of Colombo was *X. astia*, which had been taken off rats in Rangoon, and described by N. C. Rothschild in 1911. Hirst ascertained that this flea did not readily bite man if the temperature were above 80° F. A collection of 788 fleas from Madras City proved to consist entirely of *X. astia*, and Hirst suggested that the explanation of the immunity of Madras and Colombo from plague was the relative inefficiency of *X. astia* as a transmitter. Cragg's examination (1921, 1923) of 23,657 fleas obtained from rats in all parts of India shows that they include three species of Xenopsylla—namely, *cheopis*, *astia*, and *brasiliensis*. This last species is common in the central and northern uplands of peninsular India, but its bionomics have not yet been investigated. *Cheopis* is the predominant species in the plague areas, while *astia* is the common flea in those areas which have remained free from plague or have suffered only lightly. In Madras City, for instance, during the twenty-one years, 1897-1917, plague has occurred in twenty of these years, but the average mortality was only .013 per thousand—that is, though the infection has been repeatedly introduced there, it failed each time to set up an epidemic.

The significance of an imported case of plague depends in large measure on the local species of Xenopsylla. Hirst has made numerous attempts during the plague season in Colombo to transmit plague by means of *X. astia* from rat to rat, but with negative results, and *X. astia* was never found to behave like a 'blocked' *cheopis*.

The distinction of *X. cheopis* from *X. astia* is not an entomological refinement with purely systematic significance, but corresponds with a different relation of the species to the epidemiology of plague, and hence becomes a factor of great practical importance. If through these researches it has become possible by examination of the rat-fleas of a locality to estimate accurately its liability to plague, anti-plague measures may henceforward be restricted to those areas in which plague is likely to occur, *i.e.* where *cheopis* is the predominant flea. Thus a great economy of effort and of expenditure and a higher degree of efficiency may be achieved; in fact, the problem of the prevention or reduction of plague may be brought from unwieldy to practicable proportions. When it is remembered that since we last met in Liverpool some ten and a quarter millions of people have died in India from plague we have a more than sufficient index of the importance of a precise knowledge of the systematics, structure, and bionomics of the insect-carrier of *Bacillus pestis*.

Another of the outstanding features of the period under review has been the extensive and intensive study of the Protozoa. The structure and the bionomics and life-history of these organisms have been investigated with the help of the finest developments of modern technique. It is fitting here to record our acknowledgment to two staining methods—Heidenhain's iron-hæmatoxylin and the Romanowsky stain (including Giemsa's and Leishman's modifications), which have added greatly to our technical resources.

There is time to refer only to certain of the Protozoa which directly affect man. Twenty years ago our knowledge of the few species of Protozoa recorded from the human alimentary canal was defective in two important respects—the systematic characters and the biology of the species—so there was much confusion. Subsequent investigations, and especially those of the last ten years (by Wenyon, Dobell, and others), have cleared up most of the doubtful points, but owing to the difficulties of size and the paucity of characters available it is by no means easy in practice to distinguish certain of the species. Of the seventeen species now known to occur in the intestine of man *Entamœba histolytica* has received particular attention. This organism lives as a tissue parasite in the wall of the large intestine, where, as a rule, the damage caused is counterbalanced by the host's regenerative processes. But when the destruction outstrips the regeneration intestinal disturbance results, leading to the condition known as amœbic dysentery. The specific characters and the processes of reproduction and encystment of *E. histolytica* are now well ascertained, and it is realised that in the majority of cases the host is healthy, acting as a 'carrier' dangerous to himself, for he may develop into a case of acute dysentery, and to the community—for he is passing in his fæces the encysted stage which is capable of infecting other persons. Whether an infected person will suffer from dysentery or act as a healthy 'carrier' apparently depends upon his own susceptibility rather than on any difference in the virulence of different strains of the Entamœba.

In all work with human Entamœbæ there is need for critical determination of the species, for, in addition to *E. histolytica*, a closely similar species, *E. coli*, is a common inhabitant of the intestine. This, however, is a harmless commensal, feeding on bacteria and fragments derived from the host's food. The distinction between the two species rests chiefly upon the characters of the nuclei and of the mature cyst—quadrinucleate in *histolytica* and octonucleate in *coli*—and considerable care and technical skill are requisite in many cases before a diagnosis can be given. And yet this distinction is definitely necessary in practice, for indiscriminate treatment of persons with Entamœba is indefensible; treatment is only for those with *histolytica*; it is useless for those with *coli*, and subjects them needlessly to an unpleasant experience.

A notable result of recent work is the proof that the more common intestinal Protozoa, formerly believed to be restricted to warmer countries, occur indigenously in Britain. This was first established by a group of observers in this city, and has been confirmed and extended by subsequent workers. There is good reason for believing that in this country the incidence of infection with *E. histolytica* is about 7 to 10 per cent., and with *E. coli* about five times as great (Dobell).

The discovery (1903) of Leishmania, the organism of kala azar and of oriental sore, added another to the list of important human pathogenic Protozoa, but the mode of transmission of this flagellate has not yet been proved.

Of the problems presented by the parasitic worms the most momentous are those associated with Ancylostoma and its near relative Necator, which are prevalent in countries lying between 36° N. and 30° S.—a zone which contains more than half the population of the earth. Heavy infection with Ancylostoma or with Necator produces severe anæmia, and reduces the host's physical and mental efficiency to a serious degree. Until 1898 there was no suggestion that infection was acquired in any other way than by the mouth, but in that year Looss published his first communication on the entry of the larvæ of Ancylostoma through the skin, and in 1903 gave an account of further experiments which proved that dermal infection resulted in the presence of worms in the intestine. At the meeting of this Association in Cambridge in 1904 Looss demonstrated to a small company his microscopical preparations showing the path of migration of the larvæ. His investigations served to establish the importance of the skin as the chief portal of entry of Ancylostoma, and pointed the way to effective methods of prevention against infection.

Another notable advance in helminthology is the working out of the life-cycle of Schistosoma (Bilharzia)—a genus of trematode worms causing much suffering in Egypt and elsewhere in Africa, as well as in Japan and other parts of the world. These worms when mature live in pairs, a male and female, in the veins of the lower part of the abdomen, especially in the wall of the bladder and of the rectum. The eggs, laid in large numbers by the female worm, provoke inflammatory changes, and cause rupture of the veins of the organs invaded. Until about ten years ago the life-history of Schistosoma had been traced only as far as the hatching of the ciliated larva or miracidium which takes place shortly after the egg reaches water, but it was then shown that this larva is not, as had been held by Looss, the stage which infects man. Miyairi and Suzuki (1913) found that the miracidium of *Schistosoma japonicum* entered a fresh-water snail which acted as the intermediate host, and Leiper and Atkinson (1915) confirmed and extended this observation, and showed that the miracidia develop into sporocysts in which cercariæ are formed. We owe chiefly to Leiper's work (1915-1916) our knowledge of the life-history and method of entry into man of the Egyptian species of Schistosoma. He demonstrated that two species of this parasite occur in Egypt, and established that the miracidia develop in different intermediate hosts: those of *S. mansoni* enter Planorbis, while those of *S. hæmatobium* penetrate into Bullinus—the molluscs being abundant in the irrigation canals. The sporocysts produce cercariæ, which escape from the snails and gather near the surface of the water, and experiments with young mice and rats showed that the cercariæ attach themselves to the skin, enter, and reach the portal system from which they travel to the veins of the lower part of the abdomen. Infection of man takes place chiefly through the skin when bathing or washing in water containing the cercariæ, though infection may also occur through drinking such water. And so, at last, these worms which have troubled Egypt for at least thirty centuries have become known in all their stages, and measures for preventing infection—which were of great use during the War—have been devised, and curative treatment introduced.

Other recent helminthological researches deserve consideration did time permit, for there has been much excellent work on the life-history of the liver-flukes and lung-flukes of man, and the life-cycle of the tape-worm, *Dibothriocephalus latus*, was worked out in 1916-17. Mention should also be made of Stewart's investigations (1916-19) on the life-history of the large round-worm *Ascaris lumbricoides*, during which he made the important discovery that the larvæ on hatching in the intestine penetrate into the wall and are carried in the blood to the liver, and thence through the heart to the lungs, where they escape from the blood-vessels, causing injury to the lungs. The larvæ, now about ten times their original size, migrate by way of the trachea and pharynx to the intestine, where they grow to maturity. During last year Dr. and Mrs. Connal have worked out the life-history of *Filaria (Loa) loa* in two species of the Tabanid fly, Chrysops, and investigations on other Filarias have thrown light on their structure, but there is still need for further researches on the conditions governing the remarkable periodicity exhibited by the larvæ of some species (*e.g. F. bancrofti*; in some parts of the world the larvæ of this species are, however, non-periodic). The period under review has obviously been one of great activity in research on helminthes, and fertile in measures tending to reduce the risks of infection.

Insects, protozoa and helminthes not only inflict direct injury on man; they also diminish his material welfare by impairing the health or causing the death of his horses, cattle and sheep, by destroying food crops during growth and, in the case of insects, by devouring the harvested grain. The measure of control which man can gain over insects, ticks and endoparasitic organisms, will determine largely the extent to which he can use and develop the natural resources of the rich tropical and sub-tropical zone of the earth.

Other applications of zoology to human well-being cannot be dealt with owing to lack of time, but mention should be made of two—the researches on sea-fisheries problems which have formed an important branch of the zoological work of this country for forty years, and the studies on genetics which made possible an explanation of the mode of inheritance of a particular blood-group, and of some of the defects (*e.g.* colour-blindness and hæmophilia) and malformations which appear in the human race.

Maintenance of Correlation between the Branches of Zoology.

The rapid expansion of zoology has brought in its train the difficulty of maintaining the connection between its different branches. There is not only the mental divergence of the different workers, due to the necessity for specialised reading, thinking, and technique, but also in some cases spatial separation, and this seems to me to be the factor of greater importance. When modern developments of the subject necessitate expansion of the staff and of the working facilities it has not infrequently happened that one of the newer branches of the subject has been placed in another building, and unless careful arrangements are devised the dissociation tends to become more marked, so that, to take Mr. Bateson's example, the geneticist becomes separated from his colleague whose interests are more largely in systematic zoology, to their mutual disadvantage.

The actively growing physiological branch of zoology will, it is to be hoped, remain an integral part of our subject; for while there are close and friendly relations between the Department of Zoology and the Department of Physiology, the latter is mainly concerned with the training of medical students, and the teaching and research are consequently, in most Universities, chiefly directed to the physiology of mammals and of the frog. The medical physiologist cannot be expected to prosecute researches on the invertebrates—these are as a rule too far removed from the matters with which he is especially concerned—and yet many of the invertebrates have been found to be especially favourable for the investigation of fundamental problems which the morphologist with physiological leanings and training seems most fitted to undertake. It is a good sign that more students of zoology are including a course of physiology in their curriculum for the science degree, thus preparing themselves for work in comparative morphology and comparative physiology.

The association of zoology with physiology, and with botany through common problems in genetics and in general physiology, is becoming more intimate. The association of zoology with medicine has become of such importance, especially in regard to its parasitological and its physiological aspects, that clearly collaboration with our medical colleagues in teaching and in research should be as close as possible.

Zoology in the Medical Curriculum.

Much has been written and said in recent years about the place of zoology in the medical curriculum, and the present seems a favourable opportunity to reconsider the position and to ascertain the general opinion of the body of zoologists on this important matter. There can, I think, be no doubt that the value of zoology taught in its modern significance is being increasingly appreciated by the majority of our medical colleagues. The minority consists of two categories—those who have not taken the trouble to inform themselves of the subjects nowadays brought to the notice of medical students in the course of zoology, and who apparently consider that this is the one subject in the curriculum in which there has been no evolution since they were themselves first-year students thirty or forty years ago, and those who feel that the increasing pressure in the curriculum calls for curtailment of the teaching in what they believe to be the less important subjects. The first of these categories need not detain us, for an opinion based on obsolete data is valueless. Those in the second category merit serious consideration, but I believe even many of these would change their views if they knew more fully what is being done in the modern course of zoology to give the medical student a broad, scientific outlook. Even if the course on zoology were cut out the time would not be wholly gained for other work, because many of the subjects now dealt with in the course would require consideration in the teaching of anatomy and physiology. The attention of the medical student is nowadays directed in his course of zoology not so much to the study of details of 'types' as to the principles which certain chosen animals serve to illustrate. A reasonable knowledge of structure is obviously requisite before the working together of the parts can be understood, and before general principles can be profitably discussed. The student at that early stage of his education must have concrete examples to enable him to grasp the functions of organs, development, ideas as to the relationships of animals, heredity, evolution, and so on, and his work in the laboratory should give him the opportunity of observing for himself the important structural points on which the principles are based. The practical work cannot be limited to what the student can do for himself, for at this stage of his training there are many things which he ought to see but which are beyond his technical powers to prepare for himself, so that a good series of demonstration objects is necessary, care being taken that the student not only sees the specimens but appreciates their significance. As the time given to zoology is limited, the examples for study and the principles to be illustrated are to be carefully chosen, for the course in zoology is not only a discipline but should give basal knowledge of value in the subsequent years of study; and, moreover, if the student can see that his zoological work bears on his later studies he will take much more interest in it. It is important, therefore, that the points of contact of his present with his future work should be successively indicated.

The details of the course of zoology for the first-year medical student will vary in the hands of different teachers, and it is well that they should be to some extent elastic. In a minimum course will be included the consideration of two or three protozoa, a cœlenterate, an annelid, an arthropod—and especially the features in which it presents advance as compared with an annelid, an elasmobranch fish, and a frog, the primitive features of the fish being emphasised, and the chief systems of organs of both vertebrates compared with each other and with those of a mammal. The functions of the principal organs of all these examples will be dealt with so far as they can be understood from the account of structure—this latter being sufficient to illustrate the principles involved, care being taken not to over-elaborate structural details. Man's place in nature should be considered either in the course of zoology or in that of anatomy. Other opportunities occur during the course in anatomy, and still more in physiology, for reference to the conditions in lower animals, and if more use could be made of these opportunities the linkage between zoology and the second-year subjects would become much more perfect, and would help in doing away with the water-tight compartments into which the average student considers his early medical education to be divided.

The course in zoology should be planned so as to give the student a wide outlook on structure and function, adaptation and environment, some knowledge of the germ-cells and their maturation, of fertilisation, growth, regulation, regeneration, decline and death, and an introduction to evolution, heredity and genetics—in general, it should aim at affording a broad conception of the activities and modifications of the organism as a living thing, and should educate the student to manipulate, to observe and record, and to exercise his judgment in matters of inference and of theory.

While some reference may be made in the first-year course to insects and parasitic organisms to indicate the relationship between zoology and pathology and public health, it has seemed to me for some years that the real instruction in entomology and parasitology should be given in the later part of the third or early in the fourth year along with the course in bacteriology. The first-year student, although keenly interested in the direct applications of zoology to medicine, is not competent at that early stage of his career to obtain full advantage from studies on parasites. In most Universities a certain amount of time is already set aside in the third year for the study of protozoa, and of helminthes and their eggs, and I have suggested to some of my colleagues in Edinburgh that the teaching on these subjects in the first and in the third year should be brought together in the latter year and remodelled to form a short course of lectures, demonstrations, and practical work to cover the essentials required for general practice in this country. By this time the student is much better fitted to appreciate the bearings of this work. I am also inclined to the opinion that a short course of six or eight lectures—on which attendance might be voluntary—on heredity and genetics would be of value in the fourth year to the good student who has a little time at his disposal.

I should be glad if my colleagues would give the Section the benefit of their views on the first-year course of zoology for medical students, and on the provision of a course on entomology and parasitology about the third year of medical study.

THE GEOGRAPHICAL POSITION OF THE BRITISH EMPIRE.

ADDRESS TO SECTION E (GEOGRAPHY) BY

VAUGHAN CORNISH, D.Sc.,

PRESIDENT OF THE SECTION.

Part I.—The Position which has been occupied.

The British Empire, although situated in every continent, with shores on all the oceans, is seen to have a definite geographical position when we consider the ports of call which unite its lands and the naval stations which guard the communications. During the growth of the Empire eastward and westward from Great Britain, numerous harbours were held at different times, those retained being a selection unrivalled by the ports of any other State in commercial and strategic position. Our many oceanic islands give us, moreover, an important advantage in the selection of maritime stations for aircraft.

The naval station of Bermuda, well withdrawn from aerial attack, has a central position in the great western embayment of North America intermediate between the ocean routes which connect Great Britain with Canada and the West Indies. No foreign ports flank the route between Canada and the west coast of Great Britain. At the western gateway of the South Atlantic we have excellent harbourage in the Falkland Isles. Malta, the capital of our Fleet in the Mediterranean, has a commanding position at the Straits which connect the eastern and western basins, and the naval station at Gibraltar helps to ensure the junction of the Home and Mediterranean Fleet and to protect the Cape route. Our status in the Sudan, the vulnerable frontier of Egypt, is still maintained, and the British army which is kept in Egypt as garrison of the Suez Canal ensures our use of this gateway as long as we can navigate the Mediterranean. If that navigation be interrupted we can still oppose the seizure of the Isthmus, for we are able to send reinforcements by way of the Red Sea. East of Egypt the British island of Perim stands in the Straits of Bab-el-Mandeb, and the garrisoned fuelling station of Aden provides the necessary port of call on the routes to Bombay and Colombo. Colombo, in the Crown Colony of Ceylon, is at the parting of the ways for Australia and the furthest parts of our Asiatic possessions, and Singapore stands at the narrow gateway of the shortest route between India and the Far East.

The Cape route to India and Australasia is improved by British ports of call in Sierra Leone, St. Helena, and Mauritius, and is more effectively dominated from British South Africa than at first appears, for although there is open sea to the south there are no useful harbours in the Antarctic continent, and on the African coasts the harbours are under British control for a thousand miles from Cape Town.

Of the six great foreign Powers the French alone are posted on the flank of both routes between Great Britain and the Indian Ocean, and no Great Power has its home territory on that ocean, or railway connection thereto from its home territory.

Thus the principal lands of the British Empire—Canada, the British Isles, South Africa, India, and Australasia—have good communications with one another across the Atlantic and Indian Oceans both in peace and war.

The conditions of strategic communication across the North Pacific, on the contrary, are adverse to us, owing mainly to the circumstance that we opened up British Columbia across the prairies and by the coasting voyage. Had our colonising route been across the Pacific, the Hawaiian Islands, which were first brought into touch with the Western world by the ships of the Royal Navy, would have been a British settlement and one of our first-class naval stations. As things happened, however, these islands were first needed by the Americans, and now form the essential western outpost of the United States Navy. Between them and British Columbia the ocean is empty of islands, and Fanning Island, south-west of Hawaii, with the adjacent small coral islands in our possession, are no adequate substitute, even apart from overshadowing by a first-class naval station in the neighbourhood. Thus there is no good strategic communication between Australasia and Canada across the North Pacific. In this connection it must be remembered that cousinship does not relieve the American Government from the obligations which international law imposes upon neutrals. It was not until three years after the outbreak of the Great War that America could offer us any facilities in the harbour of Honolulu which were not equally open to Germans. It must also be noticed that we have no control of the Panama route between New Zealand and Great Britian.

Turning to the question of communication between British Columbia and India, it is important to realise that the Pacific coasts of North America and Asia are in a direct line with one another, forming part of a Great Circle, so that there is no short cut across the ocean, as the map misleadingly suggests. Thus the course between Vancouver and Hong Kong is not only very long, but also closely flanked by the home ports of Japan and many outlying Japanese islands, so that its security in time of war depends upon the attitude of the Japanese.

When, therefore, we differentiate the routes on which we have well-placed naval stations and recruiting bases from those dominated by the ports of some other Great Power, we see that the lands of the Empire are united by the Atlantic and Indian Oceans and strategically separated by the North Pacific. Thus the form in which the Mercator map is usually drawn by British cartographers with Canada in the upper left and Australasia in the lower right corner is a good representation of our maritime Empire. It shows the lands as connected by the Atlantic and the Indian but not by the Pacific Ocean; Great Britain, the naval and military headquarters of the Empire, on the central meridian; and Port Said and Cape Town as connecting positions between the western and eastern parts of the Empire.

Upon this map a symmetrical distribution of our lands is revealed when a Great Circle is drawn connecting Halifax in Nova Scotia, the eastern terminal port of the Canadian Pacific Railway, with Fremantle, the western terminal port of the Australian railway system. This truly direct line, twisted on Mercator's map into the form of the letter S, extends just half-way round the meridians but is somewhat shorter than the semi-circumference of the globe, the difference of latitude between Halifax, N.S., and Fremantle being less than ninety degrees. The line passes through Lower Egypt close to the Suez Canal following the general direction of the Main Track of the Empire, which is the steaming route from Canada to Great Britain, and thence by the Suez Canal to India and Australia. At one end of the line lies the Canadian Dominion, and at the other Australasia, to the north the British Isles, and to the south the Union of South Africa, the chief homes of the British nation. Our coloured peoples are also distributed symmetrically about the line, India being on the east, the Crown Colonies and the Protectorates of Africa on the west, so that it is the axis of symmetry of the Empire. Not far from its middle point is the Isthmus of Suez, where our direct line of sea communication is crossed by the only continuous route for the international railways which will connect our Indian and African possessions, and adjacent to the Isthmus is the central station of our airways.

Such is the form and position of the British Empire, regarded as a maritime organisation, which in fact it is.

The Empire thus mapped has an Intermediate Position among the commercial, national, religious, and racial communities of the world such as is occupied by no other State. The ocean routes must always be the Link between the two great land areas of the world, and in the present state of land communication provide the connection between the numerous independent systems of continental railways. The chief of these systems is based on the ports of Continental Europe, of which the greatest communicate with the ocean, and therefore with other railway systems, by way of the English Channel. Thus the island of Great Britain is intermediate between the principal termini of the European railways and the other railway systems. Its harbourage is unequalled by that of any country of Continental Europe, and its supply of shipbuilding material and coal exceptionally good. Thus the physical characters of the island accord with its position on the commercial map, and the Metropolitan British in their Intermediate Position have become the chief common carriers of international commerce. Much of this profitable business used to be in the hands of smaller European States, whose commerce eventually suffered from their inability to defend themselves against more powerful neighbours. Our merchant shipping is protected by the Royal Navy, but owing to the recent development of fighting aircraft, ships of war can no longer protect the island itself, and since the close of the recent war this citadel of the Empire, the home of two-thirds of the white population, has been more exposed to attack from the Continent than at any previous time during the last eight hundred years.

The Suez Canal, where we have the principal control, is the gateway between the railway termini of Europe, the greatest manufacturing centre of the world, and those of the monsoon region of Asia, the greatest centre of population. It is also on the shortest route between the railways of North America and India.

The commercial and strategic importance of Singapore as an Intermediate Position between India and the Far East is enhanced by the circumstance that railway communication between them is debarred by the greatest mountain system in the world.

Hong Kong, at the chief gateway of Southern China, is typical of British maritime stations both in its Intermediate Position and in the facilities provided for the ships of other nations, which swell the vast tonnage entered and cleared at the port.

How far-reaching is the effect of our Intermediate Position is revealed by the important but little recognised fact that it is the British naval stations which would, if available, provide America with the best line for reinforcement of the Philippines, the Achilles' heel of the Republic. The distance of Manila from the naval shipbuilding yards of the United States is almost exactly the same by Suez and Panama, but the Pacific connection has never been good owing to the great distance between stations, and is now worse than before the Great War on account of the island mandates acquired by the Japanese. The relation of Port Said and Singapore to America and the Philippines is only one of many cases in which our position is intermediate between the home and Colonial possessions of a white nation. Thus the important French possession of Indo-China has to be reached from France either by way of the Suez Canal where we maintain a garrison, or by rounding the Cape where we have a national recruiting base, as well as a station of the Royal Navy. The true significance of our Intermediate Position has, however, been generally missed owing to a one-sided interpretation of strategical geography. An intermediate station, particularly a naval station, has commonly been regarded as a blocking position, a Barrier where freedom of movement can be interfered with. The historical fact is, however, that the harbours of the British Empire have also been a Link between nations. In the Great War the British Empire was the Link of the Allied and Associated Powers, and its geographical position is unequalled for making a benevolent alliance effective or checkmating the action of an alliance formed with a sinister purpose.

The British Empire provides in Canada the one Link between the European and American divisions of the white race, for public opinion in the United States adheres to the view that the New World, in the sense of North and South America, should be shut off and sheltered from the evils of a bad Old Europe.

In Tropical Australia the British, in the exercise of their discretion, have set up a Barrier between the white and coloured races. Australia is a land almost empty of aboriginals, which has for the most part a climate in which British children thrive and develop true to type. In the great basin of the Murray River and its confluents, not far from the huge superficial deposit of brown coal in South Victoria, is a combination of fertile soil, forcing sun, water for irrigation and cheap electric power transmitted from the coal-field. This favoured region, the 'Heart of Australia,' as it has been called, with a population of only three million, is equal in size to France, Italy, and Germany combined, which have a population of more than one hundred and thirty million. The problem of Australian settlement is, however, complicated by the circumstance that the northern coast-lands lie in the Tropics, and have a climate which makes field work very arduous to white men. It is, moreover, uncertain if British families would continue true to ancestral type in this climate. If, however, settlers from the neighbouring monsoon lands of Asia be admitted, whose descendants would rapidly increase, it would be impossible to maintain a colour line between Tropical and Temperate Australia, and the rough labour of the Commonwealth would in time be done by coloured people. The fact that this labour is cheap would result in the employment of a great number of coolies instead of the use of machinery, and Australia might become a land of coloured workmen and white overseers. Circumstances, therefore, forced the Australians to decide whether their tropical belt should be a Link or a Barrier between white and coloured labour. The decision to erect a Barrier was taken early, and has been consistently maintained. The strategic responsibility of the decision is seen to be very great when we look into the future and reflect on the facts of population.

Of the 1,650 million people in the world, the whites number about 500 and the coloured 1,150. The former are mainly grouped on the two sides of the North Atlantic Ocean; of the latter, the greater part, about 800 million, are in the monsoon region of Asia, which includes India, Indo-China, China proper, and Japan. The Australian British are far from the main body of the white race and from Great Britain, the chief recruiting base of their own nation. On the other hand, the distance by sea between Townsville, Queensland, and the Japanese coast is no longer than the course of the coasting steamers from Fremantle to Townsville; and the other lands of Monsoon Asia are even nearer than Japan.

Enough is known of the relation between geographical environment and national well-being to declare with confidence that the decision to erect a Barrier against coloured labour in Tropical Australia is best both for the white race in Australia and for the coloured people of the monsoon region of Asia. Not only is Government much more difficult with a two-colour population, but the admission of coolie labour would deteriorate the national character of the Australians, for history shows that the greatest nations are those which provide their own working class. Turning from the Occidental to the broader humanitarian view, it is only necessary to look ahead in order to see that the admission of Asiatic coolies to a British homeland is unkind to their descendants. Those that remain unmixed in race will have a stunted existence as a community cut off from full national life, whilst the case of mulatto descendants is almost worse, for the children are not brought up in the family of the British parent, and yet are cut off from the full tradition of Asiatic civilisation. Far better, then, that the Asiatic coolie should remain where the family life of his descendants will be part and parcel of national life.

Neither should it be assumed that there is not room in Asia for a large additional population. The pressure of population in China is largely due to the undeveloped condition of mining, factories, and communications. The coal-fields are unsurpassed in the world, and iron ore is abundant; if they were worked, and factories were based upon them, the new occupations and improved market for agricultural produce would provide at home for many of those who now migrate oversea. The rise in standard of living which may be expected to follow industrial development would also reduce coolie competition in the white borderlands of the Pacific. The further development of manufacture in India would operate in the same direction. The growth of a manufacturing population in China and India would stimulate cultivation and stock-rearing in the sparsely inhabited region under Asiatic rule which runs diagonally across the meridians from the Persian Gulf to the Amur, and includes the eastern provinces of Persia at the one end and Mongolia and Manchuria at the other. This has for the most part a light rainfall, but comprises much fine prairie country and some good agricultural land, whilst in the more arid tracts there are many great rivers fed from snow-fields and glaciers which could be made to irrigate large areas where the sun is as strong as in Australia. Adjacent to the Indo-Chinese peninsula are the East Indies, whose climate is suited both to Indians and Chinese, with great tracts of undeveloped land whose productivity is attested by luxuriant forest. The sparsely peopled regions of Asia near to India, China, and Japan by land and sea, and for the most part connected with them by ties of civilisation, provide an area for the overflow from these countries which is more than twice as large as Tropical Australia and British Columbia, together with California, Washington, and Oregon, the American frontier provinces of English-speaking labour.

India includes one of the most important borderlands within the Orient, that of the Mohammedan and Hindu worlds. The Punjab, with its great rivers and plain, is in such striking contrast to the mountains and plateau of Iran that we are apt to lose sight of the fact that, climatically, it more resembles the highland on the west than the rainy valley of the Ganges on the east. It is an eastern borderland of Islam, a religious world which is mainly comprised in the belt of dry country which stretches diagonally from the Atlantic shore of Morocco to the Altai Mountains. Delhi, under the Great Moghul, was an advanced capital of the Mohammedan world just within the Ganges valley, which is the headquarters of Hinduism. In this sub-imperial capital the two antagonistic civilisations are now linked to the government of the United Kingdom, and the age-long wars between them have ceased.

Up to the time of British predominance, India was the terminal position of Continental conquerors unused to the sea, who did not develop the advantages of a salient maritime position. The ports of India lie conveniently for a long stretch of coast-land on the great gulf which forms the Indian Ocean, and now, owing to the facilities provided by British shipping, much of this coast-land has easier communication with India than with its own continental interior. Several British possessions in the parts of Africa adjacent to the Indian Ocean are in the Intermediate Position between the principal homelands of the black peoples and the overflowing population of India, and nowhere has the responsibility of our Intermediate Position called for more careful examination of the rights and interests of competing coloured races. The decision with reference to Kenya which has just been given by the home Government recognises the main physical regions in the coloured world as political divisions of the Empire within which the established races have special rights.

The Union of South Africa is the racial home of white men and of the more numerous coloured people who are indigenous to the country. It is, therefore, largely a land of white overseers and coloured labour, but here, as in the other Britains beyond the seas, there is an opposition to the introduction of coloured blood into white families which is not met with where Latin races are similarly situated. The Dutch families are at one with those of British stock in the maintenance of this racial Barrier.

From the foregoing facts it is clear that the British people, Metropolitan and Colonial,[1] are in a greater degree than any other nation the doorkeepers of the world in respect of economic, strategic, and racial communications.

Part II.—The Consolidation of the Position.

The consolidation of the position which the British Nation has won turns upon the future of colonisation within the Empire. We must therefore compare the number of the Metropolitan and Colonial British with that of other peoples within and without the Empire, and take account of the relation between the present population of the world and the area of its empty lands. The British Empire comprises the fourth part of mankind, but the ratio of white to coloured people in the Empire is only about one to six. The former are mostly of British stock, and belong to the Christian world. The latter are of many stocks, differing physically from each other as much as from the white people, and belonging to diverse religions. Their population is steadily increasing under British rule, and some of them have recently made advances in political organisation and industrial efficiency. Consequently, if the Empire is to be guided by the British, the numbers of our race must also increase. There is, however, a school of thought which considers that if our ideals of ethics and efficiency are once accepted by the coloured peoples, the racial complexion of the Empire will be unimportant, as public affairs will be regulated by our principles. This point of view, which may be termed in a general sense the missionary standpoint, does not take account of the contingency that British ideals implanted in coloured stock may receive alien development in future

[1] The introduction of the term 'Dominion' served to suggest emancipation from the Colonial Office, but the word Colonial as descriptive of a people has permanent historical value and therefore should not be allowed to lapse.

generations owing to biological causes. Our confidence in Western culture in general, and the British version of that culture in particular, is based more upon the power of adaptation which it has shown in our hands since the Renaissance and the Era of Oceanic discovery than upon any system of which we can hand over a written prescription. It is only in our own national communities, mainly composed of British stock, with minorities nearly akin, that we can be confident that British ideals will develop typically in the way of natural evolution. Therefore in our own interests and in that of the coloured races (who conflict among themselves) it is desirable to maintain the present proportion of the British stock, to whom the Empire owes the just administration of law and a progressive physical science.

The co-operation of the Union of South Africa in the Great War only became possible after the failure of an insurrection by part of the Boers. Since the number of persons of Dutch and British stock is about equal, an influx of British colonists is required in order to ensure unanimity between South Africa and the rest of the Empire.

Passing to the ratios between British population and foreign nations, we have to note that the population of Australia stands to that of Japan as about one to ten. The Japanese are a patriotic as well as an advanced nation, and claim equality with the white nations from patriotic motives. It is evident, therefore, that a strong reinforcement of British population is needed to maintain the doctrine of a white Australia. For the same reason New Zealand also needs reinforcement, since Australasia is strategically one.

The number and density of the population of Canada is exceeded in the proportion of about ten to one by the white population of the United States, hence it is inevitable that there should be a large flow of people from the latter country to the Dominion. As it is essential to unanimity in the Empire that the Canadians should continue to be British in sentiment and not become pan-American, a large immigration from Great Britain is required in Canada. Moreover, the population of Continental Europe outnumbers that of Great Britain[2] in the proportion of something like ten to one, and as emigrants go to Canada from many European countries there is a further call for British immigrants to maintain the British character of the Dominion.

We have next to note that the population of Great Britain, which is now forty-three million, outnumbers the combined population of Canada, Newfoundland, South Africa, Australia, and New Zealand in the proportion of two and a-half to one, and increases more rapidly than that of all these Dominions, more than three and a-half million being added in the decade 1901-11, in spite of an emigration which much exceeded the immigration. Thus the chief source available for the British peopling of the Dominions is the Metropolitan, not the Colonial, population.

In 1891 the late Mr. G. Ravenstein calculated from the rate of increase of population the time which remained before the unoccupied lands of the world would be settled and developed in accordance with

[2] In the present condition of home affairs in Ireland it seems best to leave its population out of the numerical reckoning for Imperial purposes.

their agricultural capabilities. This period he reckoned at about two centuries, by which time the population was calculated at 6,000,000,000 instead of the 1,600,000,000 which it had reached in 1891. The figure must not be taken to indicate the final population of the world, about which we know nothing, but the epoch marks finality of a certain kind—namely, the end of the colonising period of history as colonising has hitherto been conducted. The world will then be completely parcelled out among the nations, and since it is very difficult to displace a nation, it is probable that those which occupy the world at the end of the colonising period will remain in possession for a long time, even as time is reckoned in the pages of history. If we allow a generation for the set-back of the War we may roughly reckon our zero-time as 1923 instead of 1891, which, on the basis of Mr. Ravenstein's figures, would still give about two centuries, or six generations, in which to provide the temperate climates of the British Empire with a sufficiency of British stock to ensure the continuance of their British character.

There is, however, a school of thought which sees the salvation of the home country in a reduction of its population. I take their strategic argument first. It is contended that Great Britain would be safer in time of war if it had no more people than its farms can feed. Judging by France and the former Austro-Hungarian Monarchy, this would be about one-half of our present population, for our country is small though fertile. The conditions of our strategic security have, however, undergone a great change since 1914. The best plan of campaign for a combination of European Powers bent on overthrowing the citadel of the Empire would be an attack by combined air-fleets, which could be concentrated on London, the great manufacturing towns, and the ship-building yards, wholly destroying them one by one by intensive bombardment. This plan would be more effective than naval blockade, which it is very difficult to make complete, and is liable to bring in new belligerents owing to interference with neutral shipping. In order to have strategic security in this island we must therefore be able to meet the air-force of a European combination as well as carry out our traditional plan of despatching a powerful expeditionary force for the support of a friendly Power. This active defence requires large population and high devlopment of technical industries, and therefore could not be sustained by a rural Britain.

The economic argument for reduced population has received ready but uncritical assent owing to the great want of employment since the War. It is stated that this island will never be able to support in proper comfort a population of forty-three million, the present figure. But the population which can be sustained in a country depends jointly upon internal resources and geographical position. The commercial position of Great Britain is more favourable than that of any other island of equal size, and the large amount of good coal, besides iron ore and beds of salt, enable full advantage to be taken of the geographical position in manufacturing for export. According to the estimate made in 1905 the stock of accessible coal in the United Kingdom is sufficient to last more than four hundred years at the present rate of output, and an estimate made in 1915 gives a yet larger stock.

Moreover, no change in the distribution of available minerals can ever do away with the commercial advantage conferred by our central and focal position on the natural maritime routes. Hence the population which can be supported in Great Britain depends upon services to outside nations to a much greater extent than in most countries.

The population which can be maintained in our home country depends, therefore, to an exceptional degree upon the population and prosperity of the rest of the world, so that when the world again gets into its stride there should be improved conditions here, and as the population of the world grows so should the number of jobs in the country increase. There is, therefore, no sufficient ground for stating that we have passed or reached the limit of population which the island can ever support.

The teaching of those who advocate reduction of population as the salvation of Great Britain includes eugenic and ethical arguments. Thus it is said that very small families conduce to a high standard of civilisation since more care can be devoted to the child. This, however, leaves out of account the educative influence of the children of a family upon one another. Everyone knows that an only child is at a disadvantage in life. The world being of both sexes, and the society in which we move mainly of our own generation, the full home training for life is only obtained if each child have a brother and sister, which implies a family of at least four.

The desirability of birth-restriction among the poorer classes is strongly pressed on the plea that we are breeding to an increasing extent from inferior stock, and thereby lowering the national type. As far as the allegation relates to defectives, it is indisputable that most of them are among the poorest of the poor, and that their breeding is an injury to the community, as is also the admission of defective or criminal aliens, but these are categories quite apart from our great working-class community.

The professional families are far too few to maintain the supply of original genius needed for this country's advance, for genius is largely in the nature of a sport, and has to be replenished from a very large reservoir of population. To recruit the professions entirely from the present professional families would, therefore, in the long run be fatal to originality. On the other side of the picture, a working-class home is the best preparatory school for the colonial frontier, where to have few wants is better than the possession of many attainments.

We are told that an increase of population in Great Britain will pack the slums and thereby reduce us to the 'C 3' category of physique, but this argument takes too little account of the redistribution of urban population which has been going on for the last forty years. The density of population in central London has diminished, and factories have sprung up along the railways which radiate from the town. In 1911 the five Counties surrounding London, with their two included County Boroughs, contained no less than one million residents born in London who had migrated into these more rural districts. Migration, it should be observed, whether to or from the town, prevents the close breeding which used to be a serious disgenic factor in villages.

In 1911 the birth-rate in the towns of England and Wales was higher than in the rural areas, and the Registrar-General's Report states that even when these figures are corrected for the movement of the people the rural districts would only have increased at the same rate as the country at large, adding that 'these facts are worth noting in view of the assumption, sometimes loosely made, that the population of the towns would cease to increase if it were not recruited from the country.' In this connection it should also be noted that the proportion of London residents who are London-born has steadily increased from 1881 onwards.

The growth of our towns is no longer haphazard, but has entered on the stage of planning.

A great abatement of the contamination of town air by smoke has been shown to be practicable, and it is largely in the matter of smoke and crowding that towns have been hygienically inferior to the country, for country cottages are often as bad in themselves as slum houses, and their water supply much inferior. Moreover, the hygiene of towns has always been dependent on the circumstance that here the health of many people is affected by the carelessness of a few, and it follows that the hygienic conditions of urban life are capable of immense improvement when scientific knowledge becomes general. The experience of the War has shown that the popular notion of the inferior moral of townsmen was unduly pessimistic, for our urban regiments not only showed intelligence, but exhibited a sustained valour which has seldom been surpassed in the long annals of military history.

That emigration to the Dominions brings some economic benefit to the home country cannot be gainsaid, for trade returns show that an emigrant to the Dominions buys as much here as eleven emigrants to the United States, and therefore as much as many foreigners; but those who fear additions to our people also fear the moral effects of emigration. They say that emigration will take the best and leave the worst, and so produce a disgenic effect in the home country. But the individual emigration of to-day differs in this respect from the group migrations under political compulsion, or for conscience sake, which inflicted eugenic loss upon Spain, France, and England in bygone days. The best lad for the Dominions is not necessarily the best for the home country, and an Empire which comprises urban as well as rural States requires young men whose business tenacity is sufficient to resist the restlessness of youth not less than those who are instinct with the spirit of the frontiersman.

That a relative increase of female migration would benefit national character cannot be gainsaid, for at present the Dominion frontiers lack the due weight of feminine influence, whilst in Great Britain many women are denied the full development of their character which some natures only attain by wedlock and motherhood. The Census of 1911, unaffected by War losses, shows an excess of about 1,300,000 females in Great Britain and a deficiency of about 750,000 in the Dominions. The inequality of distribution as between Great Britain and the Dominions limits the possible marriage-rate, and therefore the total births, in a way to which no other nation is equally subject. If the numbers in the Dominions be equalised as the result of special encouragement of female emigration, there will still remain a large excess of women in Great Britain who cannot be paired in the Empire unless the stream of emigrants who now leave the Empire can be for the most part deflected to the Dominions. In Great Britain the total number of families is limited by the number of males. In dealing with the size of family needed to maintain or increase population I do not reckon the present surplus of nearly two million women resulting from the joint effect of migration and war. At present our community appears to be in a transitional stage between the limitation of the family by chance and by choice, but the census shows, from the present age of marriage in Great Britain and the number of deaths before this age, that a general preference for the family of three children would not quite maintain the population, apart from migration. If, therefore, the size of family be universally decided by choice the number of the race cannot even be maintained, far less increased, under present conditions unless those who enter into matrimony cherish the ideal of a family of four children.

Unless the British race increase we cannot insure the internal peace and external security of the Empire, or the continuance of its beneficent work of enlarging commerce and restricting the range of war. Therefore the birth-rate in Great Britain should be maintained above the death-rate at least until the British population in the Dominions exceeds that in the Mother Country. The maintenance of the race will then rest chiefly with our people oversea, and, with their great resources, it should be possible for them to keep pace with the other growing nations.

POPULATION AND UNEMPLOYMENT.

ADDRESS TO SECTION F (ECONOMIC SCIENCE AND STATISTICS) BY

SIR WILLIAM H. BEVERIDGE, K.C.B.,

PRESIDENT OF THE SECTION.

THE impression that the civilised world is already threatened with over-population is very common to-day. Many, perhaps most, educated people are troubled by fear that the limits of population, probably in Europe and certainly in this country, have been reached, and that a reduction in the rate of increase is an urgent necessity. Most, if they were asked to give reasons for their fear, would refer to one or both of two reasons: they would point to the enormous volume of unemployment in this country; they would say that economic science, at least at Cambridge, had already pronounced its verdict. I propose to begin by raising some doubts as to the validity of each of these arguments.

Unemployment No Proof of Over-Population.

The volume of unemployment in Britain is undoubtedly serious, and almost certainly unparalleled in past history. Those who see, as we now do, more than a million wage-earners whom our industry for years together is unable to absorb in productive employment may be excused if they draw the inference that there are too many wage-earners in the country. The inference, though natural, is unjustified. Unemployment in Britain can in any case prove nothing about the world as a whole. History shows that it does not prove over-population even in Britain.

During the last half of the nineteenth century, the industry of the United Kingdom was finding room for a rapidly increasing number of wage-earners with an admittedly rising standard of production and comfort. Through the whole of that period there was unemployment in the country. The percentage of trade unionists out of work never fell to zero; in no year since 1874 was it less than two; at more than one crisis it reached a height comparable if not equal to that which we have just experienced. During 1922 this percentage has averaged fifteen; but it averaged over eleven in 1879 and over ten in 1886. These figures are not on an identical basis and are therefore not absolutely comparable. Taken for one year only, they understate the relatively greater seriousness of our recent experience, since the unemployment percentage was high through a large part of 1921 as well as in 1922, and still continues high. But the difference is one of degree rather than of kind. The peril of inferring over-population from unemployment is conclusively shown.

The experience of 1879 was up to then unparalleled; probably it was as much worse than anything previously recorded as the experience of 1922 appears worse than that of 1879. The experience of 1879, however, the record year of unemployment, heralded, not over-population and the downfall of British industry, but a period of expansion and prosperity which itself reached, if it did not pass, all previous records. 'Real wages,' which had risen thirty per cent. in the twenty years to 1880, rose even more rapidly in the next twenty years to 1900. Anyone who in 1879, looking at the half or three-quarter million unemployed, had argued that the existing population of the United Kingdom (then about thirty-four millions) was all that the country could support without lowering its standards, would have been lamentably discredited at once. Ten years later he would have found a population nearly three millions more, enjoying a real income per head that was a fifth greater, with the unemployment percentage reduced to two. Ten years later still the population had grown further in size and in prosperity; those trades had grown most rapidly in which there had been and continued to be the largest percentages of unemployment.

The problems of unemployment and of over-population are distinct; they are two problems, not one. Severe unemployment has occurred in the past without over-population, as a function of the organisation and methods of industry, not of its size. On the other hand, it is very doubtful if excessive growth of population has ever shown itself or would naturally show itself by causing unemployment. A more probable effect would be pressure to work more than before in order to obtain the same comforts; a fall of real wages per hour, by increase either of hours or of prices.

The same dependence of unemployment on the organisation and methods of industry, rather than on its size, appears if we look, not backwards in time, but round us in space. It has been pointed out by Professor Cannan that one of the few groups of economists who from our post-war sufferings can at least obtain the high intellectual satisfaction of saying 'I told you so,' is that which maintains that changes in the purchasing power of money are the most potent causes of the fluctuations in prosperity known as cycles of trade or booms and depressions. 'In the pre-war period booms and depressions swept over the whole western world at once and left their causes obscure. In 1922 we have been treated to a sharp contrast between two groups of countries, one group having boom and full employment, the other depression and unemployment, the difference being quite clearly due to the first group having continued the process of currency inflation, the other group having dropped it.' To bring this generalisation down to particular instances, we see in Central Europe a nation which assuredly should be suffering from over-population if any nation is; Germany, defeated in war, has been compressed within narrower limits has lost its shipping and foreign investments, its outlets for emigration and trade, and now by high birth-rates is repairing with exceptional speed the human losses of the war. Germany may or may not be suffering from over-population. She certainly has not suffered from unemployment; she has had a boom stimulated by inflation of the currency. We see on the other hand Britain, victorious in war, with expanded territories and the world open to her, pursuing a different, no doubt a better, currency policy and experiencing unexampled unemployment. To argue uncritically from unemployment to over-population is to ignore the elements of both problems.[1]

Europe before the War.

Let us turn to the second argument, the argument from authority and, above all, from the authority of Mr. J. M. Keynes. No economic writing in our generation has obtained so wide a fame as that of Mr. Keynes on the 'Economic Consequences of Peace.' None, on its merits, has deserved more. With its main argument neither I nor, I think, posterity will wish to quarrel. There are, however, in that book certain phrases about population, used incidentally, almost casually, which have none of the weight of the main argument. To these almost more than to anything else is to be attributed the general dread of over-population to-day; these call for examination.

In the second chapter of his book, Mr. Keynes paints a picture of Europe as an economic Eldorado, now devastated beyond repair by war and the peace, but even before the War threatened by internal factors of instability—'the instability of an excessive population dependent for its livelihood on a complicated and artificial organisation, the psychological instability of the labouring and capitalist classes and the instability of Europe's claim, coupled with the completeness of her dependence on the food supplies of the New World.' In naming the first of these factors of instability Mr. Keynes already passes the judgment that Europe's population was 'excessive.' Elsewhere in the same chapter he is more specific: 'Up to about 1900 a unit of labour applied to industry yielded year by year a purchasing power over an increasing quantity of food. It is possible that about the year 1900 this process began to be reversed, and a diminishing yield of Nature to man's effort was beginning to reassert itself. But the tendency of cereals to rise in real cost was balanced by other improvements.' A few pages further on he passes from possibilities to positive assertion; in the last years before the War 'the tendency towards stringency was showing itself . . . in a steady increase of real cost . . . the law of diminishing returns was at last reasserting itself, and was making it necessary year by year for Europe to offer a greater quantity of other commodities to obtain the same amount of bread.' In the seventh chapter is a wider and yet more explicit assertion of 'the increase in the real cost of food and the diminishing response of Nature to any further increase in the population of the world.' And so to Malthus. 'Before the eighteenth century mankind entertained no false hopes. To lay the illusions which grew popular at that age's latter end, Malthus disclosed a Devil. For half a century all serious economical writings

[1] In the United States, which no one suspects of over-population, 'there seems good ground for believing that in actual diminution of employment, the depression of 1921 was almost twice as acute as that of 1908' (Berridge : *Cycles of Unemployment*, p. 52). 1908 was one of the worst depressions hitherto experienced in America.

TABLE I.

AGRICULTURAL AND OTHER PRODUCTION AT CERTAIN EPOCHS.

	EUROPE.					COUNTRIES SETTLED FROM EUROPE.					EUROPE AND ITS SETTLEMENTS.		
	1880	1890	1900	1910	1920	1880	1890	1900	1910	1920	1890	1900	1910
Population (thousands)	311,619	338,847	373,517	422,853	423,000	—	75,596	91,451	111,829	131,432	414,443	464,968	534,682
Total Production (1000 quarters).													
Wheat . .	136,067	152,006	192,869	225,356	—	—	75,033	103,295	138,982	178,049	227,039	296,164	364,338
Rye . . .	130,741	145,759	173,185	194,195	—	—	3,333	3,384	4,476	8,818	149,092	176,569	198,671
Barley . .	70,254	78,343	89,427	111,665	—	—	11,113	15,412	27,601	26,401	89,456	104,839	139,266
Maize . . .	40,542	48,683	53,797	65,435	—	—	234,465	270,889	360,996	396,868	283,148	324,686	426,431
Four Crops . .	377,604	424,791	509,278	596,651	—	—	323,944	392,980	532,055	609,776	748,735	902,258	1,128,706
Area under Crop (1000 acres)													
Wheat . .	89,891	95,165	109,394	125,448	—	—	49,977	65,500	80,717	107,142	145,142	174,894	206,165
Rye . . .	100,301	99,122	101,508	102,508	—	—	2,201	1,802	2,291	5,565	101,323	103,310	104,789
Barley . .	34,953	38,449	41,163	49,458	—	—	4,104	4,957	9,280	10,769	42,553	46,120	58,738
Maize . . .	19,612	22,372	24,435	26,026	—	—	77,662	91,584	116,685	111,878	100,034	116,019	142,711
Four Crops . .	244,757	255,108	276,500	303,440	—	—	133,944	163,843	208,973	235,354	389,052	440,343	512,413
Yield per Acre (bushels)													
Wheat . .	12·11	12·78	14·10	14·37	—	—	12·00	12·62	13·78	13·30	12·51	13·55	14·14
Rye . . .	10·42	11·76	13·65	15·16	—	—	12·11	15·04	15·63	12·87	11·77	13·67	15·17
Barley . .	16·08	16·30	17·38	18·06	—	—	21·68	24·86	23·79	19·34	16·83	18·19	18·83
Maize . . .	16·54	17·41	17·62	20·11	—	—	24·15	23·66	24·75	28·38	22·64	22·39	23·90
Four Crops . .	12·34	13·32	14·74	15·73	—	—	19·50	19·19	20·32	20·73	15·40	16·39	17·62
Yield per Head (bushels)													
Wheat . .	3·49	3·59	4·13	4·26	—	—	7·94	9·04	9·94	10·84	4·36	5·10	5·45
Rye . . .	3·36	3·44	3·71	3·68	—	—	0·35	0·30	0·32	0·54	2·88	3·04	2·97
Barley . .	1·81	1·85	1·92	2·11	—	—	1·18	1·35	1·97	1·58	1·97	1·80	2·08
Maize . . .	1·04	1·15	1·15	1·24	—	—	24·81	23·70	25·82	24·16	5·47	5·59	6·38
Four Crops . .	9·70	10·03	10·91	11·29	—	—	34·28	34·38	38·06	37·11	14·43	15·51	16·89
Production per Head (cwt.)													
Coal . . .	15·08	18·24	21·74	25·33	—	—	39·61	54·96	81·01	—	22·14	28·27	36·60
Iron Ore . .	1·93	2·06	2·73	3·47	—	—	3·98	6·00	8·68	—	2·41	3·37	4·57
Crude Steel . .	—	·45	·93	1·45	—	—	1·13	2·46	4·2[illegible]	—	·58	1·22	2·02

held that Devil in clear prospect. For the next half-century he was chained up and out of sight. Now perhaps we have loosened him again.'

These quotations set the problem. The question is not indeed whether Malthus' Devil is loose again. Mr. Keynes has seen to that; he stalks at large through our lecture-rooms and magazines and debating societies. The question is rather whether Mr. Keynes was right to loose this Devil now upon the public. Was there in Europe or in the world as a whole before the War clear evidence, first, of 'a diminishing yield of Nature to man's effort'; and, second, of a 'rising real cost' of corn?

The Course of Agricultural Production.

The answer to the first question is given by the table of 'Agricultural and other Production at certain Epochs' which is printed above.

Notes to Table I.

The figures of acreage and corn production at the successive epochs are averages for the six years 1878-1883, 1888-1893, 1898-1903, 1908-1913, and for the two years 1920-21, or for as many of those years as were available in each case.

The populations are those given in censuses or official estimates relating to dates within six months of January 1, 1881, 1891, 1901, 1911 and 1921, or are estimated for about those dates (being the centre of the six years taken for averaging) where no such census was available.

The figures for 'Europe' relate to Austria, Belgium, Bulgaria, Denmark, France, Germany, Holland, Hungary, Italy, Roumania, Russia (with Poland), Serbia, Spain, Sweden, and the United Kingdom, containing between them 94% of the total population of Europe in 1910. Norway, Finland, Portugal, Switzerland, Greece, Turkey, Bosnia and Herzegovina and a few minor states alone are excluded. The figures for 'Countries settled from Europe' relate to Canada, United States of America, Argentina, Uruguay, Australia, and New Zealand. At the epochs 1900 and 1910 actual returns are available for all those countries; at the earlier epochs the yields or acreages or both have had to be interpolated for a few countries (of which Spain and Roumania are the most important).

The yields, acreages, and populations for 1920-21 are based on the statistics given in the year book for 1921 of the International Agricultural Institute. The yields and acreages for earlier years are based on the statistics in the annual Agricultural Returns published by the English Board of Agriculture and Fisheries. The populations for these earlier years in Europe are based on the statistics compiled by the International Statistical Institute) *Etat de la Population*, published 1916).

Weights have been converted into quarters on the basis of 480 lbs. to the quarter of wheat, rye, and maize, and 448 lbs. to the quarter of barley.

The figures for coal, iron ore and steel production are five or three year averages centering on the years 1880, 1890, 1900, 1910. For Europe the production is actually that of Austria, Hungary, Belgium, France, Germany, Italy (not steel), Russia (not iron ore), Spain (not steel), Sweden, and United Kingdom. For European settlements the United States contribute all the steel and all but a little of the iron ore; for coal Canada, Australia and New Zealand are included. The production 'per head' is based on the same populations as those used for agriculture in Europe and its settlements respectively.

The population for Russia at January 1, 1911, is obtained (as 133,500,000) by interpolation from censuses and estimates for earlier years and from the official estimate of 130,820,000 at January 1, 1910, given both in the Agricultural Returns of the English Board of Agriculture from which the acreages and crops are taken, and in the *Annuaire Statistique* of 1916 (*Etat de la Population*). The 1921 year book of the International Agricultural Institute gives for January 1, 1911, an estimate of 138,274,500. This is inconsistent both with the estimate for January 1, 1910, and with the census of 1897, requiring an impossible rate of increase. It must refer to an area larger than that covered by the crop returns.

The first section of this table shows at four successive epochs—1880, 1890, 1900, 1910—the total yield and acreage of corn and the yield per acre and per head of population in Europe as a whole (including Britain), with corresponding figures for coal, iron ore, and steel. The second section gives corresponding facts for the principal countries settled from Europe—Australia, New Zealand, the United States, Canada, and parts of South America. The third section covers Europe and its settlements together, practically the whole of the 'white man's countries.' The figures for each epoch represent an average of years, generally six, centering about the end of the year named. The records are not absolutely complete; one or two small European countries have been left out altogether; one or two gaps at the earlier epochs have to be filled by estimate or interpolation. The substantial accuracy of the main results is beyond question.

The European section shows at each successive epoch a greatly increased population and acreage under corn, and a production increasing faster than either, so that yield per head and yield per acre alike both rise materially and steadily. Nature's response to human effort in agriculture, on each unit of soil and for each unit of total population in Europe, has increased, not diminished, up to the very eve of the War. Needless to say, this greater production of corn has not been due to a shifting of population from industry to agriculture, and has not been offset by a decline of manufacturing. The general movement of population has probably been in the opposite direction, from agriculture to industry; the output of coal, iron ore, and steel, the basic materials and products of industry, has risen yet more rapidly than the output of corn.

There is no trace of reaction, either in industry or in agriculture, in the last ten years of the table; nothing to suggest a turning-point at 1900. It is true that the rate of increase in the yield of corn per head and per acre from 1900 to 1910 is less than in the preceding decade, but it is as great as in the decade from 1880 to 1890. In any case, a slowing down in the rate of increase proves nothing. Corn is produced only to be consumed, and there is a limit to consumption. In the best and most progressive of all possible worlds, the consumption, and so the production, per head of wheat, rye, barley, and maize could not rise endlessly; when saturation-point had been reached the yield per head of these elementary necessaries would cease to rise, and the people would use their increasing powers over Nature to win luxuries and leisure. Something of this movement is already seen in the growth of wheat at the expense of rye between 1900 and 1910.

The second section of the table, covering the countries settled from Europe, begins only in 1890, but can be continued to 1920. It shows a very similar picture, not a markedly better one, in agriculture up to the War. From 1890 to 1910 the yield per acre of wheat has increased in the settlements a little faster than in Europe (15 against 12½ per cent.), but that of all crops taken together has increased more slowly (4 against 18 per cent.). The yield per head has also increased for wheat a little faster in the settlements than in Europe (25 against 19 per cent.), and for all crops a little more slowly (11 against 12½ per cent.). The actual yield per head is, of course, much higher in the settlements; the yield per acre is lower for wheat, though higher for the other crops.

In general, as we find European agriculture more progressive than might have been expected, so we find the superiority of the new lands in that field less clear. It is in the industrial field, with doubled or trebled output of coal, iron ore, and steel per head between 1890 and 1910, that the progress of Europe's settlements is most marked.

In the third section of the table, taking Europe and its settlements together, we see progress, both in yield per acre and in yield per head of the four crops, more marked from 1900 to 1910 than from 1890 to 1900, and nothing to suggest a limit to the expansion of the white races in the countries which they hold.

The inclusion of Russia in any statistical table induces an element of uncertainty; it is difficult to be sure that figures for successive years relate to the same area. As a check upon this a second table has been prepared, giving figures for Western and Central Europe; that is, Europe without Russia and Poland. The broad results of this table from 1880 to 1910 are the same as those for Europe as a whole. The yield per acre for each crop and for all crops together is at each epoch higher than when Russia is included and has increased more rapidly. The yield of all crops per head of population has also increased, though less rapidly than for Europe as a whole; this is natural, for the exclusion of Russia means the exclusion of a country which has suffered least from urbanisation.[2]

The main interest of the second table lies in the fact that it can be continued to a fifth epoch—1920—after the War. It shows that at that epoch the total production of wheat in Western and Central Europe was back again near the point where it stood in 1880; for the four crops together, production was about half-way between 1880 and 1890. In acreage under cultivation Europe had gone back still further, probably fifty years at least; the yield per acre was at the point where it stood twenty or thirty years before. The population of course was much greater. Taking the years 1920-1921 together, two and three years after the last shot of the Great War had been fired, Western and Central Europe in total agricultural production had gone back a generation; in production per head of population it had gone back fifty years and more. If Russia and Poland could be included the comparison

[2] The maintained increase in the yield per acre and per head of total population in Western and Central Europe is remarkable, in view of the common assumption that in 'old countries' the point of maximum return to agriculture has long been reached. Unfortunately actual census figures of occupations are available only for seven countries (Austria, Belgium, Denmark, France, Hungary, Italy, and the United Kingdom), omitting all-important Germany: these show for the seven countries a stationary yield of corn per head of the total population and a markedly higher yield per head of the agricultural population in 1910 than in 1900 or 1890. The figures themselves are open to criticism, but it seems safe to assume that in Western and Central Europe as a whole, with the great industrial states of Germany and Britain, the agriculturists form, from 1880 onwards, a diminishing proportion of the total population; per head of those actually employed on the land the yield must have risen yet more markedly than appears in the tables.

TABLE II.

AGRICULTURAL PRODUCTION IN WESTERN AND CENTRAL EUROPE.

Epoch	1880	1890	1900	1910	1920
Population (thousands)	225,613	242,847	264,517	289,893	291,713
Total Production (1000 quarters)					
Wheat	110,796	120,311	137,635	149,466	112,924
Rye	57,196	62,904	76,146	91,949	55,738
Barley	53,580	55,575	60,163	63,738	51,602
Maize	38,205	45,725	48,516	57,763	51,712
Four Crops	259,777	284,515	322,460	362,916	271,976
Area under Crops (1000 acres)					
Wheat	59,960	61,448	63,287	65,139	57,456
Rye	30,716	31,477	31,128	32,305	23,521
Barley	21,752	21,873	20,740	21,718	20,746
Maize	17,849	20,142	21,455	22,147	22,534
Four Crops	130,277	134,940	136,610	141,309	124,257
Yield per Acre (bushels)					
Wheat	14·78	15·66	17·40	18·97	15·72
Rye	14·89	16·00	19·54	22·77	19·40
Barley	19·71	20·33	23·21	23·48	19·90
Maize	17·12	18·16	18·09	20·86	18·36
Four Crops	15·95	16·87	18·88	20·55	17·48
Yield per head (bushels)					
Wheat	3·93	3·97	4·16	4·13	3·10
Rye	2·03	2·07	2·30	2·54	1·53
Barley	1·90	1·83	1·82	1·76	1·41
Maize	1·35	1·51	1·47	1·59	1·42
Four Crops	9·21	9·38	9·75	10·02	7·46

Note to Table II.

The countries included up to 1910 are those forming ' Europe ' in Table I, with the exception of Russia and Poland.

For 1920 the area is nearly but not quite the same. The Polish war gains from Germany and Austria, being reckoned with Poland in the latter year, are excluded. On the other hand, Bosnia, Herzegovina and Montenegro (now part of the Serbo-Croat-Slovene state), Bessarabia (gained by Roumania from Russia), and the Serbian and Bulgarian gains since 1910 from Turkey are included. So far as can be judged, the excluded regions are somewhat less in area (122,000 square km. against 165,000) and somewhat greater in population (11,000,000 against 6,000,000 in 1911) than those included ; that is to say, the term ' Western and Central Europe ' in my table represents a slightly larger area and a slightly smaller population in 1920 than in 1910. The differences, however, are unimportant ; substantially the exclusions and inclusions balance one another and the total regions remain comparable.

would be worse. To point the contrast, we have the figures for Europe's settlements; from 1910 to 1920 a further growth of acreage under crops and of crops per acre, and a yield per head of population only slightly less.

This result is only incidental to the present inquiry. The main object of my calculations has been to test whether the facts suggested any diminution of returns to agriculture in Europe between 1900 and 1910. Having regard to Mr. Keynes' words, I expected to find in the last years before the War a falling yield in Europe, balanced by increased drawing on the virgin lands of the new world. Actually we find in Europe, decade by decade to the eve of war—population rising, acreage under corn rising, total production rising still more, so that we get a greater yield per acre and per head of the total population.[3]

The Movement of Corn Prices.

The answer to our second question, as to the real cost of corn, is as certain and hardly less surprising. If before the War it was becoming 'necessary year by year for Europe to offer a greater quantity of other commodities to obtain the same amount of bread,' the money price of corn must have been rising relatively to the money price of other commodities. There is no trace of such a rise; the movement was in the opposite direction; up to the eve of war the price of corn was falling relatively to the price of other commodities.

Table III shows the movement of wholesale prices from 1871 to 1913 as recorded in the two best-known British indices: that of the

[3] Detailed examination of the figures yields a number of interesting results which can only be briefly indicated here:

(1) The progress shown for all the countries taken together represents a general movement in the fifteen countries taken separately. Taking wheat alone, from 1880 to 1910 every country for which figures are available shows a large increase in the yield per acre, varying from 18 per cent. in France to 68 per cent. in Germany, and averaging 43 per cent.; the other countries show large increases from 1890 to 1910. Even from 1900 to 1910 of the fifteen countries every one but three shows an increased yield per acre; the United Kingdom is stationary and France has a trifling decline; the Danish figures are incomplete and abnormal. More surprising still, every one but four (Belgium, France, Holland and United Kingdom) shows an increase of wheat per head of total population in the decade. For crops other than wheat the figures are less uniformly progressive; generally between 1900 and 1910 yield per acre increased in each country for each crop, except barley (which increased in eight and decreased in six countries), but yield per head of total population increased only for wheat. This greater progress of wheat is in itself a sign of greater ease rather than stringency; it represents a rising, not a falling, standard of life.

(2) During the thirty years 1880 to 1910 the total acreage under each crop and the yield per acre, in Europe as a whole, have both grown. But the rates of growth for acreage and for yield per acre vary inversely. The acreage has increased most for barley (41 per cent.); next for wheat (38 per cent.); next for maize (33 per cent.); and least of all for rye (2 per cent.). The yield per acre has risen most for rye (45 per cent.); next for maize (22 per cent.); next for wheat (19 per cent.); least for barley (13 per cent.). This is an interesting statistical confirmation of expectations based on economic theory. The greater total production has been secured in wheat and barley mainly by bringing fresh lands under cultivation; in maize and rye, mainly by getting more out of lands already cultivated.

TABLE III.

RELATIVE MOVEMENTS IN WHOLESALE PRICES.

Board of Trade Index.

	All Articles	Corn	Meat & Dairy Products	Coal & Metals	As percentages of all articles (Col. 1) Corn	Meat & Dairy Products	Coal & Metals
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1871–80 .	138	166	119	81	126	86	59
1881–90 .	111	129	108	60	116	97	54
1891–00 .	95	108	96	65	113	101	67
1901–10 .	101	106	104	77	106	103	76
1911–13 .	114	116	115	84	102	101	74

Sauerbeck Index.

	All Articles	Vegetable Food	Minerals	As percentages of all articles (Col. 1) Vegetable Food	Minerals
	(1)	(2)	(3)	(4)	(5)
1851–60	94	98	99	104	105
1861–70	100	95	90	95	90
1871–80	96	96	98	100	101
1881–90	75	71	73	95	98
1891–00	66	61	73	92	110
1901–10	73	65	89	89	122
1911–13	83	72	105	87	126
1919	206	179	220	87	107
1920	251	227	295	90	117
1921	155	143	181	92	117
1922	132	108	137	82	104

Board of Trade and that of Sauerbeck. Both indices refer formally to the United Kingdom only, but there can be little danger in taking them as an indication of world conditions; United Kingdom prices from 1871 to 1913 must have followed world prices in all important movements.

From the early 'seventies prices generally first fell heavily to about 1896 and then rose, though not to the height from which they had fallen; that is to say, the value of money in relation to commodities first rose and then fell. Through this complete reversal in the movement of prices generally, the price of corn in relation to other articles has moved steadily—and downwards. Decade by decade from 1871 and to the last three years before the War the price of corn, as recorded by the Board of Trade, has fallen relatively to prices as a whole (column 5); with less regularity, but even more markedly, the relative price of coal and metals has risen (column 7). The result of these two movements is startling; to get in 1911-13 the same amount of corn as in 1871-80 or 1881-90, it would have been necessary to offer, not more coal and metals at the later than at the earlier dates, but one-third less. The Sauerbeck index leads to substantially the same results; it shows from 1871-80 onwards a steady fall in the price of vegetable food and an even greater rise in the price of minerals relatively to all articles (columns 4 and 5); the cost in terms of minerals of a given quantity of vegetable food would have been one quarter to a third less on the eve of the War than it had been a generation before. Both indices point emphatically to a falling, not a rising, real cost of corn.

Index numbers of wholesale prices are open to criticism, in this connection as in many others, because they refer mainly to raw products and give little or no representation to manufactured articles. It would be consistent with the figures quoted above to argue that though the price of coal and of other minerals, which are the basis of manufacturing, had risen relatively to corn, the price of manufactured articles themselves as a whole had fallen relatively to corn. Such a result, paradoxical as it is, could occur in two ways: either if increases in manufacturing efficiency reduced the cost of manufacture or distribution, or if a superfluity of labour fit only for industry, as distinct from agriculture, reduced the reward to such labour, by an amount sufficient in each case to outweigh the increased cost of coal and other minerals. The first is a real possibility; it is just in the spheres of manufacturing and distribution that increased efficiency most naturally accompanies a growth in population and that invention and organisation win their last victories over diminishing returns. But a cheapening of manufacture in this way involves not a decreasing but an increasing return to each unit of labour in industry; it would cause a fall of the real cost of corn measured in labour. The second way assumes a fall in real wages of industrial workers both absolutely and relatively to those of agriculturists such as quite certainly has not taken place in Europe.

In regard to Europe as a whole we find no ground for Malthusian pessimism, no shadow of over-population before the War. Still less do we find them if we widen our view to embrace the world of white men. Mr. Keynes' fears seem not merely unnecessary but baseless; his specific statements are inconsistent with facts. Europe on the eve of war was not threatened with a falling standard of life because Nature's response to further increase in population was diminishing. It was not diminishing; it was increasing. Europe on the eve of war was not threatened with hunger by a rising real cost of corn; the real cost of corn was not rising; it was falling.

Room for Expansion.

I have dealt at some length with Europe before the War because that is Mr. Keynes' theme; in his view the society that seems bent on self-destruction by the Carthaginian peace that crowned the War was already in deadly peril from Nature. If now, with better assurance as to the past, we look for a moment at the distant future of the European races, the first though not the only point for consideration is the extent of the world's untouched or half-used resources in land and minerals. On this point, unfortunately, the existing information goes only part of the way. It is certain that enormous areas of the earth which are fit for cultivation are not yet cultivated at all, and that of other areas only the surface has been scratched; but it is not certain how great the areas that could be cultivated are; how much of the land that is now unproductive of anything must for ever remain so.

In most European countries from 70 to 95 per cent. or more of the total area is now classed as ' productive '; it is being turned to some use—as arable, pasture, forest, and the like. In nine provinces of Canada (excluding the desolate Yukon and North-West Territories) the percentage of all the land that now produces anything is 8, in Siberia 18, in Australia 6, in South Africa 3. Even for the United States it is only 46, and for European Russia 55.[4] Part, no doubt, of the ' unproductive area ' in all those countries is beyond possibility of cultivation; it is impossible on the present information to say how large a part. But the figures as they stand are eloquent of how little the European races have yet done to fill the lands that they hold; how ample the room for their expansion. Any suggestion that these races have reached or are within sight of territorial limits to their growth hardly deserves serious consideration.

Material Progress in Britain.

It is reasonable to suppose, however, that Mr. Keynes, though he speaks throughout of Europe, though he emphasises his European standpoint, was at heart concerned mainly for his own country, and may thus have generalised impressions derived from Britain. For us at least the position in these islands, rather than that in Europe or in the world as a whole is of prime importance If we look at Britain in the last years before the War and ask if all was then well and the prospect cheerful, we get no clear answer to our question. The picture that our economic records paint is half in shadows; to many the shadows will seem ominous of ill.

Unfortunately on this issue, so vital to our interests, the use of statistical tests is peculiarly difficult. The yield of our soil in agriculture is clearly irrelevant; only less so is the yield in such elementary industries as coal or iron mining or pig-iron production. Britain is essentially a manufacturing, commercial, and financial country; the return to its labour is measured by its output or gain from finished articles and services which themselves, by their infinite variety, escape all measurement. Current statistics both of production and of prices refer mainly to raw materials or food; they miss the main features of British economic life and service.

With this warning I invite consideration of the accompanying table of ' Material Progress in the United Kingdom relative to Population.' The table shows at six successive epochs, beginning with 1860 and ending with 1910, the course of some of the most important indices of economic conditions. The figure for each epoch is an average for ten years in which the epoch is central; thus for ' 1860 ' the average of 1855-64 is taken, for ' 1870 ' the average of 1865-74, and so on; for the last epoch, ' 1910,' the average is for the nine years 1905-13 alone; all War years are omitted. The various indices cover the activity

[4] *International Yearbook of Agricultural Statistics*, 1921, pp. 20-21.

TABLE IV.

MATERIAL PROGRESS IN UNITED KINGDOM RELATIVE TO POPULATION.

Epoch	Coal Production per head. tons	Pig-iron Production per head. cwt.	Ship-building Tonnage per 1000.	Raw Cotton Consumption per head. lbs.	Raw Wool Consumption per head. lbs.	Exports Index*	Real Wages†	Real Income per head‡ at 1913 prices. £	Consumption of Food, Drink, etc.§	Housing‖ (Scotland)
1860 (1855–64)	2·62	2·70	9·72¶	28·1	—	48·5	60·7‡‡	26·0‡‡	86·1	43·4
1870 (1865–74)	3·59	3·60	13·52	33·5	10·40	71·6	67·8	29·6	92·8	46·1
1880 (1875–84)	4·21	4·20	15·99	38·6	10·25	80·0	77·4	34·1	103·5	49·2
1890 (1885–94)	4·62	4·00	16·68	40·6	11·85	97·4	91·6	40·0	109·8	51·8
1900 (1895–04)	5·22	4·30	20·36	40·1	12·35	102·7	101·0	45·9	120·9	54·3
1910 (1905–13)	5·89	4·34	21·49	42·2**	12·56††	126·1	101·0	46·9	122·9	56·4
1860 (1855–64)	50·2	62·8	47·7	70·0	—	47·2	60·1	56·6	71·3	79·9
1870 (1865–74)	68·8	83·7	66·4	83·5	84·2	69·7	67·1	63·8	76·8	84·7
1880 (1875–84)	80·6	97·7	78·5	96·3	83·0	77·9	76·6	74·3	85·7	90·6
1890 (1885–94)	88·5	93·0	81·9	101·2	96·0	94·9	90·7	87·1	90·9	95·4
1900 (1895–04)	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0
1910 (1905–13)	112·8	100·9	105·5	105·2	101·7	122·8	100·0	102·2	101·7	103·9

Notes to Table IV.

* Value of exports per head divided by Sauerbeck Index of Wholesale Prices. The 'actual figures' are index-numbers on basis 1900=100.

† Mr. G. H. Wood's Index Number (*Statistical Journal*, March 1909) brought up to 1913 by Professor Bowley and reduced to basis 1913=100.

‡ Money Income calculated on basis adopted by Professor Bowley (but without allowing for unemployment) and divided by Mr. G. H. Wood's Index Number of the Cost of Living (*Statistical Journal*, March 1909) brought up to date by Professor Bowley.

§ Based on Mr. Wood's Index Numbers of Consumption (*Statistical Journal*, December 1899), omitting cotton, wool, wine and spirits, weighted on System V in Mr. Wood's paper and carried forward by figures supplied by Professor Bowley. The first figure relates to 1860, 1862, and 1864. Mean of 1870–79=100.

‖ The figures give the percentage of persons living not more than two to a room in Scotland at each census from 1861 to 1911. Comparable figures for successive censuses are not available for England and Wales.

¶ 1858-64. ** 1905-12. †† 1905-11. ‡‡ 1860-64.

of five important industries (coal, pig iron, shipbuilding, cotton, wool), measured either by production or by consumption of raw material, and of our export trade as a whole; the course of 'real wages' and of 'real income,' *i.e.* of money rates of wages and of money income per head, corrected to allow for changes in the purchasing power of money; the consumption of certain articles of food and drink; and housing. The influence of the growth of the population and the influence of fluctuations in prices have both been eliminated. The figures are presented in two ways; the upper half of the table gives actual figures of production, consumption or 'real income' per head; the lower half gives the same figures as index numbers in which the figure for 1900 is taken=100 and forms the basis. Comparisons with this critical epoch are thus made easy. What does the table show?

It shows, first, for every separate index a marked and almost unbroken rise, epoch by epoch, to the last but one in 1900. There are occasional reactions (as with pig iron from 1880 to 1890 or cotton in the following decade), but these are only ripples on a powerful and rapid stream. From starting-points of about 50 or 60 the various indices moved in fifty years to 100; the general progress from 1890 to 1900 was not less than in previous decades. Unquestionably up to 1900 the average productivity and prosperity of each unit of the population rose as the number of units rose; there was a rapidly increasing return to labour as a whole. This was the complacent Victorian Age which led the world in material progress and piled up savings without effort.

The table shows, next, from 1900 to 1910 a more interesting but more dubious picture. With one exception—real wages—every index has risen, but with two exceptions—coal production and exports—the rise is slower than in previous decades, and in more than one case is barely perceptible. Running our eyes along the last three lines of the table, we see pig iron going from 93 in 1890 to 100 in 1900 and only 101 in 1910; shipbuilding goes 82, 100, 105; wool 96, 100, 102; real wages 91, 100, 100; real income 87, 100, 102; consumption of food and drink 91, 100, 102; housing 95, 100, 104. In index after index a rapid rise to 1900 is followed by a smaller rise, or by no rise at all, to 1910. In cotton there had been reaction from 1890 to 1900; the resumed progress to 1910 was at much below the former average rate. Only in coal production and exports is the rapid progress of Victorian days maintained or accelerated; those two indices represent largely one factor, not two, for coal more than anything else swelled our recent exports.[5] In every other case, rapid certain growth to 1900 gives place

[5] Curiously enough coal is the product for which a diminishing return to labour in this country, not since 1900 merely but long before, seems to be most definitely established. In relation to the number of persons actually employed in mining the output has fallen rapidly, from 324 tons per head per annum in 1881-85, to 288 tons in 1895-99 and 254 tons in 1909-13. If we combine these figures with those showing the relative movement in the wholesale prices of coal and of corn, we find that the amount of corn that could be bought by one person's output of coal in a year rose 30 per cent. from 1881-85 to 1895-99, and was stationary from then to 1909-13; as the hours of work had been reduced between the two latter epochs, the real cost in mining labour of a given quantity of corn had continued to fall slightly even in Britain. The increasing response of Nature to agricultural effort was just more than sufficient to outweight the effects of her diminishing response to the British miner.

to small and dubious improvement in the next ten years. This is the cramped, uneasy, envious, but not impoverished age of Edward.

None of the indices, indeed, records an actual decline; all still show progress however small. Even if the index of 'real wages' —stationary from 1900 to 1910—be accepted without question, the workman was slightly better off at the later epoch, since hours of work were less; he was getting the same wages for a shorter week. We cannot speak of a falling return to labour; at most we see a lower rate of increase, such as might, or might not, precede an actual fall. The contrast, however, between the Victorian and the Edwardian ages is unquestionably disturbing. In Britain, if not in Europe as a whole, the turn of the century seems to bring a turn of fortune. What conclusions are we to draw? What remedies, if any, can we apply? We shall find reasons for not being too ready to despair of the commonwealth.

The Edwardian Age and its Meaning.

In the first place, there is ground for optimistic doubts as to the figures themselves. Several of them, particularly the indices of real income, real wages and consumption, are elaborate structures based largely on estimates; others are suspect for various reasons; none need be believed to the death.[6] And even if the structure be sound, no established index of material prosperity can be expected to rise indefinitely. Progress involves change. When a nation has reached a certain point in the consumption of necessaries, it will utilise further purchasing power, not in consuming more of those necessaries, but in other ways: in buying bananas and condensed milk instead of more bread or meat, in tasting leisure, education, travel, football, cinemas, and other delights which do not appear in any index. So there may be a saturation-point in production; after putting its growing strength for many years into shipbuilding or cotton a nation may find greater need for its services in other directions—in transport, commerce, or finance.

[6] Two special causes of doubt are worth mentioning :—

(1) The presentation of the figures as averages for particular decades, necessary as it is in order to give within reasonable space a summary picture of the whole, is deceptive, because the various decades are unequally affected by the phases of the trade cycle. The years 1895-1904 contain but one year of slight depression (1904) and an undue proportion of 'good' years. The nine years 1905-13 contain the end of the slight 1904-5 depression and the whole of the exceptionally severe depression of 1908-9. The course of cyclical fluctuation unfairly weights the comparison against the later epoch.

(2) The falling off of cotton, not only in the last decade but ever since 1880, is in large part apparent only. British industry was concentrating more and more on fine counts, using more spindles and producing more value for the same weight of raw cotton.

A point on the other side, *i.e.* making the comparison unduly favourable to later epochs, is the change in the age-constitution of the population. The population in 1910 included a larger proportion of adults and a smaller proportion of children than that of 1900; production and consumption 'per head' should have been slightly higher to maintain the same standard in relation to capacity. The correction to be applied on this account is too small to disturb the comparison appreciably.

In the second place, even if we admit, as I, for one, am prepared to admit, that there was some real change in our conditions, some faltering in our progress in the first years of this century, it may yet be no more than a transient phenomenon, a result of special causes not pointing to permanent change. At the turn of the century we do in fact find special and temporary influences disturbing our ordinary development. One of these is the South African War; that war, like other wars, probably caused a greater loss of savings than of human life; it would leave capital scarce relatively to labour and in a stronger position to bargain. Another is the change in the movement of prices. Just before 1900 the falling tide of prices turned. From 1900 to 1913 we lived on a rising tide. This also is an element favouring capital as against labour, profits rather than wages. Yet another special influence at the turn of the century is a change in the rate of labour supply, due partly to the course of birth- and death-rates more than twenty years before and partly to the development of compulsory education. This point calls for explanation.

In 1876 the birth-rate in this country reached its maximum. At the same time, or just before, important steps were taken for the improvement of public health; the death-rate, which had changed little for thirty years, began to fall, and fell steadily thereafter. There followed a quarter of a century later, as a wave follows a distant earthquake, an abnormal growth in the supply of adult labour. As has been pointed out by Mr. Yule, the number of males aged twenty to fifty-five rose 19 per cent. from 1891 to 1901, as compared with a rise of 14 per cent. from 1881 to 1891, and 10 per cent. in earlier decades.[7] If we take five-year averages the rate of natural increase (difference of birth- and death-rates) reached its highest points in the years 1876-1880 and 1881-1885. Normally, this would have shown itself first by large numbers of boys entering the labour market in the early 'nineties. At the same time, however, the Education Acts were withdrawing more and more boys under fourteen into the schools. The State dammed up the rising flow of juvenile labour for a year or two. The main pressure in the labour market began to be felt later, *i.e.* about 1900, and presented itself as the 'problem of boy labour,' which was really the problem of those who had got boys' work easily enough between fourteen and twenty (replacing the younger children kept at school), but found themselves in difficulties when they reached man's estate. This abnormal movement was bound, for the time at least, to disturb the balance between the growth of capital needed to employ labour and the growth of labour seeking employment. Some temporary pressure in the labour market was inevitable. It might cause a check in economic progress as measured per head of the total population; it would certainly, in the bargaining between labour and capital for the division of their joint product, make labour for the moment relatively weak and capital for the moment relatively strong because scarce. Wages would lose relatively to profits.

[7] See Mr. Yule's paper on 'Changes in the Birth and Marriage Rates' in the Journal of the Royal Statistical Society, March 1906.

All these special influences favour capital against labour. It is in accord with them that, of all our economic indices, that which shows worst, the only one that shows no progress at all from 1900 to 1910, is real wages, the reward to labour; that which almost alone shows continued progress at the full Victorian rate is exports, to be explained perhaps in large measure as the surplus profits of capital.

With these points in mind, we reach an economic interpretation of the Edwardian age, reasonable in itself and consistent with other than economic records. That age does not live in our memories and will not live in drama and fiction[8] as a season of hard living and hard labour. It comes back to us now rather in the guise of the ball before Waterloo, as an episode of unexampled spending and luxury; as the time when we saw our roads beset by motors, our countryside by golfers, our football grounds by hundred thousand crowds and a new industry of bookmakers, our ballrooms and dining-rooms by every form of extravagance. The smooth development of Victorian days was broken, but the characteristic of the time was rather inequality of fortune than general misfortune; discontent rather than poverty; a gain by capital in relation to labour, by profits in relation to wages, by some classes of workmen at the expense of others, even more than a check to our progress as a nation. Some check to our national progress there probably was, but we are not bound to believe that the check was permanent. The three factors described above—the earthquake wave of labour supply, the South African War, and the upward turn of prices—are all peculiar to their time. The relative shortage of capital would tend to produce its own corrective. Difficulty in absorbing an abnormal flood of new labour does not prove permanent over-population; if all the hundred million persons who now find room and growing opportunities in the United States had landed there at once they would all have starved.[9]

In the last three years before the War we find in nearly all indices resumption of a rapid upward movement. What would have happened if the War had not come? Would the Edwardian age have proved a passing episode of unrest or the beginning of a serious threat to our prosperity? This is one of many questions whose answer is buried in the common grave of war.

In the third place, even if the new century was to see in Britain a lasting and not a transient harshening of conditions, if the rich ease of the Victorian age had gone for ever with Victoria, there is little ground for surprise. Malthus or no Malthus, it was not reasonable to expect Britain to keep up for ever the speed that marked her start in the industrial race. Providence had not concentrated in these islands the coal and iron supplies of all the world. As the United States and Germany and France developed their own mineral resources, Britain was destined to find her general industrial supremacy challenged, now in one field now in another; she would be driven to discover and maintain those branches of work in

[8] *Sonia*, by Stephen McKenna; *Tono-Bungay*, By H. G. Wells; *The Regent*, by Arnold Bennett.

[9] This is pointed out by a recent author, Mr. H. Wright, in *Population*, p. 110 ('Cambridge Economic Handbooks,' 1923).

which she had the greatest economic advantage, and to withdraw from the rest. This process of challenge and adjustment was bound to occur irrespective of the growth of population, and as it occurred to give rise to strains and pressures; when accomplished it might yet leave room for progress, if not at the full Victorian pace.

Of Britain before the War we may conclude that the position called for serious thought, not tears or panic. The economic records are open to diverse readings. The check to material progress in the Edwardian age may in part have been less than appears, and in part real but due to transient causes. At worst our industrial rank was challenged, not destroyed; forgetting some of the slacknesses of our easy days, we might through science and system and industrial peace have won a new lease of rapid progress. In this direction lay our remedy; in this, I think, rather than in hastening the process of birth restriction which had begun a generation before.

Britain and Austria after the War.

Let us pass to Britain after the War. Here, statistical tests of progress must be abandoned altogether. War's disturbance of our economic life and all its standards and records is barely subsiding; to found judgments of the future on the course of production or wages or prices in the years of demobilisation is vanity. Judgment by recorded results is impossible; we are driven back to general considerations for an estimate of prospects in this new but not better world.

The first principle of population to-day is that under conditions of economic specialisation and international trade the population problem in any particular country cannot profitably be considered without reference to other countries. The problem in every country is a problem of the distribution of the population of the world as a whole. The actual density in different regions of the earth varies fantastically, according to the part which that region plays in the life of the world, from less than one person per square kilometre in Canada or three in the Argentine, through 186 in Britain, or 245 in Belgium, to 760 in Monaco or 3,538 in Gibraltar.[10] The 'optimum density'[11] for any one country at each moment depends not solely or even mainly upon its own resources of natural fertility or mineral treasure, on its own achievements of technique or co-operation, but on how in each of these matters it compares with other countries, on whether other countries are prospering or depressed, on the relations of its own people—in respect of peace or war, of trade or tariffs—towards other peoples.

Britain illustrates this principle more clearly than any other great

[10] These figures relate to 1911 and are taken from Table I of the International Yearbook of Agricultural Statistics. A remarkable instance of the density possible to a purely agricultural population is presented by Java and Madura, which in 1921 had a population of 35,000,000, living 266 to the square kilometre, more than the most crowded industrial states of Europe. This involves of course a Chinese standard of life.

[11] That is, the density which will bring the largest return per head of the population. *Cf.* Cannan, *Wealth*, p. 68, and Carr-Saunders, *The Population Problem*, pp. 200 seq.

country, because of all great countries Britain has grown to be the least self-sufficient, the most highly specialised, the most dependent on trade and peace and world-wide co-operation. A pregnant analogy will make the position clear.

In Central Europe, before the War, lived, under one dynastic ruler, a congeries of communities known collectively as the Austro-Hungarian Empire. These communities formed together a single economic unit, a free-trade area with fifty million inhabitants, in which every stage of economic activity, from the simplest agriculture to the most developed finance, was strongly represented, in which all the separate functions came to be distributed locally according to economic advantage without regard to internal boundaries. Some regions—east and south—were predominantly agricultural; in the north-west were extractive industries of coal and iron, and manufactures founded upon them; further south were other manufactures, and the main seat of commerce and finance. Here was timber; there water-power. Each industry tended to settle where it could most profitably be carried on. Within each industry local specialisation often went very far; thus, in cotton, one region predominated in the first and final processes (spinning and bleaching), another had more than its share of intermediate processes (such as weaving); the locomotives for railways came to be built in one region and the waggons in another. In the centre lay Vienna, a natural meeting-point entrenched by art in a system of radiating railways, concentrating on itself the most advanced stages of social life—fine manufactures, commerce, distribution, transport, finance, administration—a large and prosperous head directing and nourished by a large body. While the Austro-Hungarian Empire lasted, this headship brought with it the first place in prosperity. The wealth, pleasure, and extravagance, no less than the government, education, science and art, of fifty millions made Vienna their centre.

The War came and went, and with it went the Empire. The dynastic ruler disappeared; the congeries dissolved; each community became a separate body desiring and needing a separate head, aiming at self-sufficiency, seeking it by economic barriers against intercourse. In that break-up the average prosperity of all the fifty millions has sunk. Nearly every region is in some way poorer than before. But no region has suffered as much as Vienna; in none does the loss take the characteristic appearance of over-population. Vienna remains a head grotesquely too large for the shrunken body of German Austria, manifestly over-populated, as little able to support its former numbers at their former standard, as would be Monaco if the nations gave up gambling or Gibraltar if they gave up war. It is over-populated, not through exhaustion of its natural resources, not because in the past its people were too prolific, but because the world outside has changed too suddenly.

De nobis fabula—the fate of German Austria is the moral for Britain. No other country of comparable size is so highly specialised as Britain. None produces so small a proportion of the food that it requires, or of the raw materials of its industries. None is so predominantly engaged in the advanced ranges of economic activity;

in industry rather than agriculture; in finishing processes rather than the extraction of raw material; in transport, commerce and finance, rather than manufacture. No other country, therefore, is so completely dependent upon the restoration of peace and trade and economic co-operation. None is destined to suffer so acutely from any general disorder. At this moment perhaps none is suffering so much.

It is needless to seek in excessive fecundity an explanation of our present troubles. There are other reasons, enough and to spare, why we should expect now to suffer from unexampled unemployment. Two exceptional causes of unemployment are now added to the normal movement of cyclical fluctuation. One is the difficulty of passing from war and war industries to peace—the difficulty of making swordsmen into ploughboys. The process of training and directing the new supplies of labour to fit the changing needs of industry has been broken by the War; there is a maladjustment of quality between labour supply and labour demand. The second cause lies in the damage done by the War and its aftermath to the economic structure of the world; the destruction of capital, the relapse of great nations towards barbarism, the breaking of easy and friendly intercourse, the continuance of war measures, the smaller volume of international trade and its shifting into new channels. The world has changed suddenly, if less completely, round us as round German Austria. Many of our trades find their former customers dead or impoverished or cut off by new barriers; the labour trained to those trades cannot shift to fill the gap in production which is left by the disappearance of those customers and their work. In both these ways, in terms which I used in writing of unemployment fifteen years ago, we have leading instances of those 'changes of industrial structure' which leave legacies of enduring unemployment, to be reduced only as the labour ill-fitted for new needs is slowly and individually absorbed again or is removed by death or emigration.[12]

The fate of Austria has a bearing not on war alone. The world may change otherwise than by war. The 'optimum density' of population for any country may be diminished not by anything happening in that country, but by the discovery and exploitation of resources in other countries; possibly even by tariff changes. The more any country is specialised in its economic functions, above all if it is specialised in the most developed rather than in the primary functions, the greater is its liability to such changes. Britain, becoming yearly less self-sufficient, setting each year a swiftly growing people to more and more specialised labour, increasing each year its inward and outward trade, was before the War taking more and more the Austrian risk. It is arguable that with this lesson before us we ought no longer to take the risk so fully; should retrace our specialisation and aim at self-sufficiency—in practical terms, under a system of tariffs or bounties,

[12] Uncertainty as to the course of prices, with its paralysing effect on business enterprise, ought perhaps to be named as yet another special cause of post-war unemployment. Alternation of upward and downward movements of prices is, of course, one of the elements in normal cyclical fluctuation.

should grow more corn and do less trade. The practical answer to that argument is that we are already too far from self-sufficiency to make worth while any attempt to return. Any change great enough to diminish seriously our dependence on overseas trade, in other words our exposure to the Austrian risk, would involve an impracticable reduction in our total population and our average wealth. A middle course that is sometimes suggested is to aim at self-sufficiency in the British Empire, by tariff arrangements favouring Imperial rather than foreign trade. The adoption of such arrangements clearly depends more on the wishes of the Dominions than on those of Britain, and their value for the purpose in view upon the readiness of the Dominions to acquiesce in a division of economic functions which would leave the most advanced and most profitable ones to the British Isles. It is more than doubtful whether this is the Dominion view of Imperial economics. In the last analysis, the long road which Britain has travelled to dependence on international trade, as general and as free as possible, will, I believe, be found to be irretraceable. Like the hero of one of Mr. Wells' novels, the Britain that we know, the Britain of forty millions, has been made for a peaceful and co-operative world; she must try to create such a world if she does not find it ready to hand.

Recapitulation.

Let me try to gather together the threads of this long discussion. A further quotation from Mr. Keynes' writings will serve for a starting-point:—

'The most interesting question in the world,' he writes, '(of those at least of which time will bring us an answer) is whether, after a short interval of recovery, material progress will be resumed, or whether, on the other hand, the magnificent episode of the nineteenth century is over. In attempting to answer this question it is important not to exaggerate the direct effects of the late War. If the permanent underlying influences are favourable, the effects of the War will be no more lasting than were those of the wars of Napoleon. But if even before the War the underlying influences were becoming less favourable, then the effects of the War may have been decisive in settling the date of the transition from progress to retrogression.' [13]

The warning deserves attention. Yet, as I am less inclined than Mr. Keynes to be pessimistic about the tendencies before the War, I feel perhaps more pessimistic than he is in this passage about the effects of the War, and the possibly enduring damage it may have done and be destined to do to humanity.

Before the War, as I have tried to show, there is nothing to suggest that Europe had reached its economic climax; Malthus' Devil, unchained again or not, cannot be found where Mr. Keynes professes to find him. For the world of white men as a whole there is even less ground for pessimism; the limits of agricultural expansion are indefinitely far. If we regard only that part of this world which is known as Britain,

[13] 'An Economist's View of Population,' in the Manchester Guardian Reconstruction Supplement, Section Six (1922).

judgment is not so easy. Some change did come over our economic life, or certain parts of it, with the turn of the century; our effortless supremacy was challenged. Reasonable men may dispute, and since the decisive evidence has perished will probably dispute for ever, whether the unrest and uncertainty of the Edwardian age marked a passing episode destined but for the War to give place to a fresh stage of swiftly rising prosperity, or, on the other hand, recorded the first shock of permanent forces working to make life in these islands less easy and to set a term to material progress.

After the War—for that phase, if indeed we have reached it, I doubt whether we may find much comfort in Napoleonic parallels. The Napoleonic wars were wars between Governments and armies rather than peoples; they did not bite deeply into economic life; they left it possible for the best contemporary fiction to show a picture of English society in which the military figure chiefly as dancing partners.[14] The war of 1914-18 was waged on millions of non-combatants, as much as on armies; it is being continued in the same form to-day; the economic structure of the world, battered out of shape by four years of open war, is still twisted by human passions. The lesson of compulsory self-sufficiency has been learnt too well; in all parts of the world, by new economic barriers, nations are endeavouring to safeguard, at the expense of their native and natural industries, the industries which were forced on them by the extremities of war. The world is poorer in resources by its lost years and ruined capital; of those diminished resources it makes worse use.[15]

To sum up, for Europe and its races the underlying influences in economics were probably still favourable when the War began. But the war damage was great and we are not in sight of its end. Man for his present troubles has to accuse neither the niggardliness of Nature nor his own instinct of reproduction, but other instincts as primitive and, in excess, as fatal to Utopian dreams. He has to find the remedy elsewhere than in birth control.

The Population Problem Remains.

Let me add one word of warning before I finish. Such examination as I have been able to make of economic tendencies before the War yields no ground for alarm as to the immediate future of mankind, no justification for Malthusian panic.

It has seemed important to emphasise this, so that false diagnosis should not lead to wrong remedies for the world's sickness to-day. But the last thing I wish is to over-emphasise points of disagreement with Mr. Keynes. The limits of disagreement are really narrow. The phrases which I have criticised are incidental, not essential, to Mr. Keynes' main argument as to the consequences of the War and the Peace. And whether Mr. Keynes was right, or, as I think, too

14 Jane Austen's first three novels were written during the Revolutionary Wars (1796 to 1798); her last three between Wagram (1809) and Waterloo (1815).

15 The recent development of prohibitive tariffs is very fully described in a special supplement by Dr. Gregory to the London and Cambridge Economic Service.

pessimistic in his reading of economic tendencies before the War, he will be regarded as unquestionably right in calling attention again to the importance of the problem of population.

Nothing that I have said discredits the fundamental principle of Malthus, reinforced as it can be by the teachings of modern science. The idea that mankind, while reducing indefinitely the risks to human life, can, without disaster, use to the full a power of reproduction adapted to the perils of savage or prehuman days, can control death by art and leave births to Nature, is biologically absurd. The rapid cumulative increase following on any practical application of this idea would within measurable time make civilisation impossible in this or any other planet.

In fact, this idea is no more a fundamental part of human thought than is the doctrine of *laissez faire* in economics, which has been its contemporary, alike in dominance and in decay. Sociology and history show that man has hardly ever acted on this idea; at nearly all stages of his development he has, directly or indirectly, limited the number of his descendants.[16] Vital statistics show that the European races, after a phase of headlong increase, are returning to restriction. The revolutionary fall of fertility among these races within the past fifty years, while it has some mysterious features, is due in the main to practices as deliberate as infanticide. The questions now facing us are how far the fall will go; whether it will bring about a stationary white population after or long before the white man's world is full; how the varying incidence of restriction among different social classes or creeds will affect the stock; how far the unequal adoption of birth control by different races will leave one race at the mercy of another's growing numbers, or drive it to armaments and perpetual aggression in self-defence.

To answer these questions is beyond my scope, as it is beside my purpose to pass judgment on the practices from which they spring. The purpose of my paper is rather to give reasons for suspending judgment till we know more. The authority of economic science cannot be invoked for the intensification of these practices as a cure for our present troubles. But behind these troubles the problem of numbers waits —the last inexorable riddle for mankind. To multiply the nation and not increase the joy is the most dismal end that can be set for human striving. If we desire another end than that, we should not burk discussion of the means. However the matter be judged, there is full time for inquiry, before fecundity destroys us, but inquiry and frank discussion there must be. Two inquiries in particular it seems well to suggest at once.

The first is an investigation into the potential agricultural resources of the world. There has been more than one elaborate examination of coal supplies; we have estimates of the total stock of coal down to various depths in Britain and Germany, in America, China, and elsewhere; we can form some impression of how long at given rates of consumption each of those stocks will last; we know that 'exhaustion' is not an issue for this generation or many generations to come. There has been no corresponding study of agricultural resources; there is not

[16] See *The Problem of Population*, by A. M. Carr-Saunders.

material even for a guess at what proportion of the vast regions—in Canada, Siberia, South America, Africa, Australia—now used for no productive purpose could be made productive; at what proportion of all the 'productive' but ill-cultivated land could with varying degrees of trouble be fitted for corn and pasture. Without some estimate on such points, discussion of the problem of world population is mere groping in the dark. The inquiry itself is one that by an adequate combination of experts in geographic, agricultural and economic science —not by a commission gathering opinions or an office gathering statistical returns—it should not be difficult to make.

The second is an investigation into the physical, psychological, and social effects of that restriction of fertility which has now become a leading feature of the problem. This also is a matter neither for one person—for its scope covers several sciences—nor for a commission; facts rather than opinions or prejudices are required.

If the question be asked, not what inquiries should be made but what action should now be taken, it is difficult to go beyond the trite generalities of reconstruction, of peace and trade abroad, of efficiency and education at home. The more completely we can restore the economic system under which our people grew, the sooner shall we absorb them again in productive labour. Unless we can make the world again a vast co-operative commonwealth of trade, we shall not find it spacious enough or rich enough to demand from these islands the special services by which alone they can sustain their teeming population. Even if the world becomes again large enough to hold us, we shall not keep our place in it with the ease of Victorian days; we dare no longer allow, on either side of the wage bargain, methods which waste machinery or brains or labour. Finally, if there be any question of numbers, if there be any risk that our people may grow too many, the last folly that we can afford is to lower their quality and go back in measures of health or education. Recoil from standards once reached is the gesture of a community touched by decay.

TRANSPORT AND ITS INDEBTEDNESS TO SCIENCE.

ADDRESS TO SECTION G (ENGINEERING) BY

SIR HENRY FOWLER, K.B.E.,

PRESIDENT OF THE SECTION.

I FEEL that it is right that the Engineering Section of the Association here in Liverpool should devote one of its sessions to the subject of traction. There is no city in the Empire, or in the world, which is so dependent on traction in one way or the other as the one in which we are meeting to-day, and I can also say without fear of contradiction that there is no city in the world which has acted as so great a pioneer in traction development as this one on the Mersey.

Its very birth was caused by the physical features it presented at a time when the estuary of the Dee was silting up, whilst whatever may be the derivation of the first portion of its name, there is no question but that the latter portion refers to the advantages it offered for water transport.

It is not necessary, nor am I qualified, to speak of the development of the 'pool' into the port which means so much to Liverpool at the present day, but there are other methods of transport in which it has played an important part that I should like to mention.

As early as 1777 Liverpool realised the necessity and advantages of easy and cheap transport, and the canal from Liverpool to the Trent was constructed at that date, having a length of ninety-six miles. This joined the Trent at Shardlow, not far from Nottingham, and it has recently been suggested the river should be canalised from there to the sea on the East Coast.

More recently Liverpool has become connected with its sister city of Manchester by the Ship Canal, in the carrying out of which many interesting engineering problems were met and solved.

The better-remembered event is, however, in connection with transport by rail. It was the construction of the Liverpool and Manchester Railway in 1829 and its immediate success that more than anything else impressed on the country the fact that a new system of traction was opening out unheard-of possibilities. It is not too much to say that the production of the 'Rocket' for the trials at Rainhill in October 1829 marked the first step in the practical commercial success of railways.

This, however, has not been the last association of the city in pioneer work on the rail in this country. In 1904 the Liverpool and Southport section of the Lancashire and Yorkshire Railway was electrified, this being the first inter-urban electric line in this country. The change was due to the enterprise and foresight of Mr. (Sir) John A. F. Aspinall, a distinguished son of Liverpool, and the Directors of the Lancashire and Yorkshire Railway. The electrification of the line was preceded by exhaustive trials to determine the tractive force required to overcome the resistance on railways,[1] and with these trials I had the honour of being connected.

The other matter in which Liverpool has done pioneer work on traction is that of heavy motor traffic. From its inception in 1895 the Liverpool Self-propelled Traffic Association was specially connected with this method of transport. Under the presidency of the late Sir Alfred Jones, with the guidance of Dr. Hele Shaw and under the organising ability of its enthusiastic and energetic secretary, Mr. E. Shrapnell Smith, it organised and carried out trials of commercial vehicles in 1898, 1899, and 1901. In May 1898 were carried out the first practical trials of these vehicles held in the country, and I had the honour of being the observer of the first lorry to leave the yard. The Motor Car Act of 1903, which allowed a practical weight for commercial road motor vehicles, was the result of a deputation of the Liverpool Self-propelled Traffic Association waiting on the President of the Local Government Board (the Right Hon. Walter Long, now Viscount Long) when he was on a visit to Liverpool.

I think I have said enough to justify the statement I made that it is fitting that one of our sessions here in this city of Liverpool should be devoted to the question of transport, and I wish to speak of its indebtedness to Science, and trust I may be able to show that, as with other branches of engineering, its progress is due to science, and, in concluding, speak of how it may repay, if inadequately, the debt under which it is placed.

We are perhaps too apt at the present time to forget the obligation which the world owes to transportation, so commonplace have the improved methods become. We are already forgetting the lesson that the submarine menace gave us on this matter during the War, and again looking upon the movement of matter from point to point as a commonplace occurrence. It has been said that effective transportation is one of the great aids to civilisation, but it must not be forgotten that all movement of material from place to place is economically waste as far as the dissipation of work is concerned. Problems of transportation have been solved more or less successfully in all ages, and some of them, such as the moving of the stone to Stonehenge, &c., still excite our wonder and admiration. Such works, and similar ones of much greater magnitude in the East, however, we feel as engineers could be accomplished by quite crude methods if there was unlimited labour available and if time were of no consequence.

The transportation which aids civilisation is that which cuts down the wastage of power to a minimum and which reduces the time occupied in carrying this out. It is here that science has helped in times past, and will help increasingly in the future if we are to go forward. In no other branch is Telford's dictum that the science of engineering is 'the art of directing the great sources of power in Nature for the use and

[1] See Mr. (Sir) J. A. F. Aspinall's paper on 'Train Resistance,' *Proceedings of the Institution of Civil Engineers*, vol. 147, 1901.

convenience of man' so well exemplified, and this utilisation has been carried forward at ever-increasing speed during the last hundred years.

If we take the definition of Science as 'ordered knowledge of natural phenomena and of the relations between them,' as given by W. C. D. Whetham in the 'Encyclopædia Britannica,' we shall easily see how transportation has been dependent upon it.

It may be that some may not agree with this definition of 'ordered knowledge of natural phenomena,' but I feel that after thought it will be recognised that it covers very completely what we call Science. We are rather apt to confuse the knowledge with the means and apparatus applied in getting it. Recently I have read an article which called attention to the dependence of science upon engineering or mechanical achievement, but surely the accuracy we get, the lack of which was such a great drawback to the investigations of a century to a century and a half ago, is itself based upon 'ordered knowledge.'

Dealing with transport, it may be said roughly that it is mainly dependent upon three things—the method of propulsion, the material available for use, and the path over which traction takes place. I cannot deal fully even with one of these, and propose to confine my remarks to the first two, which are the ones I am best acquainted with.

It may be said that advance in traction really became rapid when methods of propulsion other than those of animals and the force of the wind became available. The greatest step forward—wonderful as some of the achievements of aeronautics have been of recent years—came with the development of the steam-engine.

Like most great achievements in the world, it was not a lucky and sudden discovery of one individual, although here as elsewhere we associate the work with the name of one man especially. This has usually been the case, and without wishing to detract from the work of the individuals who are fortunate enough to utilise the ordered knowledge available to the practical use of man, one must not forget the labours of those who have sought out that knowledge and have given it freely to the world, thus placing it at the disposal of the one whose imagination and creative faculty were great enough to see how it could be utilised in the service of man.

The first attempt at traction by using a steam-engine was a failure because of the lack of this knowledge. I refer to the work of Jonathan Hulls and his attempt in 1736-7 to apply one to the propulsion of a boat on the River Avon in Worcestershire. He failed because of the lack of that knowledge, although undoubtedly he possessed the necessary imagination.

Although James Watt is not directly associated with traction, it was his application of science to practical use that finally gave the greatest impulse to transportation that it has ever had. No advance had taken place to Newcomen's engine of 1720 until Watt's work of 1769. His knowledge of Black's work at Glasgow on the latent heat of steam and his own experiments with the Newcomen model led to the success of his improvements of the steam-engine. His scientific knowledge is clearly shewn in his patents and publications, for he dealt with steam-jacketing in 1769, with expansive working in 1782, and he devised his parallel motion in 1784. His direct connection with transport includes the reference to a steam-carriage and a screw-propeller in 1784, whilst the firm of Boulton & Watt corresponded with Fulton for a period extending from 1794 to 1805.

Although Cugnot in 1770 and Murdoch in 1786 had made models of vehicles propelled by steam, it was Richard Trevithick with his steam-carriage in 1801 and 1803 and ill-fated railway in 1804 who first showed the practical application which could be made. It is probable that the engine which his assistant, Steel, took to the wagon-way at Wylam in 1805 turned the thoughts of George Stephenson to the work that has meant so much for us. No one can read the early life of the father of railways without appreciating that he was from young manhood a searcher after scientific knowledge. Doubtless he owed much to the friendship of Sir William Fairbairn, the President of our Association in 1861. The advances he gave to the world of transport were all due to his practical application of the knowledge he had obtained himself or had learned from others. It is so often thought that because the early inventors and engineers of the beginning of last century had not received what we now call a scientific education they were not in any sense of the term men of science. It must be remembered that at that time the knowledge of natural phenomena was very limited, and it was possible to know much more easily all the information available on a subject than at the present day, when we have such a mass of miscellaneous information to hand on every conceivable subject. It was ordered knowledge which led Stephenson to adopt the blast-pipe of Trevithick. It was the desirability of obtaining ordered knowledge that caused him to carry out those experiments which showed to him the advantages of using rails, and it was the scientific appreciation of the necessity of increased heating surface that made him adopt the suggestion of using tubes through the water-space in the boiler of the 'Rocket.' His appreciation of the advantages of science was shown by his acceptance of the Presidency of the Mechanical Science Section (then as now Section G) of our Association in 1838. It is interesting to note that one of the earliest grants in Section G was for a constant indicator (for locomotives) and dynamometric instruments in 1842-43, whilst Stephenson was still alive. Let me remind you of his ready grasp of the application of a known principle to a different object by the story of the invention of the steam-whistle. On the Leicester and Swannington Railway, which followed the Liverpool and Manchester, one of the Newcastle locomotive-drivers—R. Weatherburn—at a level-crossing ran into the cart belonging to an old lady, destroying her eggs and butter. Upon his return to Leicester, and reporting this to Stephenson, he was at once told to go down the town to a trumpet-maker and get him to make a trumpet which could be blown by steam. None but a mind in which the knowledge of natural phenomena was very carefully ordered could have so readily solved such a problem.

From the time of Stephenson the progress in propulsion on rails by steam-locomotives was steady if slow. The investigations for a long while were largely confined to the question of expansion and condensation, and although the results attained were noteworthy in the case of steamships, on the rail—to which for the moment I will confine myself—there was little advance in the principle of propulsion, but, as I shall show later, the improvements in materials allowed a steady growth in power and size. Although work was done by compounding and using higher pressures, the greatest advance has come to steam-locomotives by the use of superheated steam. This was no new thing, for Papin in 1705 seemed to have an appreciation of its value. As pressures and the resultant temperatures increased there came difficulties with lubrication. With the increased use and knowledge of mineral lubricants Dr. Schmit was in 1895 able to devise methods of using superheated steam which have been of the greatest use to transport and to the community.

The progress of transport on the rail has latterly strongly followed other lines, and I must for a few minutes go back again to the development of the use of steam in a turbine in order to speak of the subject of electric traction.

In spite of the fact that the idea of the utilisation of steam for giving rotary motion is old, its commercial adaptation in the turbine is modern. Rarely, if ever, has there been such a direct and instantaneous application of science to practice. We are too close at present to the matter to realise what a change has taken place in the world owing to the introduction of the steam-turbine.

If we think for a moment we shall realise what a change has come over our lives, not only in an engineering but in a general sense, since the end of last century. It has truly been said that this is very largely due to an Italian experimenting with Hertz waves, to numberless young men lying on their backs on muddy roads under motor-cars, and not least to a young Irish engineer who revolutionised transport.

One realises the work done by De Laval, Curtiss, Rateau, and the brothers Ljungstrom, but the name which will always be associated with the steam-turbine as firmly as that of James Watt is with the inception of the steam-engine is that of Sir Charles A. Parsons, our President for the Meeting of 1919 at Bournemouth. The success of his work is due to his application of scientific principles to the many points of the turbine and its accessories. Apart from its application to marine work, it is the turbine which has made possible the economical production of electrical energy, which is doing so much, and will do so much more in the future, for rail transport. To-day it may be said, as it often has been, that there are no mechanical or electrical difficulties in the electrification of railways, the only difficulties being financial ones, although one could hope that the induction troubles could be overcome by a cheaper method than at present available.

It is impossible here to trace the development of electrical science from the experiments described by Gilbert in 1600 to the equipment of electric locomotives on the railways of Switzerland and the United States of America. If we were able to trace this development we should see that it has been not only a gradual but a continuous and ordered increase of knowledge of natural phenomena. One must mention, however, what a change electrical traction by train and tube has made to our town life. It has rendered our large towns possible and given a chance to millions of our workers of a wider outlook on life and the opportunity of living amongst healthier and more pleasant surroundings. This, as just stated, is not the result of a sudden discovery of some fundamental principle, but to a studied advance, step by step, from very elementary knowledge to the information we have available and at our disposal to-day. This is very largely the result of endless laboratory research and experiment.

The last method of propulsion that I can deal with is that by means of the internal-combustion engine. This, as we almost universally have it to-day, is the result of the cycle adopted by N. A. Otto in his gas-engine in 1876. Here again the engines we have to-day are the result of careful and studied investigation. It may be truly said that the advance made has been so much more rapid than in the case of the steam-engine and electrical machinery because of the more advanced state of scientific knowledge, and it furnishes an example of the assistance which this gives to progress.

In relation to transport the work has proceeded on two distinct lines, the Daimler and the Diesel engines. In 1885 Gottlieb Daimler produced the engine that is associated with his name, and which utilises a light spirit which supplies a carburetted air for the explosive mixture for the cylinder. The development of this engine has itself proceeded in two directions. In the one it has been made very much more flexible and silent in its adaptation to motor-car work, whilst in the other the great desideratum has been lightness and in association with the improvements in the necessary materials has rendered possible the aeroplane as we have it to-day. In both cases the development to the degree reached has been due to a careful study primarily of the pressures, compression, and composition of the mixture.

The Diesel engine was invented in 1894 by Rudolph Diesel, and consists of the injection of oil or pulverised fuel into the engine cylinder. Its development has taken place both on the four- and two-stroke cycle, and although considerable progress has been made with land engines, it has chiefly been used for marine transport.

The internal-combustion engine has not been largely used for rail transport owing to its comparatively high cost of fuel per horse-power and its lack of flexibility. The latter is particularly the case when one remembers the high torque which is so desirable, and which can be attained in both the steam and electric locomotives in starting.

Throughout these remarks on methods of propulsion I have dealt with the points connecting them with rail transport as they occurred, as this is not only the method with which I am most familiar, but is the oldest means of using mechanical power. I must, however, say a few words as regards transport by sea, road, and air in connection with methods of propulsion.

I have already spoken of the early efforts of Hulls, and it was only natural that the work of Watt on land should be followed by application of the new power available to propulsion on the water. Although the growth after the work of Symington, Fulton, and Bell may have seemed to be slow, it was continuous, and constant experiments and research were made both in marine engines and in their application. Saving of fuel has played a much more important part here than with the locomotive, whilst, more space being available and greater power required, the advantages of the expansion of steam were rendered more imperative and had greater scope than in the other long-established method of mechanical transport. The great advance came with the turbine, and it is interesting to notice that whereas in early days engines were geared up, most of them now are geared down to the screw. Scientific methods have been applied to all those details of measurement and experiment that have led to transport by sea being carried on at increased speed and with decreased cost per ton carried. The application of liquid fuel and the introduction of Diesel engines, both with the object of increasing the space available for cargo, have been carried out on true scientific lines.

Of transport by road it may be said that its commercial inception came at a time when scientific knowledge was well advanced, and its progress was in consequence more rapid. It must not be forgotten that in the fairly early part of last century considerable work was done on scientific lines with steam-cars, only to be abandoned when legislation made its continuance impossible. The development of the motor-car engine from the small unit of Daimler to the present car is undeniably due to the use of 'ordered knowledge' of the gaseous mixture, of its ignition, of the fuel itself, and of the compression that should be employed. Here again we have a case of the careful application of the principle developed with ever-increasing care until we get engines as noiseless, as efficient, as reliable, and as flexible as we have them to-day. It is a case, too, where the development is so recent that many of us can remember the scorn and distrust that this method of traction excited even here in this city that was so prominent in its inception twenty-five years ago.

Very much more could be said as to the indebtedness of aeronautics to science, but the fact that this indebtedness is so self-evident, as well as the question of space at my disposal to deal with a subject of such a size, make it impossible to attempt to do justice to this part of my subject. I will speak only of the aeroplane, and its development has been even more rapid than that of the motor-car. I personally feel this when I remember that Mr. A. V. Roe was one of my students here in Lancashire in the 'nineties.

It was not until the development of the internal-combustion engine that the matter became a really practical one. The early work of Santos Dumont, Henry and Maurice Farman, Wilbur and Orville Wright, A. Vernon Roe, Cody, Rolls, Blériot, Paulhan, and others led to the close scientific consideration of the whole problem.

Step-by-step investigations have led towards the perfecting of this type of transport. In all cases the developments have followed careful scientific research. Amongst our fellow-countrymen the work of Rolls, Godden, Cody, Busk, Keith-Lucas, Hopkinson, Pinsent, and others has unfortunately been terminated by their deaths in the cause to which they were devoting their lives. In no other field has scientific work demanded so great a toll. This must be so when one is dealing with transport in such a medium as air. The work of others, such as—to name but a few—Bairstow, De Havilland, Sopwith, Barnwell, Handley Page, B. M. Jones, and O'Gorman, has fortunately continued. The War was naturally a great incentive to the advancement of our knowledge of aeronautics, and I feel proud that at Farnborough, at the Royal Aircraft Factory, I was allowed to be associated with such men as Aston, Dobson, Farren, Gibson, Green, Grinstead, Hill, Irving, Linderman, Thompson, and McKinnon Wood.

These were scientific men working on scientific lines, and their work was put to full practical test at once. The mass of information collected and used has been immense. One cannot in any collection of names omit one to whom one must ever be grateful—Sir Richard Glazebrook, again a son of Liverpool, who not only as Director of the National Physical Laboratory, but also as chairman, under the presidency of Lord Rayleigh, of the Advisory Committee of Aeronautics, did so much towards the development of this method of transport.

It is impossible to touch more than in the lightest possible manner on the developments which have taken place in aeronautics due to scientific work. In the means of propulsion research has given an engine of such size and so light in weight per horse-power that what was a laboured struggle against the effects of gravity has changed into the ability to rise at considerably over 1,000 feet per minute to heights where the rarefaction of the atmosphere renders it necessary for oxygen for breathing to be obtained artificially. The safety of flying as the result of the work of Busk has rendered the machines stable even in such a medium as the air. There is no greater instance of the indebtedness of transport to science than the rapidity with which the possibilities of transport by air have advanced. That the realities have not advanced at the same rate is due to financial reasons. As a rule we have a close relationship between these two, but in this instance, owing to the demands of war, this has not been the case, for we have the knowledge before we are financially able to use it to the greatest advantage.

The other point I would deal with in some detail is the question of materials. Here we are dealing with a matter which has to be considered in an entirely different manner. We to-day have no basic metal or material which was not known when transport first turned to mechanical methods for assistance. The change which has come about has been as largely due to the advances made in metallurgy as to the inventions in mechanics that have led to the improvements in means of propulsion and in machinery. I am aware that neither of these would have been of any use were it not for the increase in facilities of production, but most certainly the scientific work of the metallurgist is one of the many points which, taken together, have caused the resultant progress. The early builders of steam-engines were not only troubled through inability to get their engines machined properly, but also with the difficulties of obtaining suitable material for the parts they required. Steel has been known for thousands of years, but its rapid and economic production is of very recent growth. It has very truly been said that every great metallurgical discovery has led to a rapid advance in other directions. I will as before deal with the railway as an example. We can hardly appreciate at this date the conditions which existed from a metallurgical standpoint on our railways when our first Meeting at Liverpool was held in 1837. Iron—made laboriously, heterogeneous in character and expensive of production not only in money but, owing to the heavy character of the methods employed, detrimental to the very character of the workman—was the only material available. Remember for a moment that this was not only the material employed for the various parts of the mechanism of the locomotive, but for the rails. However improved the methods of manufacture were, there could never have been a universal development of rail traction if it had depended upon material made in such a way. We are especially interested in the manner the growing demand was met, for it was at the Cheltenham Meeting of the Association in 1856 that Bessemer made public the invention he had already been working on for two years, and which was to insure a cheap method of production of a material so essential to transport. One should mention with Bessemer the name of Mushet, whose work helped so materially in getting rid of the red shortness which in the early days gave such trouble. We are apt at the present day, I am afraid, to somewhat belittle the work of Bessemer in view of the more improved methods now employed, but his name must for ever stand out as the one which made cheap transport possible. After the use of manganese in one form or the other as a deoxidiser and a 'physic' for sulphur, there, however, still remained the baneful effect, due to phosphorus, which prevented the use of the ores of more general occurrence. There have been few more epoch-making announcements made at meetings of technical subjects—although this was not appreciated at the time by many of the audience—than S. G. Thomas's announcement of the discovery of the 'basic' process, which he made at the meeting of the Iron and Steel Institute in March 1878. I say advisedly that many did not appreciate the news, for an old friend of mine who was present was impressed by the earnestness of the remarks of Thomas and the little notice taken of the short statement made. His work, associated with that of his cousin, Gilchrist, was the result of close scientific research.

Another investigation which has given great results in transport has been the ever-growing use of alloy steels. For the scientific inception of these we owe a great debt to Sir Robert Hadfield, whose inventive genius and scientific mind are still active in that field he has made so particularly his own. His first investigations materially affect transport to-day. It is true that Mushet had previously worked on self-hardening tool-steel containing tungsten, but the work was carried out only on a small scale. In 1882 Hadfield had produced manganese steel.[2] This is a most remarkable product with its great toughness, and is extensively used for railway and tramway crossings, where resistance to abrasion is of great value. This was the first of that very remarkable series of alloys about which I must say a few words, for they have made possible the motor-car and the aeroplane as we have them to-day. Continuing his investigations, in 1889 Hadfield produced the compound of iron and silicon[3] known as low hysteresis steel. Indirectly this is of the greatest interest from a transport standpoint, as when used in transformers it not only reduces the hysteresis losses, but allows of a considerable saving in the weight of core material.

From these early uses of alloy steels there has grown up a large number of various alloys, many of which are of the very greatest use for various transport purposes. It is not too much to say that the modern aeroplane is the result of the material now at the designers' disposal both for the engine and for the structure itself. The strength

[2] *Inst. of Civil Engineers*, vol. 93, 1888.
[3] *Iron and Steel Institute*, p. 222, Pt. II, 1889.

of some of the chrome-nickel steels combined with their ductility is extraordinary, and is due not only to the composition of the metal, but to the results which have been obtained by patient scientific investigations relating to their heat-treatment. Taking one other example, one may quote the use of high chrome steel—for the early investigations into which we owe so much to Brearley, and for its later developments to Hatfield also—for the valves of aeronautical engines, subjected as they are to high temperatures. At one time it looked as if the advantages which follow high compression and its resultant high temperatures might be lost owing to the inability of ordinary steels to resist this heat, but the employment of 13 per cent. chrome steel allowed work in this direction to be continued. Not only the aeroplane but the motor-car is, as has previously been said, the result of the work done on alloy steels.

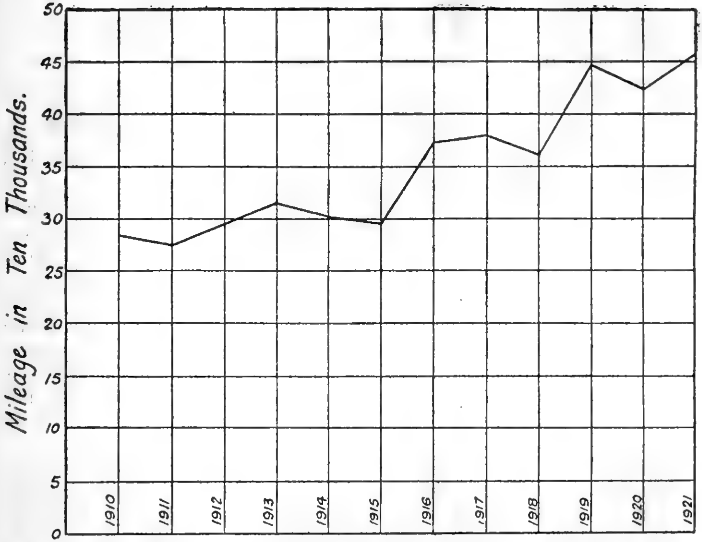
It is not only with steels that we have been benefited so much from research. The case is as marked with light alloys, which have aluminium as a base. The latter itself is the result of investigation along scientific lines, and in aeronautical work particularly much has been done towards giving a metal both light and strong by the work of Walter Rosenhain, F. C. Lea, and others.

It may be said that all I have dealt with up to the present has been the result of special investigation, and that 'ordered knowledge' is not of assistance to an everyday engineer such as myself. I may perhaps be forgiven if I refer to some personal work where the collection of that knowledge, with the assistance of my colleagues, especially L. Archbutt and H. A. Treadgold, has been of great assistance to that large transport institution, the Midland Railway, with which we were so long associated. I have dealt briefly with the subject in a general way in a paper I read a little while ago before the Institution of Locomotive Engineers,[4] but would like to speak of it in more detail and in view of the fresh information that is now available. I would first speak of the results obtained with solid locomotive crank-axles. Here we have a large mass of metal which in the rough state weighs about 40 cwt. It is forged from the ingot into a block about 25 in. by 18 in. in section, and this is then worked down at the two ends and in the middle to about 11 in. in diameter, the pieces of the original section of the block remaining being the throws, which are twisted to an angle of 90° to each other. A block about 1½ in. thick is slotted out of each web, and from these the tests to which the crank is subjected are taken. Sometimes a crank has to be taken out of service owing to the journal wearing down below a diameter at which it is judged safe for it to run, but more often flaws are developed, which, however, are progressive, and with ordinary examination can be detected before any risk is taken in running. A crank-axle is an expensive portion of a locomotive, and its replacement is not only costly but takes a considerable amount of time, as the driving-wheels have to be removed and replaced. These considerations have led us to give a good deal of attention to this piece of mechanism on what we believe to be scientific lines. Careful note has been taken not only of the mechanical tests made on the portion removed from the

[4] *Inst. of Loco. Engineers*, vol. 12, 1921.

throws, but of the micro-structure of the metal itself. The first question which rises in our mind is why the cranks develop flaws at all. It is, of course, known that with ordinary structures one is able to calculate the stresses in them, but this is not so with a locomotive crank-axle. Not only is it being subjected to the stresses set up by revolving it while it is loaded with the weight of a portion of the locomotive on its axle-bearings and by the steam pressure on the pistons transmitted to the crank-pins, but it has to withstand the shocks set up by its running on the rails, which cannot be calculated. These include the pressure set up on the edge of the wheels when entering a curve at a speed other than that which the super-elevation is allowed for, running over uneven rail joints and crossings, and also what I believe is one of the worst, if infrequent, the striking of check rails. These stresses and the resultants of them are most severe at the corners of the crank-pins and at the radii where the webs or throws join the rounded portions of the axle. These are the points at which flaws usually occur.

For about twenty years we have endeavoured to get the knowledge we have obtained into an ordered state, from observation and discussion with the metallurgists attached to the various manufacturing firms. Certain points are obvious, such as the necessity of a good micro-structure, and whilst the details in connection with exactly what micro-structure is the best are somewhat uncertain and open to debate, we can with confidence say that the steel 'shall be as free as possible from non-metallic enclosures, and that the micro-structure should show uniformly distributed pearlite in a sorbitic or very finely granular or lamellar condition and be free from any nodular or balled-up cementite. It must also be free from any signs of segregation and from any coarse or overheated structure.' (Extract from Midland Railway specification for crank-axle forgings.) The dimensions I have given of the size of the block of metal from which the axle is made show that it cannot have received much work, and therefore any non-metallic enclosures present will be only slightly drawn out, and will not occur as threads as they do in bars of small diameter and even in steel tyres. One of the first observations we deduced was that the life of the crank in miles had a direct relation to the ductility of the test-bar taken across the section of the throw and near the centre of the original ingot. This is the point at which non-metallic enclosures are most likely to be found, as well as that at which the greatest stress occurs. The inference is obvious that a flaw is likely to develop at some sharp corner of such an enclosure. In a section of steel such as that which must be used non-metallic enclosures are very likely to occur, and so steps had to be taken to ascertain what the best practical remedy was. With decreased carbon content greater ductility was likely to follow, and this has been shown to be the case. In a word, it is toughness rather than strength which is required, and the studied consideration of these points has led to an increased life in miles of the crank-axles of the 3,000 locomotives owned by the Company, in spite of the fact that they have been constantly growing in size, in pressure on the pistons, and in the work expected from them. This is shown in the following curves, which represent the mileage of crank-axles scrapped in the last twelve years.



Average Mileage obtained from Crank-Axles for Years 1910 to 1921 inclusive.

It will be appreciated that the above result, which is unquestionably the result of 'ordered knowledge of natural phenomena and the relation between them,' is only one example, if perhaps the most marked one, in our experience. A somewhat similar one could, however, be written on locomotive tyres and other matters if space and time permitted.

This example finishes my general remarks, and I cannot do so without expressing the indebtedness I feel to the various members of the scientific staff of our great firms for all the assistance and help they have ever so readily given us in the case I have just quoted.

One would like to press home strongly on engineers generally a point made by Dr. Maw in his Presidential Address to the Institution of Civil Engineers in November last. He pointed out the large amount of scientific knowledge—much of which was accumulated during the War—which is available at the present day. Here is the knowledge if we will but apply it to the service of man. This is our function as engineers. In times past we have had to wait for this knowledge, and, as I trust I have shown, as it slowly became available it has been used in our service and in that of the world. One great need is for men with the education, the capacity, and the imagination necessary to use this scientific knowledge for the advancement of our profession. I use these three requisites advisedly, for each one of them is necessary to take full advantage of the opportunities which now exist. The trouble is that whereas we can supply education, can increase the capacity of the individual, it is difficult to instil or cultivate that imagination which allows one to see the way in which the knowledge available can be applied in a practical way.

I think I have shown adequately the debt which transport, as well as other branches of our profession, owes to the study of 'ordered knowledge.' That in the future this will be even more marked than at present, one can say without fear of contradiction. Not only so, but there must be more and more interdependence between science and engineering. More and more as we advance—as we are doing so rapidly—in the knowledge of natural phenomena will the necessity of the practical application of this knowledge on a large scale become necessary to confirm it and to bring out fresh features. One trusts that our Association, which has done so much in this direction in the past, may continue increasingly useful in the branch of its work which brings together those whose work is purely scientific with those who are applying that knowledge to the direct service of man. Although the old idea of antagonism between the two has disappeared, we cannot but feel that in spite of the advance of recent years the extent to which the engineer depends on the scientist for knowledge, and the scientist depends upon the engineer for the practical application of the knowledge he has gathered, is not realised as fully as it should be by either. The terms scientific and practical should be synonymous.

One would like to feel that the meeting of our Association was more generally used as the occasion on which the scientist and the engineer would meet in larger numbers. I know that the scientist is often an engineer, and that the engineer has nowadays to be a scientist with a broad outlook, but the personal contact of the two which this meeting offers gives an opportunity the results of which would be incalculable if that opportunity were fully grasped. If one might use an illustration which I trust will not offend my scientific friends, scientific knowledge is a tool of infinite possibilities, and this knowledge is possessed by so many who attend here. The practical engineer is always attracted by tools. There is no better method of ascertaining what new and improved tools of this type are available than by coming here. Beyond all this, personal acquaintance is of greater and more permanent value from every point of view than a paper acquaintance.

I would like, in closing, to make an appeal for a freer disclosure of results obtained in practical working. This can only be done by taking care in noting the behaviour of apparatus, material, &c., in use, and placing the results freely at the disposal of the man of science and of the manufacturers. At the present day there is no lack of those who are trained observers, and I believe one of the troubles often encountered by manufacturers who are applying some new method is the difficulty of getting dependable figures of performance. With transport companies this should not be a difficult matter, for one great advantage they have now is that there is no trade necessity to hide their results in any way. It is one small way in which they can repay the great debt they owe to science, which has allowed them to complete so satisfactorily their task. As Kipling has so rightly and concisely stated:

> 'It is their care that the wheels run truly, it is their care
>   to embark and entrain,
> Tally, transport, and deliver duly the Sons of Mary by
>   land and main.'

EGYPT AS A FIELD FOR ANTHROPOLOGICAL RESEARCH.

ADDRESS TO SECTION H (ANTHROPOLOGY) BY

PROFESSOR P. E. NEWBERRY, M.A., O.B.E.,

PRESIDENT OF THE SECTION.

WHEN I received the honour of an invitation to preside at the Anthropological Section of the British Association my thoughts naturally turned to the subject of the Presidential Address, which, if I accepted the invitation, it would be my duty to prepare. On looking back over the Addresses of past Presidents of this Section since its institution in 1884 I found that no one had dealt with Egypt as a field for anthropological research. It was because of this that I decided to accept the Council's invitation, and I am here to-day to bring before your notice some facts regarding the civilisation of the country with which I have long been associated, and in which I have spent many years of my life.

In 1897, when the British Association last met in this great city on the Mersey-side, Sir Arthur Evans occupied the Presidential Chair of this Section, and the subject of his address was 'The Eastern Question in Anthropology.' Surveying the early history of civilisation as far as it was then known, he insisted that the adequate recognition of the Eastern background was essential to the right understanding of the Ægean. He laid stress on the part which Crete had played in the first emancipation of the European genius, and pointed out that in Crete, far earlier than elsewhere, can be traced the vestiges of primeval intercourse with the Nile Valley. Nineteen years later, years that were extraordinarily prolific in archæological discovery in every part of the Near East, Sir Arthur occupied the Presidential Chair of the British Association at Newcastle. He then addressed us on 'New Archæological Lights on the Origins of Civilisation in Europe.' Referring to his epoch-making discoveries in Crete he said, 'It is interesting to note that the first quickening impulse came to Crete from the Egyptian and not from the Oriental side; the Eastern factor in it is of comparatively late appearance.' By that time Sir Arthur's researches had led him to the 'definite conclusion that cultural influences were already reaching Crete from beyond the Libyan Sea, before the beginning of the Egyptian Dynasties.' He further said 'the impression of a very active agency indeed is so strong that the possibility of some actual immigration into the island of the older Egyptian element, due to the conquests of the first Pharaohs, cannot be excluded.'

I propose to-day to deal with some of the questions relating to the origins of the Egyptian civilisation, and incidentally shall touch upon this Cretan problem. At the end of my address I shall very briefly refer to the much-neglected modern Egyptians, and to the need there is to study them. Much has been written during the last twenty years about the origins of the Egyptian civilisation, but there are some facts which, I think, have either escaped notice or have not been duly considered, and there are others upon which, in my opinion, insufficient stress has been laid. I am not going to deal with the physical characteristics of the people, for that is not my province. I shall confine myself to certain inferences that I believe can be drawn from the monuments of pre-dynastic and dynastic times.

It is generally agreed that the habits, modes of life, and occupations of all communities are immediately dependent upon the features and products of the land in which they dwell. Any inquiry into Egyptian origins ought, therefore, to begin with the question, What were the physical conditions that prevailed in the Lower Nile Valley immediately preceding, and during, the rise of its civilisation? Until this question is answered I do not think that we are in a position to deal with such important problems as, *e.g.*—agriculture, architecture, shipbuilding, tool-making, or weaving. The first thing that we ought to know is what were the kinds of trees, plants, and animals that were to be found in Egypt in the wild state, and what was the economic value of the indigenous flora and fauna. We ought, in fact, to know what the country was like in pre-agricultural days. If there was no timber in the country, then it may, I think, be confidently said that the art of the carpenter did not originate in Egypt; that the architectural styles founded on wood construction could not have arisen there; that the art of shipbuilding (at all events of building ships of wood) did not originate there. Similarly, if there were no incense-bearing trees or shrubs in the country, it is difficult to imagine that the ceremonial use of incense arose there. Again, the art of weaving presupposes the presence of sheep or goats for wool, or of flax for linen thread. All these kinds of problems depend upon the natural products of a country, or they did so depend in the early days of civilisation.

We are accustomed to regard Egypt as a paradise, as the most fertile country in the world, where, if we but scratch the soil and scatter seed, we have only to await and gather the harvest. The Greeks spoke of Egypt as the most fit place for the first generations of men, for there, they said, food was always ready at hand, and it took no labour to secure an abundant supply. But there can be no doubt that the Egypt of to-day is a very different place from the Egypt of pre-agricultural times. There has been a great, but gradual, change in the physical condition of the whole country. In the mortuary chapels of tombs of the Old and Middle Kingdoms, as well as in many of the Empire, are scenes of papyrus swamps and reed marshes; in these swamps and marshes are figured the animals and birds that then frequented them. Among the animals are the hippopotamus and the wild boar, the crocodile, the ibis, and a great variety of water-fowl. These animals, and some of the birds, have now disappeared from the region north of the First Cataract. Only very recently has the crocodile become extinct north of Aswân. It was still occasionally seen in the Delta as late as the middle of the eighteenth century, and it was fairly plentiful in Upper Egypt up to the middle of the nineteenth century, but it is now rarely, if ever, seen north of Wadi Halfa. It is the same with the hippopotamus. In the twelfth century this mammal still frequented the Damietta branch of the Nile, and two specimens were actually killed near Damietta by an Italian surgeon in the year 1600.[1] In the Dongola Province of Nubia it was very common at the beginning of last century, and Burckhardt states that it was then a terrible plague there on account of its voracity. In 1812 several hippopotami passed the Second Cataract and made their appearance at Wadi Halfa and Derr, while one was actually seen at Darâwi, a day's march north of Aswân.[2] The wild boar is apparently now extinct in Egypt, but specimens were shot in the Delta and in the region of the Wadi Natrûn during last century. The ibis has gradually disappeared from the Lower Nile Valley, where it was once so common. The last specimen of this bird recorded in Egypt was shot in 1877 in Lake Menzaleh. It is sometimes seen in Lower Nubia, but has now entirely disappeared from Egypt proper.

Much is known about the ancient fauna of the desert wadies from the paintings and sculptured scenes in the tombs of the Old and Middle Kingdoms and of the Empire. On the walls of many of these tombs are depicted hunting scenes,[3] and among the wild animals figured in them are the lion, leopard, Barbary sheep, wild ass, wild ox, hartebeest, oryx, ibex, addax, dorcas gazelle, fallow deer, giraffe, and ostrich. As several of these animals are not now known in Egypt it has been argued that the scenes do not faithfully represent the ancient fauna of the country. But I can see no reason to doubt that the scenes depict actual hunts that took place in the Arabian and Libyan Deserts not far from the localities in which the tombs figuring them are found. There is some corroborative evidence in the references in the ancient literature to the hunting of the wild animals that frequented Egypt. Thutmose IV., for example, hunted the lion and ibex in the desert plateau near Memphis;[4] Amenhotep III. killed 102 fierce lions during the first ten years of his reign,[5] and in his second regnal year he hunted wild cattle in the desert near Keneh;[5] he saw there a herd of 170, and of these he and his huntsmen captured 96. The desert to the east of Kûft was a famous hunting-ground at the time of the Eighteenth Dynasty. At the present day all but one of the animals represented in these ancient hunting scenes are found in the Nubian Deserts to the south of Egypt. The exception is important; it is the fallow deer, which belongs to the Holarctic, not to the Ethiopian, zoological zone. Although most of the animals that were hunted by the dynastic Egyptians have now disappeared from their northern home, many have been recorded in recent years as occurring in the Arabian and Libyan Deserts. We can, in fact, follow them gradually receding southwards. The dorcas gazelle is still common in both deserts, and the addax sometimes occurs in the region of the Wadi Natrûn. The ibex is occasionally seen on the mountains north-east of Keneh. The Barbary sheep (*Ammotragus tragelaphus*) was observed by Dr. Schweinfurth in 1878 in the Wadi Shietun, which opens on the Nile below Ekhmim.[6] The wild ass was recorded by James Burton in 1823 in the desert north-east of Keneh; he remarks that then the Arabs of this part of the desert let their female donkeys loose to be served by the wild males.[7] Later, in 1828, Linant de Bellefonds saw many wild asses in the region between Darâwi and Berber; they were, he says, often trapped by the Bisharîn, who used the flesh as food. During the first half of the eighteenth century the ostrich frequented the desert near Suez.[8] A hundred years later it was reported to be numerous in the Arabian Desert opposite Esneh, and there is a wadi, some distance south-east of Aswân, that is called by the Arabs Wadi Naam, 'the Wadi of Ostriches.' In the Libyan Desert the bird was fairly common in the eighteenth century. W. G. Browne, who travelled along the coast west of Alexandria in 1792, states that tracks of the ostrich were frequently seen, and he noted also that the bird sometimes appeared in the neighbourhood of the Wadi Natrûn.[9] Geoffroy Saint-Hilaire in 1799 reported that it was then common in the mountains south-west of Alexandria.[10] In 1837 Lord Lindsay saw the ostrich near Esneh,[11] but the northern limit of the bird is now very much further south. The lion is mentioned by Sonnini at the end of the eighteenth century as one of the larger carnivora which then approached the confines of Egypt, but did not long remain in the country.

Now the appearance of all these animals in Egypt and in its bordering deserts in dynastic times presupposes that the vegetation of the wadies was much more abundant then than now, and this again presupposes a greater rainfall than we find at present. The disappearance of the dynastic fauna is not, however, entirely due to the change in climatic conditions. The Arabs have a saying that it was the camel that drove the lion out of Egypt, and this is doubtless true. The lion depends mainly on the antelope tribe for its food supply. The antelopes, on the other hand, depend for their sustenance on herbage and grass, and this has been consumed to a great extent by the camels, which, since Arab times, have been bred in great numbers in the Arabian and Nubian Deserts. It is certain that the advent of the camel was a factor in driving southwards many of the wild animals that were at one time so common in Egypt, but are now characteristic of the Ethiopian region.

The characteristic wild trees of the dynastic flora of Egypt, as we know from the remains of them that have been found in the ancient tombs, were the heglik (*Balanites ægyptiaca*), the seyal (*Acacia seyal*), the sûnt (*Acacia nilotica*), the tamarisk (*Tamarix nilotica*), the nebak (*Zizyphus spina-Christi*), the sycomore-fig (*Ficus sycomorus*), and the moringa (*Moringa aptera*). The dom palm (*Hyphæne thebaica*) and the Dellach palm (*H. argun*) were also common. The heglik does not now grow wild north of Aswân, and, of the other trees, only the sûnt and the tamarisk are really common in the Lower Nile Valley. All these trees, however, now grow in abundance in the region north of the Atbara, and it is here, in what is called the Taka country, that we find also the fauna that was once so abundant in more northerly regions.

But if the fauna and flora of the Arabian and Libyan Deserts in dynastic times approached more closely to that now seen in the Taka country, we have to go further south again for the earliest pre-dynastic fauna and flora of the Lower Nile Valley. This pre-dynastic fauna is particularly interesting, because, in addition to several of the animals already mentioned as occurring in dynastic times, we meet with others, such as the elephant,[12] the kudu (*Strepceros kudu*),[13] the gerenuk gazelle (*Lithocranius walleri*),[14] a species of *Sus*[15] (which is certainly not the wild boar, *i.e.* *Sus scrofa*), and the marabou stork (*Leptoptilus crumenifer*).[15] From the nature and habits of these mammals and birds it is evident that there must have been a considerable rainfall in the Valley of the Nile north of Aswân when they frequented Egypt. Dr. Anderson has referred to this subject in his monograph on the Reptilia of Egypt. He notes that the physical features on both sides of the Nile 'indicate the existence of a period long antecedent to the present, in which a considerable rainfall prevailed, as in the eroded valleys of the desert may be observed rocky ravines which have been carved out by the action of water, which has left behind it dry channels over which waterfalls had once precipitated themselves, and others down which cataracts once raced. The rainfall of the present is not sufficient to account for such a degree of erosion.'[16] This evidence sanctions the conclusion that a material change in the character of the climate of North-Eastern Africa, so far as its rainfall is concerned, has taken place since pre-dynastic days. The flora of the valley of the Lower Nile also points to the same conclusion. Dr. Schweinfurth[17] has drawn attention to the fact that many plants, now known in Egypt only under cultivation, are found in the primeval swamps and forests of the White Nile. He not unreasonably draws the inference that in ages long ago the entire Nile Valley exhibited a vegetation harmonising in its character throughout much more than at present. The papyrus swamps and reed marshes that lined the Lower Nile Valley in pre-agricultural days have been changed into peaceful fields, in which now grow the cereal grains, wheat and barley, and the other crops that have made Egypt famous as an agricultural country. It was the canalisation of the Valley, carried out by man, and the consequent draining of the swamps and marshes that displaced the ancient flora from its northern seat, and made it, as at the present day, only to be found hundreds of miles higher up the river. The land of Egypt has, in fact, been drained by man; each foot of ground has been won by the sweat of his brow with difficulty from the swamp, until at last the wild plants and animals which once possessed it have been completely exterminated in it. The agricultural Egypt of modern times is as much a gift of man as it is of the Nile.

I have dwelt at some length on the ancient fauna and flora because I want to bring out as clearly as I can two facts concerning the Egypt of pre-agricultural days—the Egypt of the time before man began to win the alluvial soil for the purposes of agriculture. (1) The aspect of the Lower Nile must have been very different from what it is now; it was a continuous line of papyrus swamps and marshes inhabited by hippopotami, wild boars, crocodiles, and immense flocks of wild-fowl of all kinds; it was singularly destitute of trees or plants that could be put to any useful purpose, and timber-trees were non-existent; its physical conditions resembled those prevailing on the banks of the White Nile to-day. (2) The deserts bordering the Lower Nile Valley on both sides were much more fertile, and their fauna and flora resembled that of the Taka country in Upper Nubia. Of the animals that frequented the wadies only the ass and the wild ox were capable of domestication. If man inhabited Egypt in pre-agricultural times—and there is no valid reason to suppose that he did not—he probably lived a wandering life, partly hunter, partly herdsman, in the fertile wadies that bordered the valley, only going down to the river to fish or to fowl or to hunt the hippopotamus. In the valley itself there was certainly no pasture-land for supporting herds of large or small cattle. It was probably also in these wadies that agriculture was first practised in Egypt. Even at the present day a considerable number of Ababdeh roam the wadies of the Arabian Desert between Keneh and the Red Sea, where, at certain seasons of the year, there is fair pasturage for small flocks of sheep and goats. I have myself seen many of these people in the course of several journeys that I have undertaken to the Red Sea coast. Some of these nomads sow a little barley and millet after a rain-storm, and then pitch their tents for a while till the grain grows, ripens, and can be gathered. They then move on again with their little flocks. What the Ababdeh do on a very small scale the Hadendoa of the Taka country do on a much greater one.

If we turn to the Taka country we see there people living under much the same physical conditions as those which must have prevailed in the Arabian and Libyan Deserts in early times. The inhabitants of the Taka country are Hamite, and, as Professor Seligman has pointed out,[18] the least modified of these people are physically identical with the pre-dynastic Egyptians of Upper Egypt. I would suggest that they, like the fauna and flora of ancient Egypt, receded southwards under the pressure of the advance of civilisation, and that the physical conditions of the country have preserved them to a great extent in their primitive life and pursuits. The picture of the Taka as Burckhardt draws it would, I believe, describe almost equally well the earliest pre-dynastic Egyptians. This country, called El Gash by its inhabitants, has been described by Burckhardt.[19] In his day the people there were in the transition stage between the pastoral nomad and the agriculturist. It was a fertile and populous region. About the end of June large torrents coming from the south and south-west pour over the country, and in the space of a fortnight or so cover the whole surface with a sheet of water, varying in depth from two to three feet. These torrents were said to lose themselves in the eastern plain after inundating the country, but the waters remained upwards of a month in Taka, and on subsiding left a thick slime or mud upon the surface. Immediately after the inundation was imbibed the Bedawin sowed their seed upon the mud, without any previous preparation whatever. The inundation was usually accompanied by heavy rains, which set in a short time before the inundation, and became most copious during its height. The rains lasted some weeks longer than the inundation; they were not incessant, but fell in heavy showers at short intervals. In the winter and spring the people of Taka obtained their water from deep wells, extremely copious, dispersed all over the country, but at a considerable distance from each other. The people appeared to be ignorant of tillage; they had no regular fields, and the millet, their only grain, was sown among thorny trees. After the harvest was gathered the peasants returned to their pastoral occupations. When Burckhardt visited this region in the hottest part of the year, just before the period of the rains, the ground was quite parched up, and he saw but few cattle; the herds were sent to the Eastern Desert, where they fed in the mountains and fertile valleys, and where springs of water were found. After the inundation they were brought back to the plain. The quantity of cattle, Burckhardt believed, would have been greater than it was had it not been for the wild beasts which inhabited the district and destroyed great numbers of them. The most common of these wild animals were the lion and the leopard. The flocks of the encampment were driven in the evening into the area within the circle of tents, which were themselves surrounded by a thorny enclosure. Great numbers of asses were kept by all these Bedawîn. They also possessed many camels. The trees are described as being full of pigeons. The Hadendoa were the only inhabitants of Taka seen by Burckhardt. Each tribe had a couple of large villages built in the desert on the border of the cultivable soil, where some inhabitants were always to be found, and to which the population, excepting those who tended the cattle in the interior of the desert, repaired during the rainy season. After the waters had subsided they spread over the whole district, pitching their camps in those places where they hoped for the best pasturage, and moved about from month to month, until the sun parched up the herbage. The settlers in the villages meantime sowed the ground adjoining the neighbouring desert. The camps consisted of huts formed of mats; there were also a few huts with walls, resembling those in the countries of the Nile, but smaller. Even the settlers, however, preferred living in the open under sheds to inhabiting these close dwellings.

It has often been stated that civilisation in Egypt spread from the south, and considerable stress has been laid upon the fact that so many pre-dynastic and early dynastic remains have been found in Upper Egypt in the region between Edfu and Thinis, especially at Hierakonpolis and Naqada, and north of Naqada, in the neighbourhood of Abydos. Opposite Edfu is a desert route leading to the Red Sea; at Kûft, opposite Naqada, is the beginning of the road leading to Kosêr, the port on the Red Sea. It has been thought that the people who brought culture to Egypt reached the Nile Valley by one or by both these routes from a 'God's Land' situated somewhere down the Red Sea coast. But throughout the whole history of Egypt culture has always come from the north, and spread southwards.

From a study of the monuments of the First Dynasty that had been found at Abydos and elsewhere in Upper Egypt I ventured, nearly twenty years ago,[20] to suggest the existence in pre-dynastic times of a Delta civilisation which, in culture, was far advanced beyond that of Upper Egypt, and I pointed out that it was probably to a Delta civilisation that the Dynastic Egyptians owed their system of writing. I was led to this conclusion by the following facts. Although many pre-dynastic cemeteries had been thoroughly explored in Upper Egypt no grave had yielded a single fragment of hieroglyphic writing. The only inference that can be drawn from this is that hieroglyphic writing was unknown, or at all events unpractised, by the inhabitants of Upper Egypt before dynastic times. On the other hand, the discoveries at Naqada, Hierakonpolis, and Abydos had shown us that all the essential features of the Egyptian system of writing were fully developed at the beginning of the First Dynasty. Hieroglyphic signs were already in full use as simple phonograms, and their employment as phonetic complements was well established. Determinative signs are found beginning to appear in these early writings, but, as Erman and Griffith have noticed, even as late as the Fifth Dynasty their use was very restricted in the monumental inscriptions, although they were common in the cursive and freely written texts of the Pyramids. At the very beginning of the First Dynasty the numerical system was complete up to millions, and the Egyptians had already worked out a solar year of 365 days. This was indeed a remarkable achievement.

These facts are of great significance, for it is clear that the hieroglyphic system of writing, as we find it at the beginning of the First Dynasty, must have been the growth of many antecedent ages, and yet no trace of the early stages of its evolution have been found on Upper Egyptian soil. There is no clear evidence, however, that the system was borrowed from any country outside Egypt; the fauna and flora of its characters give it every appearance of being indigenous. It is apparent, therefore, that we must seek the cradle of the Egyptian system of hieroglyphic writing elsewhere than in Upper Egypt, and as the fauna and flora of its characters are distinctly Egyptian the presumption is that it must be located to the Delta. An important indication as to the original home of Egyptian writing is given by the signs which, in historic times, were used to designate the points of the compass. The sign for 'east' was a drop-shaped ingot of metal upon a sacred perch, and this was the cult-object of a clan living in predynastic times in the Eastern Delta. The sign for 'west' was an ostrich feather placed in a semicircular stand, and this was the cult-object of the people of the Western Delta. The sign for 'south' was a *scirpus*-reed; this was the cult-object of a clan which dwelt on the east bank of the Nile a little above the modern village of Sharona in Middle Egypt. The country south of the apex of the Delta was known as *Ta Shema*, 'Reed Land.' It must, therefore, have been at some point north of the apex of the Delta that the scirpus-reed was first used to designate the south. It must also have been somewhere in the Central Delta that the cult-objects of the peoples of the Eastern and Western Delta were first used to designate 'east' and 'west.'

For the Delta being the early home of writing another fact has to be taken into consideration. Thoth, the Ibis-god, was to the Egyptians the god of writing, and it was to him that they attributed its invention. The principal seat of his worship in historic times was Hermopolis, in Middle Egypt. But Thoth's original habitat was situated in the north-east corner of the Delta, where, in pre-dynastic times, had resided an Ibis clan. The tradition that named Thoth as the god and inventor of writing would, therefore, point Delta-wards. This tradition is significant also in another way. Although we cannot doubt that the Egyptian system of writing was evolved in the Delta, the germs of writing may have come into Egypt from Western Asia *via* this north-east corner of the country. In this connection it may be pointed out that the hieroglyphic signs for 'right' and 'left' were the same as those for 'west' and 'east'; the Egyptians who evolved the hieroglyphic system of writing orientated themselves facing south.

It is remarkable that so little is known about the early history of the Delta. But few excavations have been carried out there, and nothing of pre-dynastic or early dynastic times has, so far, been brought to light from the country north of Cairo. We do know, however, that before the arrival of the Falcon-kings from Hierakonpolis in the south, Middle and Lower Egypt had been, probably for many centuries, united under one sceptre, and that before these two parts of the country were united there had been a Delta Kingdom which had had its capital at Sais. The names of some of these early kings are preserved on the Palermo fragment of the famous Annals Tablet, and the list there given would alone be enough to prove how ancient the Delta civilisation must have been. There was certainly nothing comparable with it in Upper Egypt in those far-off days.

What were the physical conditions prevailing in the Delta and in the regions to the east and west of it immediately preceding Menes' arrival in Lower Egypt? For the eastern side the evidence is exceedingly scanty, but there is one fact which is significant. The chief god of the eastern nomes of the Delta in the Pyramid Age was Anzety, a pastoral deity who was the prototype of Osiris. He is represented as a man holding in one hand the shepherd's crook, and in the other the goatherd's ladanisterion. There can be little doubt, therefore, that in the Eastern Delta there lived a pastoral people who possessed flocks of sheep and goats, and this is evidence of a certain amount of grass-land. In the Central Delta at the same period there lived a series of clans, among which a Bull Clan was predominant. In historic times in Egypt the ox is often figured roaming in papyrus and reed marshes, and it may be that the Central Delta marshes supported herds of domesticated cattle. Much more is known about the western side of the Delta at the time of Menes. It formed, I believe, part of what was called Tehenu-land; at all events this name was given to the region immediately to the west of the Canopic branch of the Nile. There can be no doubt that this part of the country was a very fertile and prosperous region in the period immediately preceding the First Dynasty. Its name signifies 'Olive-land,' and we actually see these trees figured, with the name of the country beside them, on a pre-dynastic Slate Palette; on this Palette, above the trees, are shown oxen, asses, and sheep of the type later known as *ser*-sheep. It was Menes,[21] the Falcon-king of Upper Egypt, who conquered the people of Tehenu-land. This conquest is recorded on a small ivory cylinder that was found at Hierakonpolis. Another record of the Southerner's triumph over these people is preserved on his famous Slate Palette; here the Upper Egyptian king is depicted smiting their Chieftain, while on the verso of the same Palette is the scene of a festival at the Great Port, which was perhaps situated near the Canopic branch of the Nile. The mace-head of Menes, which is now in the Ashmolean Museum at Oxford, has a scene carved upon it which shows the king assuming the Red Crown of Sais, and the inscription accompanying it records that he had captured 120,000 prisoners, 400,000 oxen, and 1,422,000 goats. This immense number of oxen and goats is clear evidence that the north-western Delta and the region to the west of it (Tehenu-land) must have included within its boundaries very extensive grass-lands. Several centuries after Menes, Sahure, a king of the Fifth Dynasty, captured in Tehenu-land 123,440 oxen, 233,400 asses, 232,413 goats, and 243,688 sheep. Senusret I. also captured in the same region 'cattle of all kinds without number.' This again shows how fertile the country must have been at the beginning of the Middle Kingdom. The history of this part of the Delta is most obscure. During the period that elapsed from the end of the Third Dynasty to the beginning of the Twenty-third, when Tefnakht appears upon the scene, we have hardly any information about it. What was happening at Sais and other great cities in the north-west of Egypt during the period from 2900 to 720 B.C.? There is an extraordinary lacuna in our knowledge of this part of the country. The people living there were certainly of Libyan descent, for even as late as the time of Herodotus the inhabitants deemed themselves Libyans, not Egyptians; and the Greek historian says that they did not even speak the Egyptian language. The pre-dynastic people who inhabited the greater part of the Lower Nile Valley were apparently of the same stock as these Libyans. There is a certain class of decorated pottery which has been found in pre-dynastic graves from Gizeh in the north to Kostamneh in the south. On this decorated pottery are figured boats with cult-objects raised on poles. Altogether some 170 vases of this type are known, and on them are 300 figures of boats with cult-signs. Of these, 124 give the 'Harpoon' ensign; 78 the 'Mountain' ensign; and 20 the 'Crossed Arrows' ensign. These cult-objects all survived into historic times; the 'Harpoon' was the cult-object of the people of the Mareotis Lake region; the 'Mountain' and 'Crossed Arrows' were the cult-objects of the people dwelling on the right bank of the Canopic branch of the Nile. Thus it will be seen that out of 300 boats figured on vases found in graves in the Lower Nile Valley south of Cairo, 222 belong to cults which can be located in the north-western corner of the Delta. Twenty-two boats bear the 'Tree' ensign, which was the early cult-object of the people of Herakleopolis, a city just south of the Fayûm. Ten bear the 'Thunderbolt' ensign of Ekhmim. The 'Falcon' on a curved perch appears on three boats, and this ensign undoubtedly represents the Falcon deity of Hierakonpolis. At the beginning of the historic period the cult-objects of the people of the north-western Delta included (1) the 'Harpoon,' (2) the figure-of-eight 'Shield with Crossed Arrows,' (3) the 'Mountain,' and probably (4) the Double Axe,[22] and (5) a Dove or Swallow.[23] With the exception of the 'Harpoon' all these cult-objects are also found in

Crete, a fact which is significant in view of Sir Arthur Evans' remark, quoted at the beginning of my address, to the effect that he considers the possibility of some actual immigration into the Island of the older Egyptian element due to the first Pharaohs. The 'Harpoon,' it should be noted, is the prototype of the bident, and later, of the trident of the Libyan god Poseidon.

Upon the mace-head of Menes the king is represented assuming the Crown of Neith of Sais. This is the earliest representation of the famous Sed Festival which is generally held to be a survival, in a much weakened form, of the ceremonial killing of the king, its essential feature being regarded as the identification of the king with the god Osiris. The festival was, I believe, of Libyan origin, and, at all events in its origin, it was not connected in any way with Osiris. On this mace-head the Upper Egyptian conqueror is shown seated under a canopy upon a daïs raised high above the ground. He is clad in a long, close-fitting garment; upon his head is the Red Crown of Sais, and in one of his hands is the so-called flail. Behind him is a group of officials, and upon either side of the daïs are two fan-bearers. In front of the king is a princess seated in a palanquin, and behind her are three men figured in the act of running. This is the earliest of a long series of representations of the festival, and we cannot doubt that the particular ceremony here depicted was the central one around which, in later times, the other ceremonies that we know were connected with it were grouped. There is no indication here of any ceremonial killing of the king, and the Red Crown which Menes wears is not characteristic of Osiris but of the goddess Neith of Sais. In the Mortuary Temple of Neuserre at Abusir, in the Temple of Amenhotep III. at Soleb in Nubia, and in the Temple of Osorkon III. at Bubastis, the Sed Festival is represented in far greater detail, but still there is no indication of the ceremonial killing of the king, or of his identification with Osiris. These later scenes show that the festival was a great national one that was attended by all the great dignitaries of State, and by the priests of the gods from all the principal cities of Egypt. In these later representations the king's daughters and the running men play an important part. Inscriptions accompanying the scenes at Soleb[23] and Bubastis state that the king at this festival assumed the protection of Egypt and of the sacred women of the Temple of Amon. The Queen at these periods of Egyptian history was the High Priestess of Amon and the Head of the Harîm of the god. An important reference to the festival is found in the inscription of Piankhy. This Ethiopian king, in his triumphant march from Thebes towards the Delta, had captured Hermopolis, the capital of a petty king named Namlot (a Libyan Dynast), and when Piankhy made his entry into the city he was acclaimed by the people, who prayed that he would celebrate there a Sed festival. 'His Majesty proceeded to the palace of Namlot, and entered every chamber. He caused that there be brought to him the king's wives and the king's daughters. They saluted His Majesty in the fashion of women,' but the Ethiopian says that he would not turn his face to them, and he did not celebrate a Sed festival. The most important point in connection with the festival is that at it the king assumed the protection of the land of Egypt. It was a kind of coronation festival. On Menes' mace-head the king is shown assuming the Red Crown, while before him is the Princess of the country that he had conquered, and below her is a statement of the number of prisoners and cattle captured by him in her country.

Now what were the rules that regulated the succession to the kingship in Ancient Egypt? It is often assumed that the kingship was hereditary in the male line, and that the son regularly succeeded his father on the throne. But we know that many Egyptian kings were not the sons of their predecessors. We also know that at some periods, at all events, the sovereign based his claim to the kingship upon the fact that he had married the Hereditary Princess. Harmhab, at the beginning of the Nineteenth Dynasty, tells us that he proceeded to the palace at Thebes, and there, in the Great House (*pr-wr*), married the Hereditary Princess. Then the gods, 'the lords of the House of Flame (*pr-nsrt*), were in exultation because of his coronation, and they prayed Amon that he would grant to Harmhab the Sed festivals of Re.' It was after his marriage to the princess that Harmhab's titulary was fixed. The reference to the House of Flame is interesting because the kindling of fire was an important ceremony at the Sed Festival; it is figured at Soleb, and there a priestess called 'the Divine Mother of Suit' plays an important rôle. This priestess may be compared with Vesta, who always bore the official title of 'Mother,' never that of 'Virgin.' It is unnecessary for me to speak of the King's Fire and the Vestal Virgins whose duty it was to keep the perpetual fire burning; the material has been collected by Sir James Frazer. This ceremony of kindling fire suggests that the festival may have been a marriage festival, and the running men figured on the mace-head of Menes, and in later representations, also points to this interpretation of it. There can be little doubt that it was a Libyan festival; at all events it is first found when Menes assumed the Red Crown of Neith of Sais. When Menes had conquered the north-western Delta, he married the Hereditary Princess of the country. She was probably the eldest daughter, or perhaps the widow, of the Lower Egyptian king whose country he had seized. Marriage with the king's widow or eldest daughter carried the throne with it as a matter of right, and Menes' marriage, we can well believe, was a marriage of policy in order to clinch by a legal measure his claim to that crown which he had already won for himself in battle. Sir James Frazer has noted that sometimes apparently the right to the hand of the princess and to the throne has been determined by a race. The Libyan king Antæus placed his daughter Barce at the end of a race-course; her noble suitors, both Libyans and foreigners, ran to her as the goal, and the one who touched her first gained her in marriage. The Alitemnian Libyans awarded the kingdom to the fleetest runner. According to tradition, the earliest games at Olympia were held by Endymion, who set his sons to run a race for the kingdom. In all the ceremonies connected with the Sed Festival I can see no feature that suggests the Osirification of the king. When he wears the Red Crown he assumes control of Lower Egypt; when he wears the White Crown he assumes control of Upper Egypt.

There is one further point connected with the western side of the Delta that must be noted. Glazeware (and glass) in Egyptian is called *tehent*; this was one of the chief articles of export of Tehenu-land. Just as we use the word 'china' for a kind of porcelain which first came to us from China, so the Egyptians called glass *thn.t* after the country of the north-western Delta from which they derived it. Here in this western side of Lower Egypt is an almost wholly unexplored field for the anthropologist.

I have already referred to the pastoral deity Anzety, who, in the Pyramid Age, was Chief of the nomes of the Eastern Delta. Among all the nome-gods he is the only one that is figured in human form; he stands erect, holding in his right hand the shepherd's crook and in his left the goatherd's ladanisterion. On his head is a bi-cornute object that is connected with goats, and on his chin is a false beard curled at the tip. He was not an oxherd, but a shepherd and goatherd. In later times the figure of this deity, in hieroglyphic writing, is regularly used as the determinative sign of the word *ity*, 'ruling prince,' 'sovereign,' a term that is applied only to the living king. In the Pyramid Texts, Anzety is entitled 'Head of the Eastern nomes,' and these included the ancient one of the Oxyrrhynchus-fish, where, later, the ram or goat was the chief cult-animal. Neither the domesticated sheep nor the goat can be reckoned as Egyptian in origin; they both came into Egypt from Western Asia. We have, therefore, in this pastoral deity Anzety evidence of immigration from the west. The only wild sheep inhabiting the continent of Africa is the Barbary sheep, and this animal was not the ancestor of any domesticated breed. Both the sheep and the goat are essentially mountain animals, though sheep in the wild state do not as a rule frequent such rugged and precipitous ground as their near relatives the goats, but prefer more open country. Sheep browse in short grass; goats feed upon the young shoots of shrubs and trees. The domesticated goat is generally recognised as descended from the wild goat (*Capra hircus ægagrus*) of Syria, Asia Minor, Persia, and the Mediterranean Isles. Two breeds of domesticated sheep were known to the Egyptians. The sheep of the earliest historical period down to the Middle Kingdom was a long-legged variety (*Ovis longipes*), with horns projecting transversely and twisted. This breed was the only one known in the earlier periods of Egyptian history; it was the predominant breed in the Middle Kingdom, but soon after the beginning of the Empire it appears to have become rare or extinct in Egypt, and was superseded by a variety with horns curving forwards in a sub-circular coil. Both varieties of domesticated sheep, according to Lydekker, were introduced into Egypt through Syria.

Among the cult-objects of the cities over which the god Anzety presided were two which, I believe, can definitely be referred to trees that were not indigenous to the soil of Egypt but to Syria. One of these cult-objects is the so-called Ded-column. This was one of the holiest symbols of the Egyptian religion. It has four cross-bars at the top like superposed capitals. Sometimes a pair of human eyes are shown upon it, and the pillar is draped; sometimes a human form is given to it by carving a grotesque face on it, robing the lower part, crowning the top with ram's horns, and adding two arms, the hands holding the crook and ladanisterion. Frazer has suggested that this object might very well be a conventional representation of a tree stripped of its leaves. That it was, in fact, a lopped tree is, I believe, certain. In the Pyramid Texts it is said of Osiris, 'Thou receivest thy two oars, the one of juniper (*uan*), the other of *sd*-wood, and thou ferriest over the Great Green Sea.' The determinative-sign of the word *sd* is a tree of precisely the same form as the Ded-column that is figured on early Egyptian monuments, *i.e.* it has a long, thin stem. This tree-name occurs only in inscriptions of the Pryamid Age, and it is mentioned as a wood that was used for making chairs, tables, boxes, and various other articles of furniture. In the passage quoted from the Pyramid Texts it is mentioned together with juniper, and the latter was employed in cabinet-making, etc., at all periods of Egyptian history. There is no evidence that juniper ever grew in Egypt, but we have numerous records of the wood being imported from the Lebanon region. The *sd*-tree, as we see from the determinative-sign of the name, had horizontally spreading branches, and was evidently some species of conifer. No conifers, however, are known from Egypt; the *sd*-wood must, therefore, have been of foreign importation. As it is mentioned with juniper, which we know came to Egypt from Syria, it is possible that it came from the same region. Among the trees of the Lebanon there are four that have horizontally spreading branches. These are the cedar (*Cedrus libani*), the Cilician fir, the *Pinus laricio*, and the horizontal-branched cypress (*Cupressus sempervirens* var. *horizontales*). Much misconception at present exists with regard to the Lebanon Cedar, because the name 'cedar' is applied to a large number of woods which are quite distinct from it, and the wood which we generally call cedar (*e.g.* the cedar of our 'cedar' pencils) is not true cedar at all, but Virginian juniper. The wood of *Cedrus libani* is light and spongy, of a reddish-white colour, very apt to shrink and warp badly, by no means durable, and in no sense is it valuable. Sir Joseph Hooker, who visited the Lebanon in 1860, notes that the lower slopes of that mountain region bordering the sea were covered with magnificent forests of pine, juniper, and cypress, 'so that there was little inducement for the timber hewers of ancient times to ascend 6,000 feet through twenty miles of a rocky mountain valley to obtain cedar wood which had no particular quality to recommend it. The cypress, pine, and tall, fragrant juniper of the Lebanon, with its fine red heart-wood, would have been far more prized on every account than the cedar.' The *sd*-tree was, I believe, the horizontal-branched cypress which is common in the wild state. In the Middle Ages this tree was believed to be the male tree, while the tapering conical-shaped cypress was considered to be the female. This is an interesting fact, because there is some evidence to show that the tapering variety was the symbol of Hathor-Isis, while the horizontal-branched one was the symbol of Osiris.

In the Pyramid Age there are several records of the priests of the Ded-column. They were called 'priests of the venerable ded-column.' The seat of the cult was Dedu, or, as it was sometimes called, *Pr-Wsr*, 'the House of Osiris,' the Greek Busiris in the Central Delta. At this city was celebrated annually a great festival in honour of Osiris. It lasted many days, and the culmination of a long series of ceremonies was the raising of the ded-column into an erect position. Osiris is intimately connected with this column; the Egyptians called it his backbone. In the myth of Osiris, as recorded by Plutarch, a pillar played an important part. Plutarch says that the coffer containing the body of Osiris was washed up by the sea at Byblos, the port of the Lebanon, and that a tree grew up and concealed the coffin within itself. This sacred tree was cut down by Isis and presented to the people of Byblos wrapped in a linen cloth, and anointed with myrrh like a corpse. It therefore represented the dead god, and this dead god was Osiris.

Not far from Dedu, the city of Osiris in the Delta, was Hebyt, the modern Behbeyt el Hagar. Its sacred name was Neter. The Romans called it Iseum, or Isidis oppidum. It was the ancient seat of Isis worship in Egypt, and the ruins of its temple to that goddess still cover several acres of ground in the neighbourhood. On the analogy of other sacred names of cities the primitive cult-object here was the *ntr*-pole. This was not an axe, as has so often been supposed, but a pole that was wrapped around with a band of coloured cloth, tied with cord half-way up the stem, with the upper part of the band projecting as a flap at top. Dr. Griffith conjectured that it was a fetish, *e.g.* a bone carefully wound round with cloth, but he noted that 'this idea is not as yet supported by any ascertained facts.' As a hieroglyh this wrapped-up pole expresses *ntr*, 'god,' 'divine,' in which sense it is very common from the earliest times; gradually it became determinative of divinity and of the divine names and ideographic of divinity. Another common ideograph of 'god' in the Old Kingdom was the Falcon (Horus) upon a perch, and this sign was also employed as a determinative of divinity and of the names of individual gods; it even sometimes occurs as a determinative sign of the *ntr*-pole, *e.g.* Pyr. Texts, 482. This use of the Falcon indicates that in the early dynasties the influence of the Upper Egyptian Falcon-god (Horus) was paramount. But there is reason for believing that the *ntr*-pole cult had at an earlier period been the predominant one among the writing people of the Delta; this, I think, is shown by the invariable use of the *ntr*-pole sign in the words for priest (*hm-ntr*, 'god's servant'), and temple (*ht-ntr*, 'god's house'). Now, on a label of King Aha of the First Dynasty there is a representation of the temple of Neith of Sais. Here two poles with triangular flags at top are shown on either side of the entrance. Later figures of the same temple show these poles with the rectangular flags precisely as we find in the *ntr*-sign. A figure of the temple of Hershef on the Palermo Stone shows two poles with triangular flags, while a Fourth Dynasty drawing of the same temple shows the same poles with rectangular flags. We see, therefore, that the triangular-flagged pole equals the rectangular-flagged one, and that the *ntr* is really a pole or mast with flag. Poles of this kind were probably planted before the entrances to most early Egyptian temples, and the great flag-masts set up before the pylons of the great temples of the Eighteenth and later dynasties are obviously survivals of the earlier poles. The height and straightness of these poles prove that they cannot have been produced by any native Egyptian tree; in the Empire flag-staves were regularly imported from Syria; it is probable therefore that in the earlier times they were introduced from the same source. A well-known name for Syria and the east coast of the Red Sea, as well as of Punt, was Ta-ntr, 'the land of the *ntr*-pole.' This was the region in which the primitive Semitic goddess Astarte was worshipped. In Canaan there was a goddess Ashera whose idol or symbol was the ashera pole. The names of Baal and Ashera are sometimes coupled precisely as those of Baal and Astarte, and many scholars have inferred that Ashera was only another name of the great Semitic goddess Astarte. The ashera-pole was an object of worship, for the prophets put it on the same line with the sacred symbols, such as Baal pillars; the ashera was, therefore, a sacred symbol, the seat of a deity, the mark of a divine presence. In late times these asherîm did not exclusively belong to any one deity; they were erected to Baal as well as to Yahw. They were sign-posts set up to mark sacred places, and they were, moreover, draped. They correspond exactly to the *ntr*-poles of Egyptian historic times. I have noted that these *ntr*-poles were tall and straight. What tree produced them? In Egyptian inscriptions there is often mentioned a tree named *tr.t*. It was occasionally planted in ancient Egyptian gardens, and specimens of it were to be seen in the Temple garden at Heliopolis. The seeds and sawdust were employed in medicine, and its resin was one of the ingredients of the Kyphi-incense. Chaplets were made of its twigs and leaves. The tree was sacred to Hathor; branches of it were offered by the Egyptian kings to that goddess. In a Saite text it is mentioned with three other trees—pine, yew, and juniper; these are all found in Northern Syria, where they grow together with the cypress; the *tr.t* tree may therefore be the cypress. Evidence has been brought forward to show that the *sd*-tree is the horizontal-branched cypress, which was believed to be a male tree, while the tapering, flame-shaped cypress was believed to be the female tree. The ded-column was the symbol of Osiris, and at Busiris was celebrated a festival of raising this column. The *tr.t* tree was sacred to Hathor, who is often identified with Isis, and there was a festival of raising the *tr.t* tree that was celebrated on the nineteenth day of the first month of the winter season. It is not known where this festival was celebrated, but it may well have been at Neter, the seat of the Isis cult near Dedu-Busiris. The two tree-cults point to Northern Syria as the country of their origin.

In the architecture of ancient Egypt two distinct styles can be recognised. One is founded on wattle-and-daub, the other on wood construction. Wattle-and-daub is the natural building material of the Nile Valley and Delta, and the architectural forms derived from it are certainly indigenous. Those styles derived from wood construction, on the other hand, could not have originated in Egypt, but must have arisen in a country where the necessary timber was ready at hand. Egypt produces no coniferous trees and no timber that is at all suitable for building purposes, or indeed for carpenter's work of any description. The wood of the sycomore-fig is very coarse-grained, and no straight planks can be cut from it. The sûnt-acacia is so hard that it requires to be sawn while it is green; it is very irregular in texture, and on account of the numerous branches of the trunk it is impossible to cut it into boards more than a couple of feet in length. The palaces of the early kings of the Delta were built of coniferous wood hung with tapestry-woven mats. The tomb of Menes' queen, Neith-hotep, at Naqada, was built of brick in imitation of one of these timber-constructed palaces, and smaller tombs of the same kind are known from the Second and Third Dynasties, but not later. As early as the reign of King Den (First Dyn.) the palaces of this type were beginning to be built of the native wattle-and-daub in combination with wood, and by the end of the Pyramid Age the style disappears entirely, though the memory of it was preserved in the false-doors of the tombs and stelæ. Brick buildings similar to those of the 'palace' style of Egypt are also known from early Babylonia, and they were at one time regarded as peculiarly characteristic of Sumerian architecture. These, obviously, must have been copied, like the Egyptian, from earlier timber forms. In Babylonia, as in Egypt, timber was scarce, and there are records that it was sometimes obtained from the coast of Syria. This was the region from which the Egyptians throughout historic times obtained their main supplies of wood, so it is not improbable that they, as well as the Sumerians, derived this particular style of architecture from Northern Syria. I may observe in passing that in this 'palace' style we have the transition form between the nomad's tent and the permanent building of a settled people. The lack of native timber in Egypt is significant in another direction. Boats of considerable size are figured on many pre-dynastic monuments. They are long and narrow, and in the middle there is usually figured a reed or wicker-work cabin. In my view these boats were built, like many of those of later periods in Egypt, of bundles of papyrus reeds bound together with cord; they were, in fact, great canoes, and, of course, were only for river traffic. They were not sailing boats, but were propelled by means of oars. No mast is ever figured with them, but they generally have a short pole amidships which is surmounted by a cult-object. On one pre-dynastic vase there is a figure of a sailing ship, but this is totally different in build from the canoes, and it has a very high bow and stern with its mast set far forward in the hull. Similar vessels are figured on the ivory knife-handle of pre-dynastic date from Gebel el Araq, but these vessels appear to be in port and the sails are evidently lowered. I have already referred to the Great Port mentioned on the Palette of Menes. A port implies shipping and trade relations with people dwelling along the coast or across the sea. It may be that the people of the north-western Delta built wooden ships, but if they did they must have procured their timber from some foreign source. Coniferous wood was already being imported into the Nile Valley at the beginning of the First Dynasty from the Lebanon region, and it must be remembered that the Egyptian name for a sea-going ship was *kbnyt*, from *Keben*, 'Byblos,' the port of the Lebanon, where these ships must have been built and from whence they sailed. The sacred barks of the principal gods of Egypt in historic times were invariably built of coniferous wood from the Lebanon. Transport ships on the Nile were sometimes built of the native sûnt-wood, and Herodotus describes them as made of planks about two cubits long which were put together 'brick-fashion.' No masts or sail-yards, however, could possibly be cut from any native Egyptian tree. In the Sûdan at the present day masts are sometimes made by splicing together a number of small pieces of sûnt and binding them with ox-hide, but such masts are extremely liable to start in any gale, and they would be useless for sea-going ships. It may be doubted whether the art of building sea-going ships originated in Egypt. It may be doubted also whether the custom of burying the dead in wooden coffins originated in Egypt. In countries where a tree is a rarity a plank for a coffin is generally unknown. In the Admonitions of an Egyptian Sage written some time before 2000 B.C., at a period when there was internal strife in Egypt, the Sage laments that 'Men do not sail northwards to [Byb]-los* to-day. What shall we do for coniferous trees† for our mummies, with the produce of which priests are buried, and with the oil of which [chiefs] are embalmed as far as Keftiu? They come no more.' This ancient Sage raises another anthropological question when he refers to the oil used for embalming. The only oils produced by native trees or shrubs in Egypt were olive oil, ben oil from the moringa, and castor oil from the castor-oil plant. The resins and oils used for embalming were principally those derived from pines and other coniferous trees. Egypt produced no kinds of incense trees or shrubs. The common incenses were pine resin, ladanum, and myrrh, and all these were imported. It is difficult to believe that the ceremonial use of incense arose in Egypt.

These are a few of the questions raised by a study of the material relating to the origins of the ancient civilisation of Egypt. There are numbers of others that are waiting to be dealt with. Egypt is extraordinarily rich in material for the anthropologist. It is a storehouse full of the remains of man's industry from pre-agricultural times right down to the present day. Almost every foot of ground hides some relic of bygone man. The climatic conditions prevailing there are exceptional, and it is largely owing to the absence of rain that so full a record of man and his works has been preserved. For more than a century excavators have been busy in many parts of the country, but there is yet no sign that the soil is becoming exhausted; it is, in fact, almost daily yielding up its buried treasures. The past two or three decades have been prolific in surprises. Mines of hidden wealth have been unearthed where but a few years ago we only saw the sands and rocky defiles of the desert. Since we met at Hull last year, the most sensational archæological discovery of modern times has been made in a place that had been abandoned by many excavators as exhausted. This discovery, due to the untiring persistence of an Englishman, promises to yield results of extraordinary interest, but it will take years before they can be adequately published. Other discoveries have been made in Egypt during recent years which have opened out a vista of human history that we little dreamt of a quarter of a century ago. Three decades

* This place-name ends *-ny*: the restoration [*Kp-*]*ny* is due to Sethe and 'suits the traces, the space and context quite admirably.'—A. H. Gardiner, *The Admonitions of an Egyptian Sage*, Leipzig, 1909, p. 33.

† The word is *as*, a generic one for pines, fir, &c.

ago not a single monument was known that could be ascribed with certainty to the period before the Third Egyptian Dynasty. To-day we possess a continuous series of written documents which carry us back to Menes, the Founder of the Monarchy, some 3,400 years or more before our era. These written documents, moreover, show clearly that Menes himself must have come at the end of a very long period of development. Egypt had already had a long history when the Upper and Lower Countries were first united under a single sceptre. From Upper Egypt we possess a continuous series of uninscribed monuments which take us back far into prehistoric times. An immense vista has been opened out before our eyes by the discoveries of the last thirty years, and now, in Egypt better than in any other country in the world, we can see man passing from the primitive hunter to the pastoral nomad, from the pastoral nomad to the agriculturist, and then on to the civilised life which begins with the art of writing. We can see in the Delta and in the Lower Nile Valley tribes becoming permanently settled in fixed abodes around primitive cult-centres, and then uniting with others into one community. We can trace the fusion of several communities into single States, and then, later, the uniting of States under a supreme sovereign. What other country in the world preserves such a record of its early history?

I have but little time left to speak of the modern Egyptians, but to the anthropologist few people are more interesting. In almost every circumstance of daily life we see the Old in the New. Most of the ceremonies from birth to burial are not Muslim, or Christian, or Roman, or Greek; they are Ancient Egyptian. In the transition of a people from one religion to another the important institutions of the older doctrine are generally completely abolished; many ceremonies and much unessential detail, however, survive, and in the Delta and Lower Nile Valley survivals are extraordinarily numerous. It was Lady Duff Gordon who said that Egypt is a palimpsest in which the Bible is written over Herodotus, and the Koran over that; the ancient writing is still legible through all. There is a passage in one of her letters which describes her visit to some Nubian women. Their dress and ornaments were the same as those represented in the ancient tomb-paintings. Their hair was arranged in little plaits, finished off with lumps of yellow clay burnished like golden tags. In their house, Lady Duff Gordon sat on a couch of ancient Egyptian design, with a semicircular head-rest. They brought her dates in a basket such as you may see in the British Museum. So closely did they and their surroundings resemble the scenes of the ancient tombs that she says she felt inclined to ask them how many thousand years old they were! The modern worship of the people is full of the ancient; many of the sacred animals and trees have taken service with Muslim Saints. Up to a few years ago cats were still fed by the 'Servant of Cats' in the Kadi's court in Cairo. Cobras are still held in great reverence in the City of the Khalifs. Some time ago the Director of the Zoological Gardens in Cairo told me that it was most difficult to procure cobras for the Gardens. It was not because they were scarce, but because the demand for them was so great that the price asked was far more than the Government would pay.

Many cobras, I was told, were kept in the upper rooms of houses in the native quarters of the city. The funeral customs of the people throughout the country are much the same as those which prevailed in ancient times. It is not only among the merchant and agricultural classes that we find the Old in the New. Mrs. Poole, the sister of the Arabic scholar Edward Lane, writing from Cairo in 1846, describes the scenes in one of Mohammed Ali's palaces on the death of a princess of the Royal Family. Immediately the royal lady breathed her last, her relations and slaves broke up all the beautiful china and glass which had been her property. 'The destruction after a death,' Mrs. Poole remarks, 'is generally proportioned to the possessions of the deceased; therefore, in this case, it was very extensive.' Many, perhaps most, of the festivals of the country are of ancient origin. In the Delta towns and villages there are several which are similar to those that were held there in ancient days. It is the same in Upper Egypt. Thebes still possesses its sacred boat, and on the festival commemorating the birthday of Luxor's patron saint, Abu'l Haggag, this lineal descendant of the sacred bark of Amon decorated with flags and gaily coloured bits of cloth, is drawn around the town in procession, amid the acclamations of the people. Modern Egypt has hardly been touched by the anthropologist. The Government official usually holds himself far too aloof to ever really get into intimate contact with the native. Edward Lane did much to record the manners and customs of the Cairene Egyptian, but he never lived among the fellahîn, and his book contains little about the modern dweller on the banks of the Nile outside Cairo. A rich harvest awaits any student who, knowing the language, will settle and live throughout the year among the peasants in any village or town in the Lower Nile Valley or Delta. It is only in this way that a real knowledge of the people can be obtained. Far less is known about them than about many a tribe in Central Africa.

Thucydides, in the preface to his 'History,' proposed to record past facts as a basis of rational provision in regard to the future, but he was not the first to whom this great thought had occurred. A thousand years before the Greek historian was born an old Vizier of Egypt said of himself that he was 'skilled in the ways of the Past,' and that 'the things of Yesterday' caused him 'to know To-morrow.' Anthropology, the Science of Man and Civilisation, aims at discovering the general laws which have governed human history in the past and may be expected to regulate it in the future. The Egyptian Vizier had, at most, a couple of thousand years of recorded history before him. Since his time the area of history has been ever widening, and we ourselves can look back over nearly six thousand years of human endeavour. We know considerably more of the past than did our forefathers, and though those who hold the reins of government do not usually learn by experience, the anthropologist ought to be able to predict a little better than the politician about the future. For thousands of years Egypt has been under foreign rule. It has been under the yoke of Ethiopian and Persian kings, under the Greek and Roman, Arab and Ottoman conquerors. Its people suffered three thousand years of oppression. For the last forty years it has had English justice. Egypt has this year been handed back to the Egyptians. It is an Oriental country. What will be the immediate future of its people? It is not difficult to predict. Seventy years ago, when Egypt was under the sway of Said Pasha, there was current among the fellahîn of Thebes a little parable, and with this I will conclude. I quote it as it was taken down by Rhind in the fifties of last century, but the story was still remembered when I lived among the natives of Upper Egypt twenty-eight years ago. It runs thus:—

'It happened once that a Sultan captured a lion, which it pleased him to keep for his royal pleasure. An officer was appointed especially to have in charge the well-being of the beast, for whose sustenance the command of His Highness allotted the daily allowance of six pounds of meat. It instantly occurred to the keeper that no one would be a bit the wiser were he to feed his dumb ward with four pounds, and dispose of the remaining two for his own benefit. This he did, until the lion gradually lost his sleekness and vigour, so as to attract the attention of his Royal Master. "There must be something wrong," said he; "I shall appoint a superior officer to make sure that the former faithfully does his duty." No sooner was the plan adopted than the first goes to his new overseer, and convincing him very readily, that if the proceeds of two pounds be conveyed to their pockets, the meat would be far better employed than in feeding the lion, they agreed to keep their own counsel and share the profit between them. But the thirst of the newcomer soon becomes pleasantly excited by the sweets of peculation. He talks the matter over with his subordinate, and they have no difficulty in discovering that the lion might very well be reduced to three pounds a day. Drooping and emaciated, the poor beast pines in his cage, and the Sultan is more perplexed than before. "A third official shall be ordered," he declares, "to inspect the other two"; and so it was. But they only wait for his first visit to demonstrate to him the folly of throwing away the whole six pounds of meat upon the lion, when with so little trouble they could retain three, one apiece, for themselves. In turn his appetite is quickened and he sees no reason why four pounds should not be abstracted from his ward's allowance. The brute, he states to his colleagues, can do very well on two, and if not, he can speak to nobody in complaint, so why need they lose the gain? And thus the lion, reduced to starvation-point, languishes on, robbed and preyed upon by the overseers set to care for him, whose multiplication has but added to his miseries.'

NOTES.

(1) Buffon's *Hist. Nat.*, vol. xii., 1764, p. 24.
(2) Burckhardt, *Travels in Nubia*, 1819, p. 67.
(3) For a characteristic hunting scene of the Pyramid Age see Borchardt, *Grabdenkmal des Königs Sahure*; for one of the Middle Kingdom, Newberry, *El Bersheh* I, pl. vii.
(4) The Sphinx Stela, 1, 5.
(5) Newberry, *Scarabs*, pls. xxxiii.-iv.
(6) *Giornale l'Esploratore*, anno ii., fasc. 4.
(7) Brit. Mus., Add. MS., 25666.
(8) Burckhardt, *Travels in Syria*, 1822, p. 461.
(9) W. G. Browne, *Travels in Africa, &c.*
(10) *Mém. sur l'Egypte*, vol. i., p. 79.
(11) *Letters on Egypt, &c.*, ed. 1866, p. 107.
(12) *Journal of Egyptian Archæology*, vol. v., p. 234, pl. xxxiii.
(13) Petrie, *Abydos I*, pl. L.
(14) Lydekker, Brit. Mus., *Guide to the Great Game Animals*, 1913, p. 39, and figs. 21, 22.
(15) *Journal of Egyptian Archæology*, vol. v., pl. xxxiii., p. 227.
(16) Anderson, *Zoology of Egypt* (Reptilia), p. xlvi.
(17) Schweinfurth, *Heart of Africa*, vol. i., p. 69.
(18) C. G. Seligman, *Journal of the Anthropological Institute*, vol. xliii., p. 595.
(19) Burckhardt, *Travels in Nubia*, p. 387, *et seq.*
(20) *Proceedings* of the Society of Biblical Archæology, Feb. 1906, p. 69.
(21) That Narmer was Menes is proved by a sealing published by Petrie in *Royal Tombs of the Earliest Dynasties*, pl. xiii., 93. His conquest of Tehenu-land is recorded on an ivory cylinder published by Quibell, *Hierakonpolis I*, pl. xv., 7.
(22) The cults of the Double Axe and of the Dove or Swallow are found on monuments of the Pyramid Age.
(23) I owe my knowledge of the greater part of the Soleb scenes to Prof. Breasted, who kindly showed me unpublished drawings of them when I visited him in Chicago in 1921.

SYMBIOSIS IN ANIMALS AND PLANTS.

ADDRESS TO SECTION I (PHYSIOLOGY) BY

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CONTENTS.

Introduction.

THE subject of symbiosis has been chosen for this address because of its broad biological interest, an interest that appeals equally to the physiologist, pathologist, and parasitologist. It is, moreover, a subject upon which much work has been done of recent years in different countries, and this seems a fitting occasion upon which to give a brief summary of what is known to-day, especially since the literature relating to symbiosis is largely foreign, somewhat scattered and relatively inaccessible.

I. Symbiosis in Plants.

(1) *Lichens.*

It is well known to botanists that the vegetative body (thallus) of lichen plants consists of two distinct organisms, a fungus and an alga. The alga, individual elements of which are called 'gonidia,' is either scattered throughout the thallus or, as in most cases, it forms a well-defined layer beneath the surface of the thallus. The view that lichens consist of the two elements mentioned was advanced by Schwendener (1867-9), who regarded the fungus as living parasitically upon the alga, a view which gained support from the researches of Bornet (1872), Voronin (1872), Treube (1873), etc., and especially of Bonnier (1886-9), wherein synthetic cultures were obtained by bringing together (*a*) various algæ obtained in the open and (*b*) fungus-spores isolated from cultures of fungi forming the one component of certain lichens.

Schwendener's view, that the fungi are parasitic on the algæ in lichens, was contested by Reinke (1873) on the ground that a state of parasitism did not explain the long and apparently healthy life of the associated fungi and algæ, a biological association for which the term *Consortium* was proposed by him, that of *Homobium* by Frank (1876), and that of *Symbiosis* by de Bary (1879), the latter term denoting *a condition of conjoint life that is more or less beneficial to the associated organisms or symbionts.*

Investigation has shown that the relation or balance between the associated organisms varies in different lichens. Thus in some forms of *Collemaceæ*, as stated by Bornet (1873), the partners as a rule inflict no injury upon each other, whilst in some species of *Collema* occasional parasitism of the fungus upon the alga (*Nostoc*) is observable, since short hyphal branches fix themselves to the alga cells, these swelling, their protoplasm becoming granular and finally being voided. In *Synalissa* and some other lichens the hypha penetrates into the interior of the alga, where it swells and forms a sucker, or haustorium. Elenkin (1902-6) and Danilov (1910) take it as proved that lichens owe their origin to parasitism, the fungus either preying upon the alga or living as an 'endosaprophyte' (Elenkin) upon the algæ that die.

Therefore, we may find in lichens the condition of true symbiosis on the one hand, ranging to demonstrable parasitism on the other, and, conversely to what has been described above, instances are known wherein algæ are parasitic on fungi (Beijerinck, 1890).

Physiology of Lichens.

The nutrition of algæ in lichens is similar to that of other chlorophyllaceous plants, the most important work on the subject being that associated with the names of Beijerinck (1890) and Artari (1902). In respect to nitrogen supply, Beijerinck cultivated various green algæ, as well as gonidia derived from *Physcia parietina*. The gonidia only multiplied rapidly in a malt-extract culture-medium to which peptones and sugar were added. This showed that the algæ associated with fungi as in lichens were placed advantageously in respect to nitrogen supply. He termed such fungi 'ammonia-sugar-fungi,' because they extract nitrogen from ammonia salts and, in addition to sugar, form peptones. Artari showed that there exist two physiological races in green algæ, those which absorb and those which do not absorb peptones. He found that the gonidia (*Cystococcus humicola*) derived from *Physcia parietina* absorbed peptones, and he consequently referred to such algæ as 'peptone-algæ.' Treboux (1912), however, denies the existence of peptone-sugar-races of algæ, and regards the algæ in lichens as the victims of parasitic fungi. Nevertheless, the important researches of

Chodat (1913) have demonstrated that cultivated gonidia develop four times as well when supplied with glycocoll or peptone in place of potassium nitrate.

The carbon supply of gonidia, according to Artari (1899, 1901), Radais (1900), and Dufrenoy (1918), is not derived photosynthetically, but from the substratum on which they grow. Whilst Tobler (1911), in his culture experiments with lichens, found that the gonidia obtain their carbon from calcium oxalate secreted by the fungus, Chodat (1913) observed that cultured gonidia grow but slowly without sugar (glucose), which he believes constitutes their main source of carbon supply.

Whereas, according to Chodat, the gonidia grow poorly on organic nitrogen in the absence of sugar, they develop rapidly when sugar is added. He therefore concludes that the gonidia lead a more or less saprophytic life in that they obtain from the fungus-hyphæ both organic nitrogen and carbon in the form of glucose or galactose.

The nutrition of fungi in lichens depends partly upon parasitism, when they invade the gonidia, and partly upon saprophytism, when they utilise dead gonidia (Chodat).

In concluding this section, the hypothesis of M. and Mme. Moreau (1921) demands mention, since it bears upon the manner in which lichens may have originated in nature. They regard the fungal portion as a gall-structure arising from the action of the associated alga. The lichen, according to this view, is to be regarded as a fungus that has been attacked by a chronic disease which has become generalised and necessary for the subsistence of the host-fungus. F. Moreau (1922) sums up this view as follows: 'The lichen-fungus appears as an organism characterised in its morphology by deformity due to an infective agent, an alga. The history of the association existing in lichens may be described as that of a contagious malady marked by the invasion, development, inhibition, and death of the infective agent on the one hand, and on the other hand by the morphological reactions and defensive processes of the attacked organism. In conformity with the virulence and relative immunity of the two opponents, the struggle may be short, the association transitory, the conflict may last indefinitely, and the association, rendered lasting, presents the appearance of a harmonious symbiosis.'

(2) *The Root-nodules of Leguminous and other Plants.*

A well-known example of symbiosis is afforded by the presence of the bacteroids in the nodules of leguminosæ, the micro-organisms being capable of fixing atmospheric nitrogen and thereby rendering nitrogen available for assimilation by the plant. This was demonstrated by Hellriegel and Willfahrt (1888), Schloesing and Laurent, whilst Beijerinck cultivated *Bacterium radicicola* from the nodules and produced nodules synthetically by bringing the plant and bacterium together on previously sterilised soil. According to Pinoy (1913), the bacteroids are myxobacteria, and, in the case of one species which he has specially studied (*Chondromyces crocatus*), it was found essential for the successful cultivation of the micro-organism, apart from its host-plant and in vitro, that it should be grown in association with a species of micrococcus; similar observations have been made on other micro-organisms by bacteriologists, and some refer to the condition as one of symbiosis. Bacteriologists, I would note, are continuously misapplying the term symbiosis in referring to bacteria grown in mixed cultures, when there is no evidence whatever that the micro-organisms are mutually interdependent for their growth. In passing, it may be mentioned that nodules on the roots of the alder are attributed to the presence therein of *Streptothrices*, and that comparable nodules occur in Eleagnaceæ. The nodules on the leaves of Rubiaceæ and tropical Myrsinaceæ are also regarded as due to bacterial symbionts.

(3) *The significance of Mycorhiza in relation to various Plants.*

It has long been known that the roots of *most perennial and arborescent plants* are invaded by the mycelium of fungi known as *Mycorhiza*, and it is to Kamiensky (1881), and especially Frank (1885), to whom we owe the hypothesis that we are here dealing with symbiotic life. Frank distinguishes two forms of *Mycorhiza*: (1) the *ectotrophic*, which surround the root externally like a sleeve and are found especially about the roots of forest trees (Conifers), and (2) *endotrophic*, which penetrate deeply into the root tissue and even into the cells of the root. The *endotrophic Mycorhiza* are derived from the outside; their mycelium enters the root by penetrating the epidermal cells at the base of the root hairs, passes between the cells and into them where the mycelium branches dichotomously, and forms ultimately a much-branched intracellular growth. By this time the fungus is no longer in communication with the exterior of the root, and it nourishes itself within the host cell, only, however, by utilising the reserve substances stored there whilst avoiding the cell protoplasm or other living host elements. The host cell, after a period of inertia, exhibits a distinct reaction to the presence of the fungus, in that its nucleus becomes hypertrophied, divides repeatedly and becomes amœbiform in contour. The contained mycelial mass undergoes degeneration, is digested by the host, and the host-cell resumes its normal life. These root-*Mycorhiza* have not as yet been cultivated,[1] as have others to which reference will presently be made, and it is as yet impossible to assign them a place among known species of fungi. Further details regarding these forms will be found in the publication of Gallaud (1904).

Mycorhiza in Orchids.

The first to note the presence and to attempt to cultivate the fungus mycelium in the roots of orchids was Reisseck (1846), and in 1881 Kamienski advanced the hypothesis that the association was one of symbiosis. Wahrlich (1889) subsequently found symbionts in all species of orchids he examined, about 500 in number, thereby showing that their distribution is generalised.

It is to the researches of Noël Bernard (1902 onward), however, that we are actually indebted for the complete demonstration of the true

[1] Magrou (1921) reports that he isolated *Mucor solanum* n. sp. from *Solanum dulca-mara*, and he seems to have infected the potato plant with the fungus.

relation existing between orchids and *Mycorhiza*, based as it is upon physiological studies. All who had to do with orchids in the last century found the greatest difficulty in raising these plants from their seed; a successful result appeared to depend largely on chance. Cultivators of orchids found that success was obtained more frequently by placing seed in soil upon which orchids had previously lived, and much secrecy was observed as to the methods employed by the more successful cultivators.

The seeds of orchids are exceedingly small—a million may be found in a single capsule of an exotic species; they possess no albumen and contain an embryo consisting merely of a mass of undifferentiated cells provided with a suspensor. The essential discovery of Bernard was that orchid seeds do not germinate in the absence of fungi belonging to the genus *Rhizoctonia*. The fungus enters the seed through its least resistant and highly permeable cells, which apparently emit a secretion that attracts the fungus. Each species of orchid, according to the subsequent researches of Burgeff (1909), possesses a special species, variety, or race of fungus that is particularly adapted to it—he distinguishes fifteen species of fungus. When mutually adapted orchid seed and fungus are brought together, the mycelium of the latter penetrates the suspensor cells by digesting their cellulose wall. The mycelium traverses the epidermal cells of the seed without undergoing development within them. As soon as the primary infestation has occurred, even where the mycelium has penetrated but slightly, the cells of the seed, situated at the posterior pole of each embryo, cease to be vulnerable. In other words, a local immunity appears to be established, this immunity lasting at any rate until new regions are attacked by the fungus. This, in Bernard's experience, is the general rule. The mycelium, having attained the parenchyma cells, develops into characteristic filamentous masses recalling the appearance seen in bacterial agglutination. Nevertheless, there comes a time, this varying according to the associated species involved, when the development of the fungus is arrested by the deeper parenchyma cells of the seeds. These cells are altered before they are penetrated by the fungus; they become hypertrophied and acquire large lobose nuclei. They digest the mycelium which enters their protoplasm, but the cell continues to harbour remains of the fungus ('corps de dégénérescence') which occur abundantly in the tissues of orchids. The seed now proceeds to sprout, giving rise to a small tubercle ('protocorm'), which only at a later period produces leaves and roots.

The cultivation of Rhizoctonia of various species was carried out successfully by Bernard, the cultures being used to reproduce germination in orchids. Orchid seeds alone remained unchanged for months in cultures on agar with salop-decoction added, but when pure cultures of *Rhizoctonia* mycelium were added to such orchid seeds, the latter were invaded by the fungus, germinated, and gave rise to a 'protocorm.' Bernard gives excellent figures illustrative of the development described.

The relation between the fungi and orchids varies in different groups and plants. In primitive forms like *Bletilla* germination occurs in the absence of the fungus, but the 'protocorm' does not develop; the rhizome, to which the plant is periodically reduced, is only periodically attacked when fresh roots are formed. *Bletilla*, however, behaves in an exceptional manner. In other orchids (*Ophrydeæ*, *Cattleyeæ*, *Cypripedeæ*, &c.) the fungus is needed for germination, and the adult plant is fungus-free except when the orchid produces fresh roots. Therefore, in such cases symbiosis is intermittent. In higher orchids like the epiphytic *Sarcanthineæ* the fungus is needed for germination, and, the roots being persistent, symbiosis is maintained continuously. Finally, in *Neottia nidus-avis* the symbiotic condition is maintained throughout the life-cycle of the orchid, the fungus being found in the roots, rhizome, and even in the flowers and seeds, and it is transmitted hereditarily.

The activity or 'virulence' of Rhizoctonia, according to Bernard, diminishes when the fungus is kept apart from the orchid, being practically lost after two or three years. An attenuated fungus regains its activity in a measure after a sojourn of some weeks in a young orchid plant; a full degree of activity under symbiotic conditions is, however, only regained slowly.

The germination of orchids in the absence of fungi was successfully induced by Bernard through cultivating them in concentrated nutrient solutions of a kind that does not occur in nature; such solutions, moreover, except under carefully carried out experimental conditions, would be rapidly vitiated through serving as a medium for the multiplication of different micro-organisms. The effect of increasing the concentration of the solution, offered to plants reared without fungi, corresponds to that obtained by raising plants with fungi of increasing activity or 'virulence.' It may be added here that when *Rhizoctonia* are cultivated on a medium containing saccharose and the substance of orchid tubers—namely, salop—they cause an increase in the molecular concentration of the medium. It is possible that the fungi, when associated with the orchids, bring about a similar increase in the molecular concentration of the sap of the invaded plant.

The Origin of Tubers in Various Plants.

The occurrence of endotrophic *Mycorhiza* in the roots of species of *Solanum* has been recorded by Janse (1897) for *S. verbascifolium* in Java, by Bernard (1909-11) for *S. dulca-mara*, by Mme. Bernard and Magrou (1911) for *S. maglia* collected in Chili, the last-named species having been regarded by Darwin as the wild type of *S. tuberosum*, our edible potato.

Experimenting with the potato, Molliard (1907, 1920) found that tubers were not formed in aseptic cultures in a poor nutrient medium, and that raising the concentration of the sugar in the sap artificially (as with the radish) led to tuberisation; concentrating the culture-medium did not induce tubers. Magrou (1921) placed potato seeds in a poor soil and close to *S. dulca-mara*, which always contains fungi, and found that only when the fungus invaded the potato plant were tubers formed.

Magrou also investigated tuberisation in *Orobus tuberosus* (Leguminosæ) and in *Mercurialis perennis* (Euphorbiaceæ), and from his collective studies the following conclusions may be drawn:—

(1) When the potato plant and *Orobus* are raised from seed, the establishment of symbiosis leads to tuberisation of the sprouts at the base of the stem; tubers are not formed in the absence of symbionts. (2) Owing to developmental differences between the two plants, symbiosis in the potato plant is intermittent, whilst in *Orobus* it is continuous. (3) It follows that these plants may develop in two ways: (*a*) when they harbour symbionts they produce perennial organs; (*b*) without symbionts they are devoid of perennial organs. (4) It is the rule for wild perennials to harbour symbionts, as Bernard has stated, whilst annuals are devoid of symbionts; three species of annuals (*Solanum nigrum*, *Orobus cœcineus*, and *Mercurialis annua*) may be penetrated by endophytes, but they quickly digest the intruders. (5) These observations confirm and supplement the view held by Bernard that tuberisation is due to the association of fungi with plants.

Mycorhiza in Ericaceæ.

Rayner (1915-16) finds that *Mycorhiza* are constantly present in heathers. He isolated *Mycorhiza* (of the genus *Phoma*) from *Calluna vulgaris*, in which the fungus is widely distributed, being found in the roots, branches, and even in the carpels, so that it occurs within the ripe fruit and seed tegument. *Calluna* seeds, when grown aseptically, give rise to poor little plants devoid of roots, but, under like conditions, in contact with *Phoma* the plants develop normally and form many roots.

Mycorhiza in Club-mosses and Ferns.

In Lycopodiaceæ (Club-mosses) and Ophioglossaceæ (Ferns), according to Bernard, the perennial prothallus is infested, and the spores whence the plants emanate will not germinate except (as with orchid seeds) with the help of fungi.

In concluding this part of my subject, dealing with symbionts of plants, I need scarcely emphasise the significance of symbiosis in the vegetable kingdom. I will close by mentioning the theoretical deduction of Bernard that vascular plants owe their origin in the past to the adaptation of certain mosses to symbiotic life with fungi.

II. Symbiosis in Animals.

(1) *Algæ as Symbionts.*

Animals of widely separated groups characterised by their green colour have long been known. Already in 1849, von Siebold attributed the colour of *Hydra viridis* to chlorophyll which, for a period, was regarded as an animal product. In 1876, Gésa Entz concluded that the chlorophyll is contained in vegetable cells living as parasites or commensals within the animals; these cells were aptly named *zoochlorella* by Brandt (1881), whilst cells distinguished by their yellow colour were subsequently called *zooxanthella*, the latter having been first described by Cienkovsky (1871) as present in Radiolaria. In the latter case the symbionts were found capable of surviving their host, of multiplying, and of assuming a flagellate stage.

Zoochlorella occur mainly in fresh-water animals, zooxanthella mainly in marine animals, the symbionts, measuring 3-10 microns in size, being found in many Protozoa, Sponges, Cœlenterates, Ctenophores, Turbellaria, Rotifers, Bryozoa, Annelids and Molluscs.

Physiological relations between Animals and Symbiotic Algæ.—In 1879, Geddes showed that green animals give off oxygen, *Convoluta roscoffensis* (Turbellaria), when well illuminated, liberating gas containing 45-55 per cent. of oxygen. Engelmann (1881), by means of his bacteria-method, showed that *Hydra viridis* (Cœlenterata) and *Paramæcium bursaria* (Protozoa) give off oxygen when exposed to light. Geddes (1882), working with a series of marine animals, found *Velella* gave off 21·24 per cent. of oxygen, and an Actinia (*Anthoa cereus*) gave off 32-38 per cent. of oxygen. Whereas animals harbouring green algæ as symbionts always liberated oxygen, the colourless varieties of these animals never did so. Geddes regarded the association of animal and alga as being mutually helpful, the oxygen supplied by the alga to the animal and the carbon dioxide and nitrogen supplied by the animal to the alga being useful to the partners. He speaks of ' animal lichens ' and ' Agricultural Radiolarians and Cœlenterates.' He found, moreover, that animals harbouring symbionts are much more resistant than those without symbionts: Medusæ (*Velella*) survived 14 days in small beakers with symbionts, only 1-2 days without them. Protozoologists have, moreover, found that Protists harbouring symbionts are easier to rear in vessels than are those without symbionts. Brandt (1883) believes that the symbionts and host aid each other in nutrition. Green *Spongilla* (fresh-water sponges) and *Hydra viridis* may live a long time in filtered water. He found that when starved green Actinia were (*a*) placed in the dark, they expelled their algæ and died rapidly, being probably poisoned by the dead algæ, but that when they were (*b*) placed in diffuse light they lived on. Actinia deprived of symbionts may become habituated in culture to live without them. Opinions (*vide* Buchner, 1921) are in conflict as to the exact relationship between the partners; in some cases (*Peneroplis* and *Trichosphærium*) the symbionts never appear to be injured, in *Amœba viridis*, &c., a limited number of symbionts are digested at all times, whereas in some Radiolarians, &c., digestion only takes place at certain stages of their development. Nutritive substances pass from the algæ into the host's cells; thus starch granules, found alongside the algæ, may be taken up by the animal cells.

Using modern methods of gas analysis, Trendelenburg (1909) concludes that green Actinias (*Anemonia sulcata*) live in true symbiosis with algæ, the algæ supply oxygen to the animal by day and at night utilise the surplus oxygen evolved, whilst carbon dioxide is furnished to the alga partly by the animal and partly by the water in which they are bathed. Rütter (1911) studied the nitrogen metabolism and concludes (*a*) that the Actinia yields to the algæ nitrogen in the form of ammonia for protein synthesis, and in darkness it adds carbon containing substances (nitrogen-free), whilst (*b*) the algæ yield to the Actinia nitrogenous substances in the dark and by light carbon-containing substances. Organisms harbouring algæ exhibit naturally a positive heliotropism.

Symbiotic algæ are not usually transmitted hereditarily, each host-generation being usually infected afresh by algæ, encountered about the host, which may be either free-living or possess a free-living stage in their development. Exceptions occur, however, where Protozoa multiply by division and the algæ pass directly (as it were hereditarily) to succeeding generations. There are also cases of hereditary transmission in hosts that undergo sexual multiplication (as in *Hydra viridis*), the zoochlorella penetrating the egg on escaping from the host's endodermal cells after the manner of starch granules or other food reserve substances (v. *supra*). From the circumstance that in most cases symbiotic algæ are not transmitted hereditarily, we may explain the occasional occurrence of alga-free individuals in a species usually harbouring the symbionts.

Studies conducted on TURBELLARIA are of special interest: These animals may contain either green or yellow symbionts, and, as in Protozoa, some allied species harbour the symbionts and others do not. The eggs of Turbellaria are symbiont-free, each generation becoming infected afresh, the symbiont either entering the host's mouth and remaining there, traversing the intestinal wall, or entering by the genital pore, according to the particular host-species it affects.

The best-known example of symbiosis in Turbellaria is found in *Convoluta roscoffensis*, a species that has been well studied by Keeble and Gamble (1903-7). Its larvæ are colourless and infection occurs after hatching. Colourless larvæ are obtainable by transferring freshly hatched examples immediately to filtered sea-water. The cocoon, on the day following its deposition, is already invaded by many algæ having a very different structure from those found in *Convoluta*; they possess four flagella and have been referred by Keeble and Gamble to the genus *Carteria* (allied to *Chlamydomonas*). The algæ within the host possess a special structure, their contour is very irregular, they have no cellulose wall, the green colouring matter is unevenly distributed, being confined to chromatophore bodies surrounding the pyrenoid body, the nucleus is eccentric, and a number of examples are found with degenerating nuclei. Naturally all attempts to cultivate these obviously degenerating algæ have failed.

The physiological relations existing between Turbellaria and algæ differ according to the species. Thus in *Vortex viridis* symbiosis is not necessary, in *Convoluta* it is necessary for both partners. Mature *Convoluta* are never found devoid of algæ in nature. The young larva can only feed itself for a week; as it grows older it becomes infected progressively with algæ and ceases to nourish itself otherwise than upon the products of its contained symbionts. Finally, having reached an advanced age, the animal becomes capable of digesting the algæ, as does *Convoluta paradoxa* under unfavourable conditions of life. Keeble and Gamble define four periods in the life of *Convoluta*, which they term respectively hetero-, mixo-, holo-, and auto-trophic, wherein the animal lives at the expense (1) of formed substances, (2) of these and alga-products, (3) of alga-products only, and finally (4) of the algæ themselves. This constitutes a true evolution in a species from a free existence, depending only on outside sources of food supply, to a symbiontic mode of life, and lastly one merging into parasitism.

(2) *Symbiosis in Insects.*

Among insects we find a whole series of progressive adaptations toward an association with micro-organisms of different categories:—

Group I.—*The utilisation by insects of micro-organisms cultivated by them outside their bodies.* To quote three examples: (1) The larvæ of the beetle *Xyloteres lineatus* (Bostrichidæ) form galleries in the wood of Pines. The galleries have a characteristic blue colour, produced by the growth of the fungus *Ambrosia* upon their walls, the fungus being cultivated by the larva for food. The beetle is incapable of digesting cellulose. Analogous cases occur among Ants and Termites thus: (2) *Termes perrieri* of Madagascar, studied by Jumelle and Perrier de la Bâthie (cited by Portier, 1918), builds numerous chambers and galleries. The termites collect dead wood, chew it up finely, swallow it, the wood passing unaffected through their intestine and out in the form of small spherical masses (0.5 mm.) which are cemented together as porous cakes that are impregnated with digestive secretions. Fungi which develop upon the cakes serve as food for the termites, and in well-cared-for nests the growth is harvested by the workers who triturate the mycelium and spores and feed the young larvæ therewith, whilst older larvæ receive spores, and large larvæ receive mycelium and the triturated wood contained in the cakes. (3) A third example is that of ants belonging to the genus *Atta* which cultivate fungi over areas of 5 to 6 square metres; here the queen, when about to found a new colony, carries away a small ball of fungus in a corner of her mouth wherewith to start a fresh culture in the new habitat.

Group II.—*Symbiotic organisms developing in the lumen of the intestine and its adnexa.* As examples may be cited the bacteria occurring in the intestines of fly larvæ (*Musca*, *Calliphora*, &c.), which aid the larva to digest meat; the bacteria associated with the olive-fly (*Dacus olea*); the Trychonymphids of xylophagous Termites (*Leucotermes lucifugus*).

Group III.—*Intestinal symbionts situated in the epithelial cells of the digestive apparatus.* The most striking instance is found in *Anobium paniceum*, a small beetle commonly occurring in flour, biscuits, dried vegetables, &c. In a part of its mid-gut are found cells filled with symbiotic yeasts undergoing multiplication (Escherich, 1900). The symbionts are not transmitted hereditarily but are acquired by the larva on hatching, being eliminated by the female beetle.

In this connection may be mentioned with reserve the observation of Portier (1918) upon xylophagous Lepidoptera (*Cossus*, *Nonagria*, *Sesia*, &c.) which, according to that author, possess intestinal fungi (*Isaria*) that multiply in the gut and form spores that penetrate the intestinal epithelium and attain the perivisceral cavity, fat-body, and muscles of the insect. As Caullery points out, however, the supposed spores closely resemble Microsporidia, and Portier's interpretation may be erroneous. In this category also belong the symbionts described as occurring in *Glossina* by Roubaud (1919) and before him by Stuhlmann, these being found in certain hypertrophied cells of the intestinal epithelium. When liberated into the gut lumen, the symbionts are stated to multiply by budding after the manner of yeasts. Roubaud regards the yeasts as fungi, allied to the *Cicadomyces* of Šulç, and finds that they are transmitted hereditarily from the adult to the egg, larva and pupa.

Group IV.—*Intracellular symbionts of deep tissues.* This group of symbionts is most frequently found in insects, but their nature was not disclosed until recent years. Already, in 1858, Huxley described an organ which is constantly present close to the ovary in *Aphis*. Balbiani (1866) named it the pseudovitellus, or green body, and Metchnikoff (1866), who followed its development, named it 'secondary vitellus.' The function and structure of this organ were studied by subsequent authors without being understood until, in 1910, there appeared two important papers by Pierantoni (February 6), and Šulç (February 11), who demonstrated their symbiotic character, recognising the intracellular inclusions as yeasts whose evolution they completely followed. Their results have been confirmed by various authors, especially by Buchner, who in a remarkable series of papers describes a number of associations existing between insects and micro-organisms and reaches important generalisations as to their significance. It is from a collective work on the subject by Buchner (1921) that most of our information regarding this class of symbionts is taken.

Among the symbionts of deep tissues in insects are found a whole series of specialisations among the host-elements harbouring the symbionts. The least specialised instance is represented by Lecaniinæ where the yeasts are distributed throughout the body (perivisceral fluid, cells of fat-body); the fat-body cells may be regarded here as facultative Mycetocytes. In cases like *Orthezia*, symbiotic bacteria occur in certain fat cells which still contain fat droplets; this condition is also found in certain Cicadas, the yeasts being contained in fat cells which continue to accumulate fat, glycogen and urates. Finally cases occur as in Blattids where symbiotic bacteria are found in special cells greatly resembling fat cells but already forming well differentiated Mycetocytes. This class is well represented in and about the digestive tract of Pediculidæ (*Hæmatopinus*) and certain ants (*Camponotus*). Still more advanced in specialisation are those cases in which the symbiont-containing cells (*Mycetocytes*) agglomerate to form true organs termed *Mycetomas*, organs that are surrounded by flattened epithelial cells, the component mycetocytes containing either yeasts or bacteria as symbionts; such cases are found in Aphids, Chermids and Aleurodids. Mycetomas may occur singly or in numbers according to the nature of the host; the epithelial covering of the organ varies in its cell structure and pigmentation, and the organ may be plentifully supplied with tracheæ whose finest branches penetrate into the interior of the mycetocytes. The relations between the mycetocytes or mycetomas and the other organs of the host vary greatly; in some cases they occur especially in the fatty tissue, in others near the gonads, in others, as in Pediculidæ around or upon the intestine. In *Pediculus* and *Phthirus*, parasitic on man, the mycetoma is disc-shaped and lies centrally as a distinct milk-white structure upon and indenting the mid-gut. Transition forms between isolated mycetocytes and differentiated mycetomas are found in various insects.

The mode of transmission of intracellular symbionts of insects from generation to generation may take place in different ways as defined by Buchner (1921, somewhat modified):

I. The larva of each generation infects itself through the mouth (Anobiidæ).

II. Infection takes place hereditarily through the egg:
  1. By symbionts set free in the blood, or which leave mycetocytes or mycetomas and attain the egg as follows:—
    (*a*) by general infection of follicles and invasion of the egg, and finally establishing themselves at the posterior pole of the egg (Ants);
    (*b*) by penetrating special parts of the follicles, producing for a period bacterial vegetation upon the whole egg and finally concentrating at the egg's two poles (Blattidæ);
    (*c*) by entering the egg via its nutritive cells
      (*a*) only some isolated fungi entering (Lecaniinæ);
      (*b*) a number of bacteria enter in the form of a gelatinous mass (Coccinæ);
    (*d*) by entering the posterior pole of the egg:
      (*a*) as isolated fungi
        (*a*) which penetrate one after another (Aphids);
        (*b*) which accumulate in follicles and enter in a mass consisting of
          (*a*) one kind of symbiont (Icerya);
          (*b*) two kinds of symbiont (Cicada, Aphrophora);
          (*c*) three kinds of symbiont (Aphalara ?);
      (*b*) as bacteria united in several gelatinous masses (Orthezia).
  2. By whole mycetomas entering at posterior pole of egg (Aleurodes).
  3. By isolated symbionts leaving special mycetomas situated at juncture of follicular tubes (Pediculidæ).

III. Embryonal infection as in parthenogenetic Aphids.

It is difficult to understand the mechanism whereby the symbionts penetrate the egg in the insect's body; in any case the complicated procedure must depend upon a mutual and parallel adaptation of the insects and micro-organisms concerned.

During embryonal development the topographical distribution of the mycetocytes varies from one group of insects to another. In *Cam-*

ponotus they occur dorsally upon the mid-gut; in Blattidæ the bacteria are at first localised in the intestinal lumen, passing thence through the intestinal epithelium and entering the fat-cells. In Hemiptera and Pediculidæ the symbionts form a mass at the posterior pole of the germinal layer, and during version or unrolling of the embryo they penetrate in the ventral region of the abdomen.

As already indicated, the symbionts may be Yeasts, Saccharomycetes, Bacteria, or even Nitrobacteria. Their entrance into the cells and their presence therein even in large numbers does not in many cases prevent multiplication of the invaded cells or affect their mitosis; in other cases mitosis is more or less affected; it may become multipolar and lead to synsytium formation; and finally, cases may occur in which mitosis ceases and the symbiont-bearing cells divide amitotically.

We know little regarding the part played by symbionts in insects; our information relates almost exclusively to their morphology, mode of multiplication, and entry into the host during its development. There are no indications that the symbionts are injurious or pathogenic. It is evident, however, that they find in certain insects favourable conditions for growth, multiplication, and transmission from host to host. In these cases, therefore, we are dealing with a constant very harmonious association which excludes even a suspicion of there being any conflict between the associated organisms. We may well ask ourselves what are the reciprocal advantages of this association, but this is a question that it is impossible to answer in view of our ignorance of physiological and biochemical processes in insects.

Various hypotheses have been advanced to explain the possible function of the symbionts. Symbiotic yeasts may decompose urates (Šulç); they may produce an enzyme that aids in digestion of sugars, as in Aphids (Pierantoni): they may aid in digestion of cellulose in xylophagous insects which alone cannot render cellulose assimilable (Portier); the Nitrobacteria found in various Hemiptera may fix free nitrogen which is conveyed to them through the host's tracheæ, and thus supply the host with nitrogenous substances, thereby meeting a deficiency in its food supply.

Phytophagous Hemiptera nourish themselves chiefly upon leaf-sap without utilising the protoplasm of the plant-cells they penetrate with their sucking mouthparts. The imbibed sap is rich in mineral substances, carbohydrates and glycosides only. In these insects Peklo finds two different symbionts, Saccharomycetes and coccoid organisms, whilst Pierantoni attributes to symbionts the pigment production in *Coccus cacti*.

(3) *Micro-organisms in Relation to Luminescence in Animals.*

A fairly large number of organisms are known which have the faculty of emitting light. They are found among Bacteria, Fungi, Protozoa, Cœlenterates, Echinoderms, Worms, Molluscs, Crustacea, Insecta, Tunicata, and Fish. As a rule luminescence in animals depends upon the action of luciferase on luciferin, but recently a number of cases have become known wherein light production has been traced to micro-organisms, and it is with these cases that we shall deal.

Luminescent pathogenic bacteria may invade the host, as described by Giard and Billet (1889-90), for the small marine amphipod, *Talitrus*, of which rare light-emitting examples may be found in nature. The affected crustacean dies in about six days. The pathogenic bacterium does not luminesce in cultures, but does so when inoculated into *Talitrus*.

Luminescent symbiotic bacteria present in various light-emitting animals are, however, of direct interest to us, since their presence has been determined in luminescent organs of certain insects, cephalopods, tunicates, and fishes:

Insects: Pierantoni (1914) investigated the luminous organs of glow-worms (*Lampyrus*), and found them to consist of parenchyma cells crowded with minute bodies having bacteria-like staining reactions, these bodies being also present in the beetle's egg, which is luminous. He cultivated two species of micro-organisms from the organs, but does not distinctly establish their causal relationship.

Cephalopods: We owe to Pierantoni (1917-20) and Buchner the discovery that luminescence in certain Cephalopods is due to light-producing bacterial symbionts living in special organs of the host. These organs may be simple or otherwise. In *Loligo* the luminous organs, hitherto known as 'accessory nidamentary glands,' represent the simpler type of organ, this consisting merely of a collection of epithelial tubes surrounded by connective tissue. In cuttle-fish (*Sepiola* and *Rondeletia*) the organs are more complicated, the glands being backed by a reflector, and provided outwardly with a lens serving for the projection of the light rays generated by the symbionts within the tubes. The symbionts are transmitted hereditarily when the Cephalopods lay their eggs. The symbionts of *Loligo* and *Sepiola* have been cultivated by Pierantoni and Zirpolo (1917-20); they inhabit the gland-tubes of the luminescent organs in large numbers, and produce light continuously, as do other luminescent bacteria in cultures.

Tunicata: The Pyrosomidæ, all of which emit light and form tubular colonies, have long attracted the attention of biologists. Each individual in the colony possesses two fairly large luminescent organs, whose structure was studied by Panceri (1871-77), Kovalevsky (1875), and especially Julin (1909-12), who observed in the cells of the luminous organ riband-like structures appearing knotted here and there. Julin regarded the structures as mitochondria or chromidia, and it was left to Buchner (1914) to explain their true nature; they are symbiotic fungi, and are transmitted hereditarily. Buchner gives a detailed study of the symbiont and a review of the physiology of luminescence and of Pyrosomes which is well worth consulting by those interested in such problems.

Fish: Of great interest are the researches of Harvey (1922) upon light prduction by two species of fish (*Photoblepharon* and *Anomalops*) which occur in the sea about the Banda Islands, Moluccas. Their life-history is unknown. They measure up to about 11cm. in length. The author writes: 'In both fishes the luminous organ is a compact mass of white to cream-coloured tissue, flattened oval in shape, lying in a depression just under the eye and in front of the gills. The organ looks as if made for experimentation, as it is attached only at the dorso-anterior end, and can be cut out with the greatest ease, giving a piece of practically pure luminous tissue. The back of the organ is covered with a layer of black pigment, which serves to keep the light from shining into the tissues of the fish. In both fishes there is a mechanism for obscuring the light, but, curiously enough, the mechanism developed is totally different in the two species, notwithstanding the fact that in structure the organ is identical in the two, and in every detail except proportion the fishes are very similar. In *Anomalops* the organ is hinged at the antero-dorsal edge, and can be turned downward until the light surface comes in contact with a fold of black pigmented tissue, forming a sort of pocket. The light is thus cut off. In *Photoblepharon* a fold of black tissue has been developed on the ventral edge of the organ socket, which can be drawn up over the light surface like an eyelid, thus extinguishing the light.' The histological structure of this organ was worked out by Steche (1909). The organ is continuously luminous day and night, and independent of stimulation. According to Steche, *Anomalops* constantly turns the light on and off (10″ light, 5″ dark), the fish using it, he supposes, as a searchlight to attract and mislead its prey. The natives use the amputated organ as a bait in night fishing; it maintains its luminosity for about eight hours. The organ is described by Steche as composed of a great number of sets of parallel gland tubes (acinose), separated by connective tissue, and extending across the organ from the back pigmented surface to the front transparent surface, each set arranged in a ring about a vessel which provides them with blood and oxygen. Near the surface a number of these tubes unite into a common reservoir opening outward through a minute pore which admits sea-water. A number of pores dot the surface of the organ. The luminous material fills the lumen of the tubes; it is extracellular but intraglandular, and is never voided from the gland. Harvey states that the luminous material filling the tubes consists of an emulsion containing many granules and rods; the latter move about with a corkscrew-like motion, and are undoubtedly bacteria. The luminosity of the organ is due to these symbiotic bacteria. An emulsion containing the symbionts behaves exactly like an emulsion of luminous bacteria in being sensitive to lack oxygen, desiccation, bacteriolytic agents, potassium cyanide, &c. The continuity of the light, independently of stimulation, is characteristic of luminous bacteria and fungi alone among organisms; this, and the circumstance that luciferin and luciferase could not be demonstrated, all go to confirm the correctness of Harvey's conclusions regarding the cause of luminosity in these fish, notwithstanding that he has failed hitherto to cultivate the bacteria found in the luminous organs.

In concluding this section dealing with light production by animals it may be repeated that we have to distinguish between (*a*) luminescence due to symbiotic organisms, such luminescence being continuous in the presence of oxygen as in cultures of luminous bacteria (of which some thirty species are known), and (*b*) that due to animal cell-products known as luciferin and luciferase which are secreted and expelled *at intervals*, in response to a stimulus, from two kinds of gland cells, the secretions, when mixed, producing light.

Portier's Hypothesis.

The numerous cases in which symbiosis occurs in nature have naturally led some biologists to ask if symbiosis is not a phenomenon of general significance, and perhaps essential, in living organisms. In this connection reference must be made to the hypothesis advanced by Portier (1918), because it formulates extreme views. Starting from his studies of symbionts of leaf-mining caterpillars (*Nepticula*) and wood-devouring insect larvæ (*Cossus*, *Sesia*, &c.), he sought to verify the work of Galippe (1891-1918) on micro-organisms occurring in vertebrate tissues. Using methods he supposed to be adequate, Portier claimed that he could isolate various micro-organisms from vertebrate tissues. On faulty premises he built up an hypothesis that may be likened to a house of cards. He divides living organisms into two groups, *autotrophic* (bacteria only) and *heterotrophic* (all plants and animals), according as they are provided or not with symbionts. Whereas some symbionts are cultivatable, others have become so domesticated in respect to their hosts that they cannot be separated from them. The essential function of symbionts is to elaborate reserve substances so that they become assimilable to the host cell. The mitochondria that are present in all plant and animal cells, though not cultivatable, are, according to Portier, nothing but symbionts, the importance of their function having recently been revealed by Guillermond, Dubreuil, and others.[2] They are derived from food, and, if absent therefrom, illness supervenes, as shown by the bad effects of sterilised food, decorticated rice, &c., causing deficiency diseases attributed to lack of vitamines, which, according to Portier, are nothing but symbionts. Where, as in *Aphis*, the animal feeds on plant sap that is filtered through a tube formed by the insect's saliva—in other words, the insect imbibing food devoid of symbionts—the animal is of necessity provided with its own well-developed store of them. Portier applies his hypothesis to such varied problems as fecundation, parthenogenesis, tumor-formation, variation, and origin of species, in all of which mitochondria, that is, his supposed symbionts, play a part. His views aroused great controversy in France, so much so that it was thought necessary for the Société de Biologie de Paris (see C.R. Soc. Biol. LXXXIII., 654, May 8, 1920) to have a Committee examine the evidence. The Committee, consisting on the one part of Portier and Bierry, and on the other of Martin and Marchoux (Institut Pasteur), by its report indicates the pitfalls, well known to bacteriologists, into which Portier was led, and thus disposes of the greater part of his far-reaching hypothesis. Nevertheless, like many exploded hypotheses, that of Portier has served a useful purpose through the discussion it has provoked and the interest in the subject of symbiosis which it has stimulated.

[2] Guillermond has shown that the mitochondria of the epidermal cells in *Iris* elaborates amyloplast and finally starch. Dubreuil (1913) found that mitochondria elaborate the fat in fat-cells. Other cytologists have shown that glandular secretions are similarly referable to mitochondria.

Conclusion.

The term 'symbiosis' denotes a condition of conjoint life existing between different organisms that in a varying degree are benefited by the partnership. The term 'symbiont,' strictly speaking, applies equally to the partners; it has, however, come to be used also in a restricted sense as meaning the microscopic member or members of the partnership in contradistinction to the physically larger partners which are conveniently termed the 'hosts' in conformity with parasitological usage.

The condition of life defined as symbiosis may be regarded as balancing between two extremes—complete immunity and deadly infective disease. A condition of perfect symbiosis or balance is realised with comparative rarity because of the many difficulties of its establishment in organisms that are either capable of living independently or are incapable of resisting the invasion of organisms imperfectly adapted to communal life. In these respects the conclusions of Bernard and Magrou in relation to plants apply equally to animals. It is difficult to imagine that symbiosis originated otherwise than through a preliminary stage of parasitism on the part of one or other of the associated organisms, the conflict between them in the course of time ending in mutual adaptation. It is, indeed, probable that some supposed symbionts may prove to be parasites on further investigation.

In perfect symbiosis the associated organisms are completely adapted to a life in common. In parasitism the degree of adaptation varies greatly; it may approach symbiotic conditions on the one hand, or range to vanishing point on the other by leading to the death of the organism that is invaded by a highly pathogenic animal or vegetable disease agent. There is no definite boundary between symbiosis and parasitism. The factors governing immunity from symbionts or parasites are essentially the same.

No final conclusions can as yet be reached regarding the function of symbionts in many invertebrate animals owing to our ignorance of the physiological processes in the associated organisms. The investigation of these problems is one fraught with difficulties which we must hope will be surmounted.

New knowledge is continually being acquired, and a glance into new and even recent publications shows that symbionts have been repeatedly seen and interpreted as mitochondria or chromidia. Thus in *Aphis* the long-known pseudovitellus has been shown to contain symbiotic yeasts by Pierantoni and Šulc, independently and almost simultaneously (1910); Buchner (1914) has demonstrated symbiotic luminiscent fungi in the previously well-studied pyrosomes, besides identifying (1921) as bacterial symbionts the mitochondria found by Strindberg (1913) in his work on the embryology of ants. The increasing number of infective diseases of animals and plants, moreover, which have been traced, especially of recent years, to apparently ultramicroscopic organisms cannot but suggest that there may exist ultramicroscopic symbionts.

From the foregoing summary of what is known to-day of symbiosis we see that it is by no means so rare a phenomenon as was formerly supposed. Symbiosis occurs frequently among animals and plants, the symbionts (Algæ, Fungi, Bacteria) becoming in some cases permanent intracellular inhabitants of their hosts, and at times being transmitted from host to host hereditarily. Among parasites, non-pathogenic and pathogenic, we know of cases wherein hereditary transmission occurs from host to host.

It is evident that we are on the threshold of further discoveries, and that a wide field of fruitful research is open to those who enter upon it. In closing, it seems but fitting to express the hope that British workers may take a more active part in the elucidation of the interesting biological problems that lie before us in the study of symbiosis and the allied subject of parasitism.

Acknowledgment.—I have pleasure in expressing my thanks to my colleague, Mr. David Keilin, for the very valuable aid he has given me in the preparation of this address.

THE MENTAL DIFFERENCES BETWEEN INDIVIDUALS.

ADDRESS TO SECTION J (PSYCHOLOGY) BY

Dr. CYRIL BURT, M.A.,

PRESIDENT OF THE SECTION.

THE most remarkable advances made by psychology during recent years consist in the rapid development of what threatens to become a new and separate branch of science, the study of individual differences in mind. Down to the close of the nineteenth century psychologists were all pure psychologists. They confined themselves, with an air of chaste aloofness, to the discussion of mind in general; they wrote and experimented solely on the abstract functions of consciousness as such. The varying eccentricities of minds in the concrete, how one man's consciousness might be unlike another's, were problems beneath their interest or beyond their ken. If, in some laboratory research, different persons gave dissimilar results, either in the sharpness of their senses or the speed of their reactions, the divergencies were treated as no more than unavoidable disturbances of measurement, vexatious errors to be eliminated by the method of averaging, not facts of special value to be examined in and for themselves. For the rest, the chief method of the psychologist was still introspection; and his chief subject, himself. Accordingly, although in this way he laid the necessary foundations of a sound terminology and a safe technique, he nevertheless exposed himself to the taunts of his literary colleagues, who knew that it takes all sorts to make a world. 'Les philosophes' (laughs an early and unorthodox observer) 'sont toujours trop occupés d'eux-mêmes pour avoir le loisir de pénétrer ou de discerner les autres.' [1]

Of late, however, a body of workers has arisen who have turned their attention more especially to the peculiarities of particular minds. The variations have attracted them more than the averages; and the mental disparities between childhood and age, between race and race, between one sex and the other, and between each unique individual and the rest, have formed their chosen topic. As a result of their labours, there has grown up, step by step, a vast and miscellaneous accumulation of data which urgently demands to be sifted and systematised. The practical needs of applied psychology, in each of its fresh spheres—the psychology of war, of education, of industry, of mental disorder, deficiency and crime—all depend for their solution upon a sound doctrine of individual differences; and their study in its turn has already contributed much welcome information to the parent science. I propose, within

[1] La Bruyère, *Les Caractères* (1687).

the limits of the time allowed me, to attempt a summary of the chief problems and principles of this new branch; and, as methodically and as completely as is possible within so narrow a compass, to plot out the ground explored by recent work.

Though the scientific study of individual minds is new, the popular interest in the practical issues has a long and venerable record; the ancient title of 'psychology' is by comparison a word of yesterday.[2] Time after time in the history of knowledge, the quack who has pandered to a public want proves to have been the primitive precursor, the earliest *avant-coureur*, of what afterwards arrives as a respected and respectable science. Astrology was the forerunner of astronomy, alchemy of chemistry, and the lore of the bone-setter and the herbalist of modern surgery and medicine. In the same way the charlatan who reads your character from the lines on your hand or the bumps on your skull is carrying on an antique tradition which embodies the first attempts at a psychology of individuals. He has seen the problem; he has met the demand; and, if his wares are sham and shoddy, he has at least thrown down a challenge to the slower and more scrupulous disciple of truth.

The blunders of pseudo-science, however, are never wholly uninstructive. Those who first practised *l'art de connaître les hommes*—the physiognomists, the phrenologists, the palmists, and their successors—were all, in their crude and curious speculations, mainly guided, and mostly misled, by three fallacious assumptions. They looked for nothing but permanent and external signs; they assumed nothing but constant connections between the outward and visible symptom and the inward and invisible state of mind; and they classified both physical symptoms and mental qualities into arbitrary and discrete types. Thus, your nose was either pointed or not pointed; and your temperament was either choleric or not choleric. If your nose was sharp, then your temper must be sharp as well: for *nasus acutus irascibiles notat*. No graduations were recognised; no exceptions admitted. The correspondence was made perfect and invariable. Indeed, if the classes were not clear-cut, if the symptoms were not patent to superficial inspection, and if the connections between the two were not absolute and uniform, how could there be any inference, any prediction, any science of whatever sort? The soul, surely, must be a riddle which could never be read.

The difficulty was solved by the discovery of a new technique. And this we owe to an original English thinker of the latter half of the nineteenth century, Sir Francis Galton. To the general public, Galton is best known by his demonstration of the hereditary factors in individual genius—a doctrine that in his own person he so remarkably exemplified.

[2] I suppose the earliest written recognition of the power of judging the quality of the mind from observable characteristics is to be found in the words of Nestor to the unknown Telemachus: 'By certain signs that I discern upon thy face, illustrious youth, I recognise what man thou art. Thy countenance is proud and generous, thine eloquence great, and thy reasoning recalls to me thy father. What manner of youth could such a one as thou be, were he not the offspring of the great Ulysses?' Homer, *Odyssey*, xi., 693. Those who care to trace the historical development of individual psychology will find most of the necessary materials and references collected in Mantegazza's *Physiognomy and Expression* (1904) and Stern's *Differentielle Psychologie* (1911).

But his most fruitful contribution lay in the development of two technical methods of inquiry, the statistical method of correlation, and the experimental method of psychological tests. These in turn rest upon a fundamental assumption, which recent work has verified—*the continuity of mental variation*. Here stands the keystone of individual psychology as a science. The differences between one man and another are always (we shall find) a matter of 'more or less'—seldom, if ever, a question of presence or absence, of 'all or none.'

'Virtuous and vicious ev'ry man must be,
Few in th' extreme, but all in a degree.'[3]

There are, in fact, no such things as mental types; there are only mental tendencies. And it becomes the main task of individual psychology, first, to catalogue and classify all the tendencies to be surveyed, and then to devise a method for the quantitative assessment of each.

It follows from this initial postulate that the mind of every individual has the same underlying structure. Men's minds are like their faces. Each seems at first unique. But patient analysis shows that the real component features are in every one the same. All have two eyes, two ears, a mouth, a forehead, and a nose. But the length, the width, and the prominence of each part may differ infinitely from man to man. Our business is thus to calculate the extent to which each known potentiality has been developed or contracted, much as a surveyor marks down, at given stations upon his map, the eminences and depressions of the land.

The Psychographic Scheme.

Since the mental ground-plan is in all persons approximately the same, the same inventory of mental tendencies will serve, no matter which particular person we are about to analyse. An identical set of questions may be asked about each. An identical series of headings will recur in our reports. Were our psychological catalogue exhaustive and complete, it would, in theory, be necessary only to measure in succession each particular capacity; and so obtain a clear and quantitative specification of the idiosyncrasy of each individual.

This view is more than a mere dogmatic postulate. It is confirmed by a close comparison of the literature in different psychological fields. It will be discovered that, whatever the nature of the case to be examined—mental deficiency or supernormal talent, educational backwardness or vocational misfit, neurotic disorder or propensity to crime—practical experience has forced each examining psychologist to work out very much the same main heads of inquiry as his colleagues in other lines. Such a working schedule of mental characteristics may be termed a 'psychographic scheme.' The scheme that I shall follow here will be one which I have found reappearing as a basis for my note-taking in investigating individuals in each of the foregoing groups. In its broadest outlines every personal examination should pursue two chief directions: first, a *retrospective* inquiry into the past history of the person studied; and, secondly, what I may call a *conspective*

[3] Pope, *Essay on Man*, 231.

survey of his mental condition at the present time. Viewing his whole life's story as a growing tree with ramifying roots and boughs, we take, as it were, first, a longitudinal section, and then one or more cross-sections, of the main trunk.

I. *Case-History.*

The historical retrospect should embrace, first of all, a *personal history*, based upon reports supplied by parents, teachers, and medical attendants, and reviewing such developmental features as conditions of birth, mental and bodily growth, past physical ailments, and early mental shocks and disorders, and general moral and intellectual progress both at home and at school.

The procedure of the modern psycho-analyst consists in little more than the taking of an elaborate mental case-history by means of a special technique. The discovery of early repressions and infantile complexes often sheds a bright flood of light upon the present mental make-up of an adult person. Think, for example, what numerous characteristics may be explained when it is reported that a neurotic bachelor of thirty was the only son of his mother, and that she was a widow. Mill, who in this country was the first to raise the science of character to a level of philosophical respectability, regarded 'ethology,' as he named it, as consisting principally in the deduction of present mental features from past encircling influences.

But the inquiring psychologist must go further back still. He must pass behind birth to ancestry; and to the personal history of his subject prefix an account (where he can get it) of the *family history*. Here he obeys the lead of Galton rather than the logic of Mill; and is seeking, by a study of pedigrees, to infer the presence of hereditary factors. Of these the ultimate significance will be presently apparent.

II. *Personal Examination.*

What I have termed taking a cross-section must include an examination of the person's present condition by the two chief instruments of all scientific inquiry—namely, observation and experiment. By whichever method they are reached the facts established will be brought together synoptically under a convenient system of tabulated heads. These headings will embrace external conditions as well as internal, and physical conditions as well as mental.

A. *Environment.*

The psychologist must never be content to look at nothing but the mind before him. It is his task to extend his survey to the surrounding influences that are making that mind what it is; he must ascertain the current situations and the crucial problems which that mind is called upon to meet. To study a mind without knowing its *milieu* is to study fishes without seeing water.

Accordingly, as he turns from the past to the present, the human naturalist will commence with a review of the person's present environment, of his material, physical, and moral circumstances, at home, at school, and at business. Recent research upon milder abnormal states

—particularly delinquency and neurosis—has shown very clearly that none of these is due exclusively to inborn constitution, nor yet entirely to shocks and mental traumata in the remote or immediate past; they spring largely out of contemporaneous conditions and conflicts. Even with the normal individual, simply to learn in what social class he moves, or in what city or street he lives, is to divine very plausibly the chief of his guiding habits and ideas—his code, his creed, and his customs. Strange persons are like strange words: their intentions are best guessed from their context. One incidental item of practical import rises to the surface in most of these investigations. Of all external factors home influences are paramount; moral influences are far more powerful than material, emotional than intellectual. Without a knowledge of the emotional attitudes elicited in a person by the attitude of his parents, of his various relatives, and of others in daily contact with him, his standpoint towards life can never be properly envisaged or explained.

B. *Personality.*

1.—*Physical Condition.*

Turning from the environment to the personality proper, from the setting to the gem, it is essential to glance first at physical conditions before we pass to psychological; to see what is reflected on the surface before we hold the centre to the light. That a man's body has a profound influence upon his mind has been realised in every age. But we are only just beginning to discover in definite detail how certain physical states and certain physical disorders are attended by certain psychical effects.

Once more it is in pathology—where more or less morbid conditions of body produce more or less morbid conditions of mind—that the most convincing instances are to be seen. At present, it is true, the tendency in the newer schools of psychology is to trace mental derangements, particularly in their milder forms, almost exclusively to mental origins. But those who deal daily with young children, where the causal factors can be more readily unravelled, find it impossible to overlook the co-operation of such purely physical conditions as rheumatism, chronic catarrh, nasal obstruction in numerous forms, minor lesions of the brain, or the absorption of toxines from internal foci or superficial sores.

The study of juvenile delinquency shows, in most unexpected directions, the influence of physique upon character. Anything that weakens physical health tends to weaken self-control. Anything that conduces to physical irritation tends to set up a mood of mental irritability. A holiday in the country is sometimes the best cure for crime. With the intellectually subnormal the efficacy of simple physical remedies is quite as striking as with those who are subnormal in character or temperament. The provision of spectacles, the extraction of teeth, the extirpation of tonsils and adenoid-growths, measures in themselves comparatively trifling, have often converted an alleged mental defective into a normal or nearly normal child.

Of all the physical influences studied in recent years the most striking is that of the ductless glands.[4] Every layman knows that thyroid insufficiency produces a cretinous type of mental defect, and that such defect may be cured or alleviated by the administration of glandular extracts. And just as thyroid insufficiency depresses, so thyroid excess may heighten, emotional states and reactions. Of other glands belonging to this class—the pituitary, the adrenal, and the sex glands—we know far less. But recent work upon their internal secretions has left no doubt as to their power over temperament and feelings. Shall we some day, when biochemistry is sufficiently advanced, be able to analyse the minute components of lymph and blood, and diagnose from the chemical constitution of small samples whether a man is oversexed, or easily fatigued, timorous, excitable, or blessed with high vitality?

The work upon these endocrine organs seems destined at length to provide a scientific basis for the doctrine of physical signs—the tradition so dear to the popular mind-readers of every place and time. The physical signs recommended for inspection are of two kinds: they refer either to the physique as a whole, or more specifically to the face or head.

The ductless glands are closely connected with body metabolism as a whole. We seem here to find an unexpected confirmation of the popular division of 'temperaments' or 'constitutions' into two or three chief types. The loose terms in vogue are, for the two extremes, 'nutritional' or 'vital,' and 'nervous' or 'mental'; and, for the intermediate, 'motive,' 'muscular,' or 'mixed.'[5] Three American physiologists—Bryant, Goldthwait, and Dunham—whose observations on this point are more careful than most, quaintly term the triad 'herbivorous,' 'carnivorous,' and 'omnivorous' respectively, thus claiming a somewhat speculative biological derivation for the supposed differences in digestion, metabolism, and general manner of life.[6] Three Italian physiologists, Viola, Naccarati, and De Giovanni, term the two extremes—the Hamlets and the Falstaffs of the psychological caste—microsplanchnic and macrosplanchnic respectively, or (in language less technical but more Shakespearean) little-bellied and big-bellied. By means of careful statistical correlations they have tried to prove that the ratio of height to weight, or better of limbs to trunk, may be taken as a trustworthy index of the so-called 'morphological type,' and is

[4] It is unfortunate for the general reader that the only systematic and non-technical account of the subject is the somewhat uncritical book by Dr. Berman on *The Glands Regulating Personality*, a work as full of ingenious speculations as it is devoid of documented references.

[5] This threefold division is found in most phrenological handbooks. Of these the least unscientific is Dr. Bernard Hollander's *Scientific Phrenology* (a title which is something of a *contradictio in adjectivo*); see pp. 38-48). The distinction, in its modern form, seems to have originated with Dr. Alexander Walker, a Lecturer on Anatomy at Edinburgh University, and contemporary of the English phrenologist Combe. It will be observed that the dichotomy is apparently a simplification of the fourfold classification of temperaments, originating with Galen (A.D. 130).

[6] For a convenient summary of the American literature see Lewis, 'Adolescent Physical Types.' *Ped. Sem.*, 1916, xxiii., 3.

demonstrably associated with tested mental differences.[7] Fat and lean is an antithesis as old as the legend of Jack Spratt and his wife; and modern physiology, it will be noted, agrees with the ancient rhyme in referring the difference largely to dietetic habits, and in connecting it in part with a difference in sex and the sex-glands. As to the concomitant psychical differences, fancies on this subject (if Plutarch is to be trusted) were entertained by so eminent a master of men as Julius Cæsar.[8] 'Your fat, sleek-headed men,' he is made to exclaim, 'I never reck of; they sleep o' nights. But these pale-visaged carrion, with the lean and hungry look, they think too much: such men are dangerous.' That the new observers have confirmed the old is more than I venture to assert. But at least they have applied the proper method to the problem.

Of their somewhat singular conclusions the real import lies in this: they emphasise, and justly emphasise, the supreme importance, for right psychological diagnosis, of viewing body and mind as a single unitary organism. A man is something more than a carcass loosely coupled with a ghost. Material and spiritual are reciprocally involved; and the two together are to be treated as inseparable aspects of one highly complex whole. Thus, in both physical and mental working, the restless, unreliable, 'carnivorous' type may be likened to a high-compression engine, capable of short but forcible output of energy, yet unsuited for long and steady running; the plodding, sedentary, 'herbivorous' type, to a low-compression engine, with a lower maximum efficiency, but a more continuous level of sustained activity. And in each the mental and physical symptoms are joint products of one fundamental mechanism. It will be remarked in passing that, alike in mind and body, the former—the slender 'microsplanchnic' type—is suggestive of hyperthyroidism, and of the tall, long-headed, active races; while the latter—the heavy 'macrosplanchnic' type—is similarly suggestive of hypothyroidism, and of the short, round-headed, stolid race.

Possibly the same twofold hypothesis—of racial stock and glandular influences—may be adduced to explain what little correlations the phrenologist[9] can claim between mental characteristics and the conformation of skull and face. The appearance of cranial types is certainly suggestive of what is known of racial stocks. The doctrine of stigmata of degeneration also finds a partial explanation in the double effects of disturbances in the ductless glands, impairing simultaneously the normal development of both skeleton and intelligence. Low, narrow, and bossed foreheads, broad, depressed, and upturned noses, narrow, high, and V-shaped palates, lobeless, projecting, and malformed ears, asymmetrical, misshapen, and small skulls—these

[7] See Naccarati, 'The Morphological Aspect of Intelligence,' *Arch. Psych.*, No. 45, 1921. The coefficients are low, .35 or less.

[8] The remark is freely paraphrased by Shakespeare, *Julius Cæsar*, I., ii., 191.

[9] Psychologists will be astonished to hear that in spite of all the recent work on intelligence-tests, one British Education Authority recently preferred to invite a practising phrenologist to assist in the examination of candidates for junior county scholarships. How many school medical officers still rely, in diagnosing mental deficiency, more upon stigmata than tests?

anatomical disfigurements were, until recently, the chief signs relied upon in the diagnosis of mental defect. They are best seen in the rarer clinical types of imbecility, in the mongol and the cretin, who, as already remarked, seem to suffer primarily from a deficiency of endocrine secretions.[10]

So far, it may be thought, bodily indications are of value only in cases of extreme pathological deviation—the obese, the emaciated, and the physically deformed; they are symptoms for the doctor, not signs for the plain man. Is there, then—

'. . . no art
To find the mind's construction in the face'? [11]

And, if not, why do so many men and women of the world claim to divine character at a glance, and profess, on the basis of a first impression and a short superficial inspection, to gauge intelligence and temperament, even among their normal fellow-creatures, with much the same exactitude which is conceded to the dog-fancier, the sheep-dealer, and the fellow with an eye for horseflesh in their somewhat lowlier spheres? That their intuitions (as they term them) often correlate highly with independent and trustworthy estimates has been shown statistically time after time. Upon what do they rely? Is there a sort of moral clairvoyance confined only to a gifted few? Or is the miracle of insight into another, a knack that each can achieve? In part these judges of men are aided, more than they themselves suspect, by semi-social criteria—accent, phraseology, manners, the elegance of handwriting, and the tidiness of clothes. Stevenson, you will remember, has declared that 'an undoubted power of diagnosis rests with the practised Umbrella-philosopher; for, whereas a face is given us ready-made, each umbrella is selected from a shopful as being most consonant with the purchaser's disposition.' [12] And other interviewers, besides Sherlock Holmes, draw unpalatable inferences from our taste in hats, and socks, and coloured ties. For the rest, so far as their procedure is unprejudiced by pseudo-scientific reading, it seems to depend chiefly upon inferences, conscious or unconscious, not so much from bodily structure or build, as from bodily posture and movement, particularly the finer movements of the hand, of the eye, of the lips and mouth, and of the vocal organs in speech. And the principle is sound. If you are buying anything that works you ask first to see it working, be it only for a second, and only as a sample. So with the connoisseur of human creatures, it is function rather than framework that should count. In the face, it is not the hard, immutable gristle and bone, but the soft and mobile mask of muscle that the sound

[10] Many of the so-called stigmata, however, together with the mental dulness they are supposed to signify, are largely attributable to petty ailments of early childhood—rickets, chronic respiratory catarrh, and nasal obstruction from adenoid growths.

[11] *Macbeth*, I., iv., 12.

[12] *College Papers*, iv., 'The Philosophy of Umbrellas.' As to handwriting, those who smile at the claims of the graphologist may be reminded that Binet, and many experimentalists and pathologists since, have not scorned to look for indications of character and mental derangement in the size, and shape, and steadiness of the letters we trace with the pen.

physiognomist observes. The neuro-muscular tonus—the tightness around the eyelids, the firmness of the lips—is an index of the general state of health and vitality upon which a man's intelligence and attention so much depend. The changes of look and glance afford a clue, however indirect, to the range, the liveliness, and even the character of his interests. Above all, it is to be remembered, almost every human emotion has its instinctive facial expression, to which, by a sort of primitive sympathy, we ourselves as instinctively respond. The emotions (we shall see) are the foundations of character. And the emotional mood that predominates in a given person's life tends, by the simple law of habit, to leave its natural expression stamped upon the countenance, contracting almost permanently the underlying muscles, and deepening the furrows and the finer lines upon the skin. Thus the bad-tempered bully comes to wear always a more or less angry scowl, and the anxious melancholic a worried look upon the brow.[13]

'In many's look the false heart's history
Is writ, in moods, and frowns, and wrinkles strange.'[14]

In the main, however, the gist of recent scientific work on connections between body and mind has been, from a practical though not from a theoretical standpoint, negative. Theories, such as that of Lombroso and his school—the notion of criminal, defective, neurotic, and supernormal types, each marked off from ordinary mankind by a specific combination of physical and mental traits—have been exploded by more careful statistical methods. The measurable correlations, though frequently positive, are almost always too slight to be trusted for the needs of diagnosis.[15] Thus a man's exterior is sometimes suggestive, but never conclusive. And so we reach the safe and central maxim of individual psychology of to-day: *Judge mental functions by mental symptoms, not by physical.* The worldly moralist agrees. 'Il ne faut pas juger des hommes comme d'un tableau ou d'une vache; il y a un intérieur et un cœur qu'il faut toujours approfondir.'[16]

2.—*Mental Condition.*

I proceed now to what consequently becomes the essential duty of the practical psychologist—the direct examination of the mental state.

The positive foundations for a practical psychology of individual differences have been laid in three broad generalisations, each the separate suggestion of recent experimental work. They consist in a trio of important distinctions, the distinction between intellectual and emotional characteristics, between inborn and acquired mental

[13] These deductions can be verified by the method of correlation, see *Child Study*, June 1919, 'Facial Expression as an Index of Mentality'; also Langfeld, 'Judgments of Emotions from Facial Expression,' *J. Abn. Psych.*, xiii., 172, and *Psych. Rev.*, xxv., 488. The general principle underlying 'whatever truth the so-called science of physiognomy may contain' is stated, as in the text, by Darwin, *Expression of Emotions in Man and Animals*, p. 388.

[14] Shakespeare, *Sonnets*, xciii.

[15] The labours of Karl Pearson and his students, following the methods of Galton, have been invaluable in this field. Goring's study of *The English Convict* is a model for inquiries upon these and kindred problems.

[16] La Rochefoucauld, *Maximes Morales*, cccxvii.

tendencies, and between special and general capacities. Upon these three distinctions the essential portion of my 'psychographic scheme' is based. The evidence for them, as yet presumptive rather than complete, I can but briefly touch upon in the appropriate place.

a.—*Intellectual Characteristics.*

With these distinctions, then, to mark our working rubrics, we begin by viewing any particular mind, that comes for valuation, as presenting two distinguishable aspects, the intellectual on the one side, and the emotional on the other. The divorce of νοῦς from θυμὸς is as old as Pythagoras.

'Two principles in human nature reign;
Passion to urge, and reason to restrain.'

The modern antithesis is something more than a convenient revival of the traditional contrast. It has a basis in recent statistical work.[17] If a large group of individuals be ranked in order for all the psychological characteristics that can be conceived, or at least conveniently estimated, and if the correlations between the several rankings, each with each, be then computed, two striking facts are instantly perceived. First, nearly all the correlations are positive; excellence in one respect tends, on the average and in the long run, to go hand in hand with excellence in every other. But, secondly, the closeness of this correspondence varies suggestively in different directions. Intellectual qualities are correlated fairly highly amongst themselves. Emotional qualities (so far as the more meagre evidence at present shows) are likewise correlated to nearly the same considerable degree. But the correlations between intellectual qualities on the one hand and emotional on the other, though still as a rule positive, are by comparison conspicuously low. We are warranted, therefore, in assuming that these two aspects are relatively independent, and in studying them separately and in succession.

i. *Inborn Abilities.*

We proceed then to estimate, in the first place, the examinee's qualities of intellect. And here our second subdivision introduces itself—the distinction between what is inborn and what is acquired. Many independent researches agree in showing that intellectual characteristics are hereditary, and that to much the same extent as physical. Even if a capacity (or, more strictly, the strength of a capacity) be not hereditary, it may still be congenitally determined. What is inherited is necessarily inborn; but what is inborn is not necessarily inherited. In the latter case, however, to separate endowment from acquirement, mental capital from mental earnings, is a more precarious task. The discrimination, wherever it is possible, is of the greatest practical moment. If a child, for example, proves to be exceedingly backward in school work it is essential to decide whether this backwardness is a legacy from backward ancestors, or merely an

[17] See, amongst other studies, Webb, 'Character and Intelligence,' *Brit. J. Psych. Mon.*, I.

accidental consequence of conditions subsequent to birth. In the former case the backwardness, being inherent, is therefore incurable; in the latter, there remains at least a hope that, by amending the unfavourable circumstances, the backwardness may be partly remedied or even wholly removed.

α. General Intelligence.

We have now narrowed our scope for the moment to qualities that are intellectual and at the same time inborn; at this point we may apply our third and last distinction. Inborn intellectual abilities are divisible, first, into a single central capacity, pervading all that we say or think or do; and, secondly, into a series of specific abilities, each entering only into processes of a more or less limited kind.

For the existence of general inborn intellectual ability (known briefly as 'intelligence') the statistical evidence is now pretty decisive. Even the critics of this so-called central factor no longer deny that, at least as a matter of mathematical interpretation, the empirical data may be formulated in these terms; and that this formulation, whatever its ultimate psychological explanation, is of the greatest value in practice, and, as a working hypothesis, works very well.

If further proof were demanded, the indubitable success of intelligence-testing has supplied a widespread verification, sufficiently business-like to convince the plain man. Indeed, over the whole realm of mental science the outstanding feat of recent years has been the application and the multiplication of innumerable tests for measuring general ability. As everybody knows, during the War the intelligence of nearly two million recruits was tested by these means for the Army of the United States. And this spectacular achievement has probably bestowed on the practical applications of psychological methods a stronger impetus than any other single piece of work.

Since intelligence, as we have defined it,[18] is an inborn quantity, the amount possessed by a given individual should, in theory, remain constant through all the years of his life. It should thus be possible to predict, from quite an early age, what will be the probable intellectual level of a child when he is grown up. Within reasonable limits such forecasts can, in fact, be made. Numerous investigations have shown that what is called the 'mental ratio'—the proportion, that is, between a child's mental age and his chronological age—tends to keep tolerably uniform throughout the years of growth. Hence it is safe to prophesy that a child (for example), aged five by the calendar, with a mental age of two (and a mental ratio, therefore, of $\frac{2}{5}=40$ per cent.), will probably attain a mental age of four at the age of ten, and a mental

[18] The reader will understand that intelligence in this sense is not to be conceived as a concrete organ, entity, or power, but a purely abstract potentiality—like electrical energy or heat as conceived by the physicist—an entirely hypothetical quantity, postulated and defined, like most other scientific concepts, for the convenience of separate measurement. It is to be distinguished from manifested intelligence (the materialisation, as it were, of that abstract potentiality), which develops during childhood and decays with loss of health or advance of age, and is measurable in terms of mental years or of some more concrete unit.

age of six at the age of fifteen. Since beyond the stage of puberty inborn intelligence does not develop to an appreciable extent (another startling paradox of psychological testing), such a person will never rise above the six-year level, and will remain mentally defective for the rest of his life.

From the numerous results obtained from the widespread employment of intelligence-scales, one fact of deep social significance emerges—the vast range of innate individual differences. A famous clause in the American Declaration of Independence proclaims that 'all men are created equal.' In the psychological sense as distinct from the political, not only are men created unequal, but the extent of the inequality surpasses anything before conjectured. In a survey carried out upon all the children in a representative London borough—a census covering more than 30,000 cases—it was found that, within the elementary schools, the mental ratios might vary from below 50 per cent. to above 150 per cent.; that is to say, the brightest child at the age of ten had the mental level of an average child of fifteen, while the dullest had the mental level of a little child of only five.[19]

Over this vast scale the distribution of intelligence is neither flat nor yet irregular; it follows a simple mathematical law. Its frequency conforms to the so-called 'normal curve,' and the abnormal and defective are found to constitute no isolated types, but to be simply the tail-end of a chance distribution. Probably all or most of our mental capacities are distributed in the same fashion. This fact, if it be a fact, greatly simplifies the problem of mental measurement. It should be a recognised maxim of procedure to measure people, not by arbitrary marks between a conventional zero and an equally conventional maximum, but by the degree of divergence above or below the average or middle line (much as we measure the depth of the ocean or the altitude of the hills from the intervening sea-level), the divergence being calculated in terms of the standard deviation. This is a technical hint of special value in estimating qualities that lend themselves to no obvious quantitative units like mental ages or additive marks.

Since variations in intelligence are so wide and so continuous, it becomes convenient to divide the entire population into about six or eight separate classes or layers. A classification of this kind, worked out empirically, for children, is already implicitly embodied in the organisation of our various schools. A second classification can be drawn up, on an analogous basis, for adults, and will be found, in the main, to reflect the amount of difficulty and responsibility entailed by their several occupations. It is interesting to find that the proportionate number of individuals falling into the parallel sections tallies pretty closely both for adults and for children (see Table I).[20] Here, therefore, lies a simple aim alike for educational administration and for

[19] *The Distribution and Relations of Educational Abilities* (London County Council Reports, 1917). *Mental and Scholastic Tests* (London County Council Reports, 1922).

[20] Compiled partly from data published in the L.C.C. Reports (*loc. cit. sup.*), and partly from a table recently included in a paper on *The Principles of Vocational Guidance* (VIIth Int. Congr. Psych., 1923). The figures and categories given in the present table are round approximations only.

TABLE.

Distribution of Intelligence among Children and Adults.

Level of intelligence (in mental ratio)	Educational category or school	Number of children (in percentages)	Vocational category	Number of male adults (in percentages)
1. over 150 . . .	Scholarships (university honours)	0·2	Highest professional work	0·1
2. 130–150 . . .	Scholarships (secondary)	2·5	Lower professional work	3
3. 115–130 . . .	Central or higher elementary	13	Clerical, technical, and highly skilled work	12
4. 100–115 . . .	Ordinary elementary	35	Skilled work. Most minor commercial positions	27
5. 85–100 . . .	Ordinary elementary	35	Semi-skilled mechanical work. Poorest commercial positions	36
6. 70–85 . . .	Dull and backward classes	13	Unskilled labour and coarse manual work	18
7. 50–70 . . .	Special schools for the mentally defective	1·5	Casual labour	4
8. under 50 . .	Occupation-centres for the ineducable	0·2	Institutional cases (imbeciles and idiots)	0·2

vocational guidance. It is the duty of the community, first, to ascertain what is the mental level of each individual child; then, to give him the education most appropriate to his level; and, lastly, before it leaves him, to guide him into the career for which his measure of intelligence has marked him out.

Of this programme, the educational part is already in execution. For the lowest section, the mentally deficient, we have begun to provide special schools and residential homes; and, thanks to the advances of individual psychology, the means of diagnosis are now exact and just. There is a similar but newer movement towards the institution of special classes for the dull and backward. It is from this larger horde of moderate dullards, not from the tiny sprinkling of the definitely defective, that the bulk of our inefficient adults—criminals, paupers, mendicants, and the great army of the unemployable—are ultimately derived. Nor will it do to confine official assistance solely to the inferior groups. The supernormal should also enjoy a special measure of care and treatment. Much is done for them by awarding free places at central and secondary schools. But both the methods for detecting them and the opportunities for educating them still admit of much improvement. Already in several foreign countries schools have been established for *Begabte Kinder.* In Berlin, the brightest children from the whole of the city are selected by means of psychological tests, and brought together at an early age to a special centre for individual supervision and training.

The determination of intelligence is equally indispensable for proper vocational guidance. Respecting intelligence, indeed, vocational psychologists seem unanimous that, as it is the easiest, so also it is the first and foremost factor to be tested. The worst misfits arise, not from forcing round pegs into square holes, but from placing large pegs in little holes, and small pegs in holes too big for them to fill. We have already seen that different occupational groups have different intellectual levels. For nearly every type of employment there exists a certain minimum of intelligence, below which a man is pretty sure to fail. For many, if not most, there is also, in all probability, an optimal upper limit. Just as some men are too dull for their jobs, so others are too clever. Hence, in the interests of the employer and of the employment, as well as of the employee and the general community, it is a blunder always to pick the brightest candidate who applies for a given job.

In this country, for the purposes of vocational selection, the most extensive application of intelligence-testing has been the introduction of a psychological 'group-test' into recent Civil Service examinations. The papers, comprising five or six graded speed-tests of well-known types, have been drawn up, after experimentation, by professional psychologists. Some 40,000 candidates have been tested in this way. And the calculated correlations demonstrate that the results of the new methods agree, both with the total marks from the whole examination and with subsequent reports on office-efficiency received from Government departments, more closely than any other single paper set.

Incidentally, the extensive data so secured ratify conclusions reached in other countries and by different means—namely, that the range of intelligence among adults is quite as wide as that observed among children, that the average level of inborn intelligence among adults aged twenty to fifty is but little above that of children of fourteen, and that the distribution of intelligence, among adults as among children, approaches pretty closely to the so-called ' normal curve.' (See fig. 1, which shows the distribution of marks in the intelligence-tests set at the last Civil Service examination—Clerical Class, 1922.)

DISTRIBUTION OF INTELLIGENCE.

8599 ADULTS.

(Civil Service Examination—July 1922.)

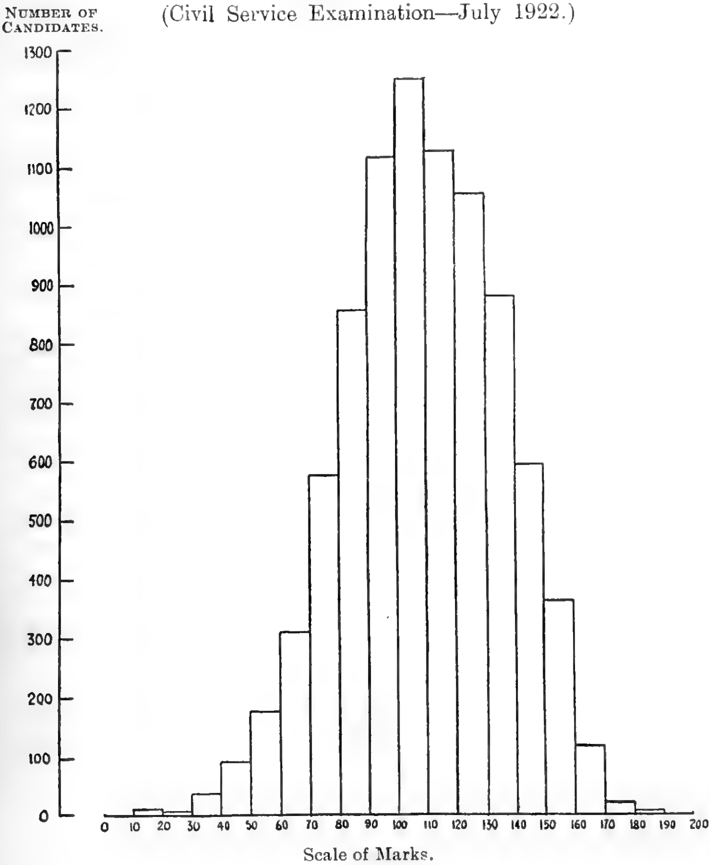

FIG. 1.

β. *Specific Abilities.*

With individual differences in general intelligence I have dealt at disproportionate length, partly because intelligence is, in Galton's phrase, a human quality of the utmost 'civic worth,' and partly because it is the one mental capacity upon which a prolonged and concentrated study has been focussed.

Over specific inborn abilities I need not linger. For them effective tests have proved disconcertingly hard to contrive. Simple correlation is here inapplicable. General intelligence is always getting in our way. We think we have tested something specific. We find we have only hit upon another test of intelligence. Its ubiquitous influence can only be eliminated by some elaborate technical device, the procedure, for example, known as multiple correlation; and the complexity of the whole task bewilders even where it does not baffle.

Nor do these special abilities, although presumably inborn, declare themselves at so young an age as the more general. Specialisation during the first twelve years of childhood is the exception rather than the rule. 'Young turtle,' says Epicurus, 'is every kind of meat in one—fish, fowl, pork, and venison; but old turtle is just plain turtle.' Similarly, the young child contains in fresh and dormant essence the germ of every faculty. Age alone betrays our idiosyncrasies. Adolescence is pre-eminently the period when many of these localised talents and specialised interests seem for the first time to mature. Accordingly, efforts at vocational guidance and educational specialisation must not be forced at too early a stage. At present, for example, the system of junior county scholarships tends to sweep all our brightest children at the age of ten or eleven into secondary schools of a somewhat academic type. When at a later period examinations are held for trade schools, most of the best instances of special talent are missing: they have already been creamed off and drafted into other directions less suited to their powers.

So far as it has been successful, the results of multiple correlation, eked out by other scattered indications, point to the following abilities as depending upon factors relatively specific: arithmetical, manual (drawing, writing, probably handwork of simpler kinds), verbal (reading and spelling), literary (composition in one's own tongue), linguistic (learning foreign languages), artistic, and musical, the last often appearing at an unusually early age. Of such specific or 'group' factors the specificity is not complete. There is much overlap; and, with every one of them, it is extremely hard to frame tests which depend mainly for success neither upon the 'central factor' of general intelligence, nor yet upon some particular capacity, so limited and local that no inference can be made from one performance to another, even within the same presumable group.

The abilities just enumerated seem undoubtedly specialised. But how far are they inborn? In practice what is actually tested must turn largely upon acquired dexterity, knowledge, and interest. And acquirements (as the classical experiments on formal training have taught us) tend always to be circumscribed; they do not diffuse or spread. The old doctrine of native faculties is out of favour with the orthodox psychologist of to-day. We are told that there is no such thing as memory: there are only memories; that there is no such thing as a general power of muscular skill: there are only separate motor habits, each independently learnt. Nevertheless, the very way in which such acquirements are limited, particularly among individuals who have had identical opportunities at school and at home, argues an innate basis; and inquiries into heredity confirm the suspicion. On the existence and nature, therefore, of these hypothetical 'group-factors'—inborn powers that seem partly general but not entirely so, partly specific but not absolutely so—further research is imperatively needed. How far, for example, is there a group-factor underlying all kinds of memory, or all kinds of imagination, every form of mental quickness, every form of motor dexterity, and every form of apprehension through the several senses? Of the great difficulty of the problem, the prolonged work on mental imagery is an excellent example. The early experiments of Galton convinced contemporary psychologists that individuals might be classified into fairly definite types—the eye-minded, the ear-minded, the motor-minded, and so forth. That these sharp lines of demarcation can be no longer drawn has since been amply proved. But yet, in spite of countless inquiries, no satisfactory tests have been devised even for a capacity so clearly definable as visualisation; nor can we guess how far it may be specific, and how far it may be inborn, nor how far it is a manifestation of something more general, or how far it is simply a question-begging term for an aggregate of yet more limited habits or tendencies, each specific in itself.[21]

ii. *Acquired Attainments.*

I turn now from inborn abilities to those that are acquired. From a practical standpoint these may be broadly grouped into educational attainments and vocational attainments respectively.

For the teacher one of the most helpful achievements of experimental psychology has been the recent elaboration of standardised scholastic tests. Simple foot-rules have been scientifically constructed for measuring a child's knowledge of the chief school subjects—reading, spelling, arithmetic, handwriting, drawing, composition, and the like. By the help of such age-scales—those, for example, published by the London County Council—it is now practicable to assign, in the space of a few

[21] To hereditary differences of race, sex, and social class I have no space to allude. The main conclusion that can be drawn from experimental work is, I think, the following: Innate group-differences exist; but they are small. Training and tradition account for the more conspicuous. The inborn mental differences between class and class, between nation and nation, and between women and men, taken on the average and in the gross, are swamped by the far wider differences among the individual members that make up any single group. As to the mental differences between the two sexes—the topic upon which rather more experimental work has been done—the reader may be referred to the recent report of the Consultative Committee of the Board of Education on *Sex-differences and the Secondary School Curriculum* (H.M. Stationery Office, 1922).

minutes, his mental level for every branch of the elementary curriculum.[22]

To measure the effects of experience or training in a trade or business is almost as easy as to measure progress in school work. To determine the speed and accuracy with which a typist types, or a shorthand-writer takes down matter in shorthand, all that is needful is, first, to construct a simple test on scientific principles, and then to draw up, on the basis of actual experiment, standards of efficiency for work of differing difficulty. Tests for such acquirements are of use chiefly in vocational selection—where, that is to say, an employer desires to pick out for a given job the best in a list of applicants. Vocational guidance, on the other hand—where the adviser picks out for a given child the best of all possible jobs—is a far more intricate task. It demands the measurement, not of attainments, but of the underlying aptitudes. To test capacity is much harder than to test acquired knowledge or skill. This we have already seen. And to determine whether a child is endowed with sufficient intelligence, sufficient finger-dexterity, sufficient quickness in analysing sounds, for it to be worth while to train him as a shorthand-typist, is an infinitely harder affair than to discover whether, once his period of training is over, he has reached the minimum of practical skill that will be expected from an office clerk. Here then is yet another pressing problem for future experimental inquiry. The vocational psychologist must work backward from the measurement of acquired dexterities in every trade to the measurement of the related capacities. At present most tests that he administers hinge upon a blend of both. And, in spite of the theoretical difficulty of disentangling the two psychological components, the methods devised hitherto have already proved their value in factories, in workshops, and in commercial firms. In this country vocational tests have been drawn up, and are now being still further refined, not only for different kinds of clerical work, but also for dressmakers, miners, and the various branches of the engineering trades. The practical results, even in these early stages, are an unquestionable success.[23]

b. *Temperament.*

We have now reached the most delicate portion of every psychological analysis. Hitherto we have been studying the man's intelligence, of which he is not likely to be ashamed. Now we have to study his character, which he naturally prefers to keep private. Having seen the full-length portrait exhibited to public gaze, our ruthless hands must lift the picture from the wall, and turn it over, that our prying eyes may look upon the back.

[22] The teacher, unacquainted with the newer methods, will find the best introduction to the subject in Dr. Ballard's excellent and attractive little book, *Mental Tests*.

[23] Those desirous of further details may be referred to Professor Claparède's little pamphlet on *Problems and Methods of Vocational Guidance* (International Labour Office, Geneva, 1922); to Professor Muscio's *Review of the Literature on Vocational Guidance* (Reports of the Industrial Fatigue Research Board, No. 12, H.M. Stationery Office, 1921); and to articles and reviews in the *Journal of the National Institute of Industrial Psychology.*

Character has been defined as the sum-total of all those individual qualities which do not constitute, or are not pervaded by, intelligence; to avoid the specifically moral implications that cling to the popular word 'character,' I prefer to retain the old term 'temperament,' and use it in the sense defined. The qualities thus negatively grouped apart are not without a positive aspect shared by them all. Though they exhibit low correlations with intelligence, they yet show tolerably high correlations amongst themselves. Analytically, they are marked by affective and conative elements rather than by cognitive; by feeling rather than by knowledge; by will rather than skill.

Temperament or character is always more difficult to assess than intelligence. Intellectual qualities are relatively constant. Emotional qualities are evanescent and evasive—hard to seize, and harder still to measure. It is significant to note that, though the idea of temperamental testing is almost as old as that of intelligence-testing, it has seen quite a different career. Every one has heard of Binet's tests for intelligence. But most of us have forgotten his efforts to measure suggestibility, conscientiousness, and fidelity of report. Of late renewed endeavours have been made to test the feelings and the will; and of these the most effective are the methods of associative reaction and the so-called psycho-galvanic reflex. Pressey has tried to detect fears and repulsions by getting the examinee to pick out, from a prearranged list of words, those that have for him a special meaning, or suggest a special worry or dislike. Downey has tried to measure what she terms 'will-temperament' by seeing how far the candidate can modify at request his style of handwriting and manner of speech. Fernald measures self-control by the time the candidate can balance himself upon the ball of the foot. The Porteus mazes are to some extent a test of recklessness and impulsiveness. And the variability in repeated tests of almost any simple kind (as measured, for example, by the standard deviation) seems partly correlated with instability. But no tests of temperament can claim to have passed beyond the stage of tentative experiment.[24]

In assessing temperament, therefore, we must fall back upon the method of observation in place of the method of experiment. The personal interview is one recognised device; and another is the collation of reports submitted by competent observers who have been acquainted with the examinee during a long portion of his life. Both interviewing and reporting has each its own technique; and in either case the technique is susceptible of great improvement by the application of simple scientific principles. Much, indeed, has already been done by drawing up questionnaires of facts to be noted and observed,[25] and by

[24] A good summary of the literature, with a detailed bibliography, will be found in Cady's article on 'The Psychology and Pathology of Personality: A Summary of Test-problems,' *J. Delinq.*, vii., 225 (1922).

[25] Of these perhaps the most suggestive are those given by Webb, 'Character and Intelligence,' *Brit. J. Psych. Mon.*, I., and Hoch and Amsden, 'Guide to the Descriptive Study of Personality,' *Rev. Neur. Psych.*, xi., 577. Cf. *Psych. Rev.*, xxi., 295.

contriving rating-scales[26] for the registration of such facts in terms of a comparable scheme.

1. *Inborn Emotional Qualities.*

As with intellectual qualities, so with emotional, it is both convenient and legitimate to distinguish at the outset the inborn from the acquired; and, so far as possible, to judge each level independently. In both directions much light has recently been thrown by the work of living authors. The inborn mechanisms have been tentatively catalogued and defined by McDougall; the acquired mechanisms by Freud and his school. The former lays stress upon hereditary factors; the latter upon developmental. But their views, however much opposed in general standpoint, are not so much incompatible as complementary. And they have this in common: both agree with one another in emphasising the dynamic elements in mental life, in contrast to the excessively intellectualistic preoccupation of the traditional psychology of the past. Each doctrine, although developed primarily as a correction of general psychological theory, is of the utmost practical value in studying the individual mind.

To sift and winnow inborn tendencies from those that are acquired is even harder in the realm of character than in the field of intellect. With adults it is all but impossible. With the young a few suggestions can at times be gleaned from the family history, or from the early personal history of the child himself. With children, too, the discrimination is more important practically. To know whether a spiteful boy is inherently ill-tempered, or only venting some half-hidden grievance; to know whether an erring girl is constitutionally oversexed, or merely putting into practice what she has picked up from corrupt companions; to separate the nervousness left by a shock from a chronic neurosis rooted in the system and likely to merge into madness or hysteria; to discriminate the excitability that is but a brief and transitory episode of some pubertal crisis from the excitability that began at birth and may last a lifetime—these are distinctions that make a world of difference in the treatment of the delinquent or neurotic while he is young.

α. *Specific Inborn Emotions and Instincts.*

English writers, McDougall, Shand, Drever, and others, find the foundations of human character in the instincts with their correlated emotions; and, taking their cue very largely from William James, they have given us useful working classifications for our common instinctive tendencies—inventories sufficiently identical for the purposes of the practical man. The strength with which each instinct is inherited is of necessity itself inborn. Accordingly, before estimating the character of a given individual, the first step is to take the universal human

[26] On rating persons either by 'relative position' or by reference to 'key-subjects' (a method elaborated with some success by the psychologists of the American Army) a rich literature has grown up. See, among other references, *The Personnel System of the U.S. Army*, vols. i. and ii.; Scott, *Psych. Bull.* xv. (1918); Thorndike, *J. Appl. Psych.*, ii. and iv. (1918 and 1920); and Rugg, *J. Educ. Psych.*, xii. and xiii. (1921 and 1922).

instincts one by one—pugnacity, fear, curiosity, disgust, sex, tenderness, gregariousness, and the like; and to ask in order with what intensity he has inherited each. In a study of juvenile crime I have endeavoured to show what an essential part the strength of the several instincts plays in determining the commoner forms of naughtiness and wrong behaviour in the young; in the elderly, and in the apparently virtuous, whether old or young, the same fundamental motives come more obscurely into play.

How can they be assessed? Not easily in the artificial and well-disciplined atmosphere of school or classroom; but with fair success, at any rate for delinquent and neurotic children, under more natural conditions where behaviour is spontaneous, as at home, in the street, in the playground, and in places of amusement generally. 'A man's nature,' says Bacon, 'is best perceived in privateness, for there is no affectation; in passion, for that putteth a man out of his precepts; and in a new case or experiment, for there custom leaveth him.'[27] The most serviceable method is to seek for certain standard situations, particularly those calculated to excite instinctive reactions; to observe the conduct of individual after individual; and so to gain by experience a notion of different grades of response. When relating to situations equally definite, the reports of parents, teachers, and the child himself provide suggestive supplements.

β. *General Emotionality.*

In a paper read some time ago before what was then the Psychological Sub-Section of this Association, I endeavoured to show that, in a random group, all emotional tendencies appeared to be correlated one with another in much the same way as intellectual. The child most prone to sorrow is often exceptionally prone to joy. The coward who bullies the weak is often the first to quake and quail before the strong. Correlations of this nature suggest the existence of a second central factor underlying the instincts and emotions, analogous to, but independent of, the factor termed intelligence. I have termed it 'general emotionality.' Those who manifest this inborn emotionality to an exceptional extent I call 'unstable'; and the most extreme cases 'temperamentally deficient.' And, in varying degrees, the existence of an unstable constitution is the chief characteristic feature of most delinquents and nearly all neurotics.

It is my view that a classification of the separate instincts, which shall be ultimately valid and convincing, can be reached only by the method of multiple correlation, by first eliminating, that is to say, the influence of the central factor, and then observing what specific factors remain, connecting particular forms of behaviour one with another.[28] If one makes a hierarchical table for the instincts and emotions, taken each as a unity, one seems to perceive the presence of a third set of factors—'group factors' of an intermediate level. When the influence

[27] *Essays*, xxxviii., 128.

[28] Only in this way can the issue between McDougall and Thorndike—whether the specific innate tendencies to behaviour are roughly six, or more nearly sixty or six hundred—be satisfactorily solved.

of the general facter has been eliminated, there emerge positive and negative correlations of a 'partial' order, which show that certain instincts tend to go more closely together than others. On the basis of such group-combinations we are led to distinguish certain broad emotional dispositions of at least two qualitatively differing kinds. On the one hand, the active or 'sthenic' emotions—anger, assertiveness, curiosity, joy, and perhaps sex—appear specifically correlated; on the other hand, the passive or 'asthenic' emotions—fear, submissiveness, disgust, sorrow, and perhaps gregariousness—seem in a similar way to be correlated with each other positively, but with the active or sthenic group negatively. Jung and his followers, working chiefly with abnormal patients, have recently thrown out some very suggestive speculations upon so-called emotional types. Their chief division consists in a revival and expansion of an old dichotomy. What have formerly been described as 'sensitive' and 'excitable' types, or 'restrained' and 'unrestrained' types, or 'subjective' and 'objective' types, or latterly 'herbivorous' and 'carnivorous' types, are now renamed 'introverts' and 'extroverts.' Once more, I believe the method of multiple correlation will afford the best way to confirm for the normal population these interesting deductions from pathology.[29]

ii. *Acquired Emotional Characteristics.*

Besides reviewing the strength of the several instincts and emotions which a man inherits, we must also investigate the more complex emotional tendencies that he has, in the course of his life-history, progressively acquired. These, according to the different angles from which they are regarded, and according to their own intrinsic nature, may be designated and sub-classified as habits, interests, sentiments, and complexes. We have, therefore, to inquire what habits each person has developed out of his instincts, what emotional attitudes he has unconsciously formed, what interests he has cultivated, and what ideals he has framed. These things are best ascertained through observation and interview. But the possibility of moral tests is already being investigated by the processes previously so successful in tests of intelligence. Attempts at measuring ethical discrimination, for example, have been made upon the following lines: a list of offences is drawn up, each described upon a separate card—breaking windows, scalding the cat, not going to church, stealing from a blind man's hat, flirting with a stranger, committing suicide, killing a thief, and the like; the examinee has to arrange them in order of wickedness. The arrangements of delinquents differ considerably from those of law-abiding children.[30] A

[29] I have no space to allude further to attempts to classify the basal psychopathic and neurotic types. I can only repeat that the trend of current work is to show that subnormalities in temperament and character, like subnormality in intellect, are extreme instances of milder deviations discoverable in the normal population. Useful references from the clinical standpoint are Wells, *Mental Regression: Its Concepts and Types*; Rosanoff, 'A Theory of Personality based on Psychological Experience, *Psych. Bull.*, xvii., p. 281; and Paton, *Human Behaviour*.

[30] Fernald, *Amer. J. Insanity*, lxviii., 547; Haines, *Psychol. Rev.* xxii., 303.

suggestive set of tests has been recently applied, by one American investigator, to a group of boy-scouts, and, by another, to groups of delinquent and non-delinquent children. The child is required to trace mazes with his eyes shut; to fill up and correct completion-tests with the key temptingly handy on the back; to state how much he knows of various topics, with the prospect of earning a box of confectionery if he obtains full marks. The measure is the number of times he cheats or overstates, and the results correlate with independent estimates of moral character to the extent of .42.[31] Sometimes (as in the last research) the examinee is also given a syllabus of questions relating to his own character: 'What kind of amusements do you prefer? Do you get on well with teachers and with other children? Would you like to wear jewellery and fine clothes? What do you think about when you are alone? What would you do if a lot of money were left you?' As a rule, however, an indirect technique is far preferable to a direct. The moral test is, as it were, to be camouflaged in the guise of a test of intelligence or information. The optional question-paper is full of possibilities in this direction. Every teacher knows how, in examinations on languages or mathematics, the routine worker chooses the mechanical questions, while the more enterprising select the problems and the riders; the cautious prefer the prepared texts, the adventurous the unseen translations. It is an interesting exercise to collect a set of picture postcards, artistic, humorous, or informative, and to request the child to arrange them in order of preference or merit. The influence of special interests, working quite unconsciously if the cards have been chosen with care, is nearly always obvious.

Few, however, would as yet pretend that such tests have more than an experimental interest. As Terman has put it: 'The reliability and validity of tests for moral traits have proved lower than an optimist might have hoped for. But the correlations obtained are quite as high as those yielded by the early intelligence tests of fifteen or twenty years ago. And this is no small achievement.'[32]

Conclusion.

Here, then, are the main items in the programme of the mental examiner. Here is my sketch of the skeleton of the mind.

Having tested all that he can test, having measured all measurable capacities, having passed in review all available data that throw light upon the rest, the psychologist must in the end bring his mixed materials together in one synoptic survey. He must reconstruct the mind dissected. The most expedient way of doing this is to plot out what is known in this country as a 'psychogram,' and elsewhere as a 'mental profile.' The various findings are to be charted diagrammatically upon some uniform and comprehensive scale. If he takes for his unit the percentile or the standard deviation, there is no capacity, no tendency,

[31] Voelker, 'The Functions of Ideals and Attitudes,' *Col. Univ. Contrib. Ed.* (1921); Cady, 'The Estimation of Juvenile Incorrigibility, *Journ. Delinq. Mon.* (1923).

[32] Preface to Cady's paper, *loc. cit. sup.*, p. 4.

no quality, in theory at any rate, that cannot thus be comparably expressed.

In his conclusions he will beware of four temptations. First, he must never court the applause of the unlearned, and the sneers of the worldly-wise, by claiming to have caught a living soul, and to have caged it in a formula, however technical, however abstruse. The growing mind is more than the sum of simple assignable elements; and all personal equations must issue in a surd. Similarly, he will avoid condensing his data at any point into vague generalisations—the announcement of a type, an average, or a total. A composite of snapshots, each taken from a different angle—a side-view, a full-view, a half-turn, and the rest—is no photograph at all; only an indecipherable blur. Thirdly, he must everywhere shun the besetting sin of the mere literary biographer—the confusing of facts with hypotheses to explain those facts, or, worse still, the submission of bare subjective inferences fortified by a string of anecdotes; data and interpretations the scientist keeps rigidly apart. Finally, throughout his inquiry, he must neither correct nor criticise, but coldly and calmly observe. His interest lies in realities, not in values; and should be 'positive,' as the philosophers say, not 'normative.' The teacher may psychologise while he is teaching, but he must not teach while he is testing. Nor should he anticipate the judgment-day by seeking to award praise or blame. His humble function is that of the recording angel, who registers, like a watch or a weighing machine, without audible comment.

There can be no denying that each inquiry will be slow, circuitous, and cumbersome. How long (it is sometimes asked) should it take to size up a single child? It was a tradition of the ancient world that no metamorphosis could hide a god from a god. And, upon a complementary principle, it seems often assumed that no disguise or taciturnity can save defectives or delinquents from the penetration of the mental expert. He is expected to cast his eye round the classroom or the prison, and to make a darting snapshot diagnosis on the spot. Our school doctors are given about ten minutes to decide whether a boy is deficient or not. Our magistrates take fifteen or twenty to determine what is best for a first offender. But the laboratory tester thinks himself a miracle of swiftness if he has measured a child's intelligence in less than an hour; and the psychoanalyst asks his startled patient for six months of separate weekly sittings to unravel a single complex. A longer period still was required by Shakespeare:

> 'It is not a year or two shows us a man.'

And Dr. Johnson thought the intimacy of a lifetime scarcely enough: 'God Himself, sir, does not propose to judge man until the end of his days.' Whether they be normal or subnormal, backward, delinquent, or neurotic, or merely youthful applicants seeking their most appropriate career in after-life, we can deal with human beings fairly and efficiently only by making an intensive, individual study of each isolated mind; there is no other way. Human personality, with all its infinite variety, is the most important single factor in all our social life; and the expenditure of time, however lavish, will never be lost.

Where the exigencies of the case demand a speedy assessment, I recommend the practical psychologist to aim chiefly at the so-called general factors. If I were permitted to measure no more than a pair of mental qualities, I should look first to the degree of a man's native intelligence—his 'general ability,' with which more special capacities are known to be correlated; and next to the degree of his native instability—his 'general emotionality,' with which his special instincts are apt to be in accord. Were I granted the grace of two or three additional estimates, they would still be of a general type—general physical health, general moral character, and general cultural attainments.

It may be that I am too optimistic, and that my views are premature. But it is my personal conviction that the main outlines of our human nature are now approximately known, and that the whole territory of individual psychology has, by one worker or another, been completely covered in the large. We have viewed the whole continent from above by rapid aerial flights towards different quarters. It remains to link up and to co-ordinate the numerous reconnoitring pioneers; then to descend, and, by the laborious method of exploring feature after feature, to correct up our maps in definite detail. Once its broad principles have been determined, it is from the close and microscopic detection of minutiæ, of tiny items and small but telling indications, that every science is eventually built up. This must be the aim with individual psychology in the near future. We must discover what mental traits are relatively independent, and which are the general among the relatively specific; we must construct precise working definitions for each, and hammer out by experiment upon experiment, research upon research, tests and rating-scales for everything that can be quantitatively expressed, inventing new tests for traits not hitherto tested, and refining the procedure of the old. Here rather than in any grand discovery must further progress lie.

Finally, let me leave the would-be analyst of character with a repetition of a warning already uttered in another place. Individual psychology is not a code of rules and principles to be mastered out of hand in the lecture-room or laboratory. It is not an affair of text-book terminology or of a teachable technique. It is the product of worldly experience acting on an inborn interest—an enthusiasm for persons as persons, in the old *nihil alienum* spirit. To take an unknown mind as it is, and delicately one by one to learn its chords and stops, to 'pluck the heart out of its mystery, and sound it from its lowest note to the top of its compass,' is an art and not a science. The scientist may standardise the methods. To apply those methods, and appraise the results, demands the tact, the temperament, the sympathetic insight of the genuine lover of strange souls.

SOME ASPECTS OF THE PRESENT POSITION OF BOTANY.

ADDRESS TO SECTION K (BOTANY) BY

A. G. TANSLEY, M.A., F.R.S.,

PRESIDENT OF THE SECTION.

We meet to-day in a city which is one of the greatest seaports of the kingdom, traditionally the main channel of our commerce and intercourse with the great English-speaking republic across the Atlantic, and also the main centre of the import of cotton and of the export of cotton goods, with which the prosperity of Lancashire, and to no small degree of the country, is so intimately associated. To the enterprise and public spirit of the citizens of Liverpool we owe the creation and development, within an astonishingly short period, of the distinguished university the hospitality of whose staffs, organisations, and buildings we shall enjoy during the coming week. Many of us can vividly remember the pride and satisfaction with which we saw arise, especially during the last decade of last century, one after another of the great institutes of research and teaching which have contributed so much to the advancement of science in the comparatively few years during which they have existed. In such surroundings we cannot but be stimulated afresh to labour to the limit of our abilities in the cause of that great human activity—the advancement of science in all its branches—which as members of the British Association we all have at heart.

Since the last meeting of the Association we botanists have to mourn the loss of two striking and dominant personalities. Sir Isaac Bayley Balfour played a great and worthy part in that revival of scientific botany in this country which marked the last quarter of last century. During his long tenure of the Chair of Botany at Edinburgh and of the Directorship of the famous Botanic Garden in that city, he was widely known for the ability and assiduity with which he carried out the work of one of the most important and onerous botanical positions in the kingdom, and for the native shrewdness and sanity, the ripe judgment and experience, which he was always ready to place at the disposal of his colleagues. Mr. Henry Elwes was a country gentleman of a type for which England has long been famous, who, like Lord Herbert of Cherbury, conceived it 'a fine study and worthy a gentleman to be a good botanique that so he may know the nature of all herbs and plants, being our fellow creatures.' To this study Mr. Elwes brought the utmost energy and vigour, pursuing to the remotest lands, both personally and by deputy, an untiring search for the objects of his attachment. He will best be remembered by that magnificent work 'The Trees of Great Britain and Ireland,' which, in conjunction with Professor Augustine Henry, he produced at his own expense on a splendid scale.

I propose to deal this morning with some aspects of the development of pure botany during the last thirty or forty years, especially in this country, and with the bearing of these developments on the present position of the subject. In seeking for a suitable starting-point from which to begin the observations I have to make I naturally turned to the address delivered by my predecessor in this chair at the last meeting of the Association in this city. On that occasion, in 1896, the chair of Section K was occupied by Dr. D. H. Scott, and I found at once that the remarks with which he began his Presidential Address were surprisingly apt for my purpose. For definiteness of outlook on the problems of pure botany and for lucidity of expression they could not be surpassed, and their author will, I am sure, forgive me if I use his statement as the primary text from which to develop my critical exposition.

'The object of modern morphological botany,' said Dr. Scott, 'is the accurate comparison of plants, both living and extinct, with the object of tracing their real relationships with one another, and thus of ultimately constructing a genealogical tree of the vegetable kingdom. The problem is thus a purely historical one, and is perfectly distinct from any of the questions with which physiology has to do.

'Yet there is a close relation between these two branches of biology, at any rate to those who maintain the Darwinian position. For from that point of view we see that all the characters which the morphologist has to compare are, or have been, adaptive. Hence it is impossible for the morphologist to ignore the functions of those organs of which he is studying the homologies. To those who accept the origin of species by variation and natural selection there are no such things as morphological characters pure and simple. There are not two distinct categories of characters—a morphological and a physiological category—for all characters alike are physiological.' And then the President proceeded to quote, evidently with full agreement, from Professor (now Sir) Ray Lankester. 'According to that theory' [*i.e.* the Darwinian theory], wrote Professor Lankester in 'The Advancement of Science,' 'every organ, every part, colour, and peculiarity of an organism must either be of benefit to an organism itself, or have been so to its ancestors. . . Necessarily, according to the theory of natural selection, structures either are present because they are selected as useful, or because they are still inherited from ancestors to whom they were useful, though no longer useful to the existing representatives of those ancestors.' And a little further on Dr. Scott said: 'Although there is no essential difference between adaptive and morphological characters, there is a great difference in the morphologist's and the physiologist's way of looking at them. The physiologist is interested in the question how organs work; the morphologist asks, What is their history?'[1]

The way of looking at the science of biology so clearly expressed

[1] *British Association Report*, Liverpool Meeting, 1896, pp. 992, 993.

in these sentences was by no means exceptional. Indeed, it may be fairly called the orthodox view at that time. Thus five years earlier, in 1891, Professor Strasburger, perhaps the most brilliant and successful German botanist of what we must now speak of as the last generation, wrote in the preface to his great work on the structure and functions of the conducting tissues: 'Morphology as such is a purely formal science, and thus corresponds approximately with comparative grammar, in that it explains forms by deriving them. It need be as little influenced by the functions of the forms to be derived as comparative grammar is influenced by the meanings of words. Not that a physiological treatment of the external and internal structure of a natural body would be less fruitful than the morphological, but it forms a different discipline.' After referring to the unfortunate effect of physiological points of view on the work of the earlier anatomists, who called, for instance, the water-conducting elements of plants 'tracheal' because they thought they were air passages, Professor Strasburger proceeded: 'With advancing enlightenment the provinces of morphology and physiology were separated from one another and developed on separate lines, without, of course, attaining complete independence . . . in fact, organs and functions are not separated in nature, and are only logically distinguished in order to subserve the building up of science. . . . Morphology finds its task only in deriving one form from another, in tracing different forms to a common origin. When this is successful the goal is reached. . . . The way which leads to morphological understanding is that of comparison, but only because this way involves a phylogenetic significance. Since a direct phylogenetic proof of the origin of a given structure is not to be had, morphology remains tied to indirect methods. It is often supported in its task by ontogeny, but only in so far as this is capable of giving phylogenetic points of view.'[2] Here we have the same insistence on the separateness of the two disciplines, morphology and physiology, and the same clear statement that the object of morphology is the elucidation of phylogeny. We may note, however, one striking difference. Professor Strasburger thinks that morphology need be as little influenced by the functions of the forms to be derived as comparative grammar by the meanings of words, and he does not claim, like Dr. Scott, that all features of an organism are, or have been in the past, adaptive.

It is, I think, impossible to regard the views thus expressed by a representative English and a representative German botanist three decades ago as representing to-day an adequate outlook on the problems of botany as a whole; and I shall be engaged this morning in endeavouring to expound the view which I think we should put in its place. First, I must pay some attention to the causes of the orthodox attitude of the last generation, the generation in which I was botanically brought up, and whose orientation I fear I passively accepted. The main cause of the greatly intensified interest in comparative morphology which led to the claim that this subject represented a separate discipline,

[2] E. Strasburger, *Ueber den Bau und die Verrichtungen der Leitungsbahnen in den Pflanzen*, Histologische Beiträge III, Jena, 1891, p. vi.

co-ordinate with physiology, was, of course, the general acceptance by biologists of the doctrine of descent with modification, popularly called evolution. Belief in the reality of this process at once invested the comparative study of structure with a new fascination. Every part, every organ of an animal or plant, could be interpreted in the light of the doctrine of descent. All the species of a group should, according to the theory of descent, be theoretically traceable to a hypothetical 'common ancestor' of the group, and these group ancestors again to remoter ancestors. Ultimately we should be able, theoretically at least, to reconstruct the whole genealogical tree of the plant and animal kingdoms. It was, of course, recognised that we could never hope to complete this task, even if we possessed an exhaustive knowledge of the structure and development of every kind of organism now living, for very many forms had been destroyed and had disappeared altogether in the course of the evolution of the organic world as it exists to-day. But the remains of many of the organisms which had lived in past ages were still preserved as fossils, and a knowledge of their structure would substantially help us on the way to the goal, even though that goal could never actually be reached. Though the geological record was extremely fragmentary, yet it did bring to our knowledge many kinds of plants, some more or less closely allied to living forms, others which could not be placed in any living group, and others, again, which suggested that they might represent or at least stand near to the common ancestors of existing groups.

If we consider the most recent developments of the subject we find that, on the whole, the search for common ancestors as such has been disappointing. The 'seed-bearing ferns' (Pteridosperms) have turned out to be, so far as we can tell, a perfectly independent group having no demonstrable connection with the true ferns. The most primitive fossil ferns known (the Primofilices or Cœnopterideæ of the Lower Carboniferous) certainly represent a very ancient group. But not only, according to Dr. Scott in his most recent statement,[3] do 'Pteridosperms and Ferns at all times show themselves perfectly distinct': 'we are dealing, in the Lower Carboniferous Primofilices, with early races already specialised on their own lines, and probably only indirectly connected with the main current of Fern-evolution.'

The remarkable Rhynie fossils described by Kidston and Lang from the Lower Devonian—the oldest vascular plants with structure preserved that are as yet known—have revealed in the genera *Rhynia* and *Hornea* a leafless and rootless type with large simple terminal sporangia and a simple stele occupying the centre of the axis. These plants show striking points of agreement with the living Psilotales, but their discoverers, so far from being prepared to assert that they are prototypes of Psilotales, create for their fossils a new class, the Psilophytales. Thus we have now recognised six distinct classes or orders of living and fossil Pteridophytes,[4] and parallel with these six distinct classes of non-

[3] D. H. Scott, 'The Early History of the Land Flora,' *Nature*, Nov. 11, 1922.

[4] Psilophytales, Psilotales, Sphenophytales, Equisetales, Lycopodiales, Filicales.

angiospermous seed-plants, two wholly and others largely fossil.[5] In addition there are still a multitude of fossil forms, largely detached fragments such as sori, seeds, leaves, or wood, which are not sufficiently known or correlated to permit of their definite assignment to one or other of these classes. From these and for other discoveries it may well turn out to be necessary in the future to construct one or more new classes.

Leaving these great series of vascular forms which played so dominant a part in the history of vegetation during the Primary and Secondary geological epochs, we may note that the gulf which has always existed for the phylogenist between Pteridophyta and Bryophyta is as wide and deep as ever, and that the same may be said of the gulf between the Bryophyta and the Algæ. The attempts which have been made from time to time to derive various groups of Fungi from various groups of Algæ seem to me quite unconvincing. The phylogeny of the Fungi themselves remains obscure, though certain lines of advance among them and among the Algæ are fairly probable. On the whole the most successful phylogenetic speculations seem to me to be those that trace some at least of the classes of Algæ back to a common origin in the great plexus of the Flagellata, which may also, perhaps, be regarded as the likeliest recognisable starting-point of the main lines of invertebrate evolution. Turning to the other extremity of the Plant Kingdom, to the characteristically modern dominant vegetation of the earth, we are scarcely able to form a trustworthy opinion as to the nature of the plants from which the two great modern groups of Angiosperms sprang, though the speculations of one of my predecessors in this chair, the late Miss Sargant, founded on wide researches and elaborated with masterly ability, are certainly of great interest, and full of suggestion as to what may have occurred. The evidence from fossil Angiosperms is still unsatisfactory, and Mr. Hamshaw Thomas's interesting discoveries of Jurassic Angiosperms scarcely throw light on the problem of the descent of the group. It has been the invariable history of such researches, pursued with a view to tracing phylogeny, that the better a newly discovered group has become known the less probably it appears to represent the common ancestors of other existing or fossil groups. The points of origin, the roots, so to speak, of each group have been constantly lengthened and shifted further back in geological time so that they become more definitely independent from one another and appear to issue separately from a past which remains obstinately obscure. 'It may be,' said Professor Seward recently,[6] speaking from the fullness of a very wide knowledge of the floras of the past, 'that we shall never piece together the links in the chain of life, not because the missing parts elude our search, but because the unfolding of terrestrial life in all its phases cannot be compared to a single chain. Continuity in some degree there must have been, but it is conceivable that plant life viewed

[5] Pteridospermeæ, Cordaitales, Cycadophyta, Coniferales, Ginkgoales, and Gnetales: see Seward, Fossil Plants, vols. III. and IV.

[6] A. C. Seward, 'A Study in Contrasts,' (Hooker Lecture), *Journ. Linn. Soc. Bot.*, October 1922, p. 238.

as a whole may best be represented by separate and independent lines of evolution or disconnected chains which were never united, each being initiated by some revolution in the organic world.' And again,[7] the development of vegetation 'appears as a series of separate lines, some stretching into a remote past, others of more recent origin.' 'It would almost seem that "missing links" have never existed.' 'There is no insuperable objection to the conception that terrestrial vegetation received additions from upraised portions of the earth's crust at more than one epoch in the history of the earth.' The picture of the history of evolution here suggested makes the search for common ancestors literally a hopeless quest, the genealogical tree an illusory vision.

But there can be no doubt whatever that the great body of work originally stimulated and inspired by the ideal of the genealogical tree has added very greatly to our knowledge of the range of the forms and structures of plants, notably of vascular plants, and of the rise and fall of the great groups during the passage of geological time. In regard to the structures of plants, it has directed attention especially to the vascular system of the plants of the middle grades of organisation, and given us a much more extensive and accurate acquaintance with the larger features of its organisation and development throughout these grades. We have discovered that vascular structure shows a type of progression from simpler to more complex forms which is broadly identical along many different lines of descent, a progression closely paralleled in the ontogeny of the individuals belonging to species which exhibit the more complex adult structure; and we have thus learned to correct the one-sided emphasis that used to be placed on the reproductive organs as guides to evolution. Though these last remain, so far as we can tell, the most trustworthy indices of *affinity*, yet 'the characters of the vascular system,' says Professor Bower in his recently published book on the Ferns, are 'the most important structural features for the phyletic treatment of the Class.'[8]

Without question, then, morphological and palæobotanical work, particularly in its extension to the internal structure of plants, has added greatly to our knowledge of the plant kingdom, and has given us a much fuller and juster appreciation of the range of the great middle groups, and to some extent of their relationship, or, as perhaps we should say, of their lack of relationship, to one another. One of the most striking results of this work as a whole has been the increasing doubt it has engendered as to whether many organs formerly regarded as homologous in the strict sense, *i.e.* homogenetic, of common origin in descent, are really homologous in this sense at all. The principle of homoplastic or parallel evolution has been more and more widely extended. And our increasing though still very rudimentary knowledge of the factors which determine organic form would suggest not only that parallel evolution has been determined by parallel conditions of life, an idea long familiar to biologists, but that we should expect a recurrence of the same formative factors, producing similar structures, on different lines

[7] Presidential Address to the Geological Society, 1923.
[8] F. O. Bower, *The Ferns* (*Filicales*), 1923, vol. I, p. 192.

of descent, and to a large extent independently of particular life conditions.

It seems to me that no structure which has been assumed to be homologous throughout a large series showing many gaps is really safe from the suspicion of having been developed independently on different lines of descent. In a recent paper Dr. Scott writes [9] of the inference 'that the Seed Plants, of which the Pteridosperms are among the earlier representatives, constitute an independent phylum, of equal antiquity with any of the recognised lines of Vascular Cryptogams.' But is it at all certain that the Seed Plants really constitute a *single* phylum? Is it not perfectly possible that the seed with its attendant mechanisms has been independently evolved in some or all of the six classes of Seed Plants which, apart from the Angiosperms, are now recognised? It is clear that the more such suspicions effect permanent lodgment in our minds the more uncertain all wide positive phylogenetic conclusions must become.

Meanwhile the whole of this branch of botany seems to leave the great majority of the younger botanists cold. No longer under the immediate influence of the revolution in biological ways of thinking brought about by Darwin, they are not greatly interested in comparative morphology, nor in the attempts to disentangle the past history of the plant kingdom, sustained and even magnificent as these attempts have been, and greatly as they have enriched our knowledge of the past life of our world. There is, to many of them, an effect of hopelessness and even of futility in the effort to trace out the course of the threads in an intricately woven carpet, with no attainable certainty that we have got them right, however long and patiently the task is pursued, partly because so many of the threads, such large portions of the carpet, have been destroyed for ever, partly because, as Professor Seward suggests, we may, in effect, be dealing not with one carpet, but with many.

While we may urge that far too much time has been, and in many places still is, devoted to the study of comparative morphology in elementary teaching, it is impossible to deny the great interest and importance of conclusions like those quoted from Dr. Scott and Professor Seward. From the point of view of the ideal of the 'genealogical tree' these conclusions are negative, but they are none the less interesting and valuable, for they are giving us a truer view of the past history of plants.

There has certainly been no loss of interest in the *process* of development, whether phylogenetic or ontogenetic. The unfolding of life upon the earth, the marvellous story of development and change, of increasing complication and endless variation on the one hand, and on the other the great problem of how the complex organism comes to develop from the minute zygote, can never lose their fascination for the human mind. It is the formal comparison of the end results of this process, with a view to the determination of phylogenetic relationships, the treatment of the problem as 'a purely historical one,' which seems to so many of the keenest younger biologists a hopeless and not a very

[9] *The Origin of the Seed Plants*, p. 227.

remunerative pursuit. Their interest is in the process itself rather than in the phylogenetic connexions of its particular results. They want to know what brings about development and evolution, what are the driving forces behind these processes.

The orthodox 'Darwinian' answer to this question, so far as it applies to phylogenesis, was 'natural selection.' The organism was supposed to be capable of indefinite 'spontaneous' but heritable variation in all directions and of various degrees, and those which happened to be useful to the organism by giving it a decisive advantage in the struggle for existence were preserved because the individuals which showed them alone survived and produced offspring, which inherited the useful variations and thus modified the species. Two or more divergent sets of variations might happen to fit different individuals of a parent species to different sets of conditions, different habitats, into which they had wandered, while the parent species remained behind unmodified in the original habitat, and thus new varieties were supposed to originate. By the further development of the new characters, *i.e.* by the favouring of further variations in the same direction as the original ones, these varieties became distinct species. The same process further continued and involving also other structural features would lead to the wider divergence of the derivatives from the original stock, and this divergence would ultimately become so great that the different forms would be placed in distinct genera. The sharpness of the specific and generic distinctions would often be enhanced by the disappearance of the original or of intermediate forms, owing for instance to the physical conditions of life changing and becoming unsuitable for them or to their suppression by rivals whose variations had been more successful. In the course of a very long time, by a continuation of the same processes, the distinctions which were at first specific, and later generic, would become family distinctions, later again ordinal distinctions, and so on up to the great phyla.

Alongside of the evolution of new species, genera, and families in the same general environment, such for instance as the tidal zone, there had been a migration of some forms to the land, or perhaps, as Mr. Church would have us suppose, a gradual raising of the land bearing aquatic forms above the water-level. These aquatic forms had thus been faced by conditions of life very different from the earlier ones, so that the variations which were preserved and perpetuated were necessarily in new directions and gradually built up the equipment of the land plant —the typical leaf and root, the vascular and aerating systems, the cuticle, the air-distributed spores. From these earlier land plants again by further variation the heterosporous forms were derived, and finally the seed and angiospermy, while various progressive complications and modifications of the primitive vascular tissue, including secondary thickening, had established both more copious and more efficient conducting and mechanical systems, and thus led to the quickly growing, largely upright, modern plants, extraordinarily 'flexible' to various life conditions.

I think this is a fair rough statement of what was often known as the Neo-Darwinian account of evolution, as applied to plants, in the last decade of last century. It was not precisely Darwin's own position, but gained its great vogue, especially in this country, largely through the writing of Alfred Russel Wallace, and through the germ-plasm theory of August Weismann. All characters whatever, as Dr. Scott and Sir Ray Lankester said, were regarded as adaptive or useful in the first instance, and as produced by the summation of small variations. The origin of these variations was obscure. The fact that such variations occurred was sufficiently established, and their occurrence was simply taken as a datum on which natural selection could work by picking out and establishing the favourable ones. The only characters which were not considered adaptive at their first origin were covered by the conception of 'correlated variation,' *i.e.* structural or functional changes necessarily involved by the primary adaptive ones, though not in themselves useful to the organism. Later on the structural changes which were at first useful might be so no longer, owing to their supersession by other structures or by a change of conditions. They were, however, or might be, still inherited, being incorporated in the constitution of the organism's germ-plasm, though superseded, so far as current adaptation went, by more recently acquired characters, as in the familiar case of the embryonic gill-slits of the higher vertebrates. Frequently an organ originally acquired for one purpose was diverted to different uses, as for instance the anterior fins of fishes, which became, in their modified terrestrial descendants, legs, arms, or wings. Thus the actual structure of an organism could only be explained by its ancestral history.

The weak point of this theory of evolution, on the facts then known, apart from the obscurity surrounding the origin of variations, was the difficulty of understanding how the first minimal variations, which were supposed to be the foundation of new structures, could, at least in many cases, be of life-preserving value—'survival value,' as the phrase goes—to the organism, and how they could avoid being 'swamped,' as it was supposed would happen, by intercrossing with other unmodified members of the species. Various theories of segregation, geographical or physiological, were proposed to get over this difficulty, but it was very doubtful if they could be considered as of sufficiently wide application for the purpose. Further, the theory required that the actual structural differences between species—apart from 'correlated variations'—should *always* be adaptive; yet the greater number of naturalists who had a wide first-hand acquaintance with species as they exist in the field, and with the actual differences between allied species, could not find that this was the case. Some people attributed this scepticism to ignorance of the functions of particular structures which seemed to be useless, the Neo-Darwinians refusing to admit that constant characters might have no 'function' after all, unless they were vestigial or 'correlated' with others that had. The field naturalists, however, remained for the most part obdurate. One distinguished biologist, referring to the hope that all specific characters would ultimately be proved adaptive, added, 'Time has been running now and the hope is unfulfilled.' Ingenious persons explained all sorts of peculiar structures and arrangements—'myrmecophily,' the insectivorous habit of some plants, extra-floral nectaries, the long tips of certain tropical leaves, and countless others—

as of use to the species that exhibited them, always with the implication, and sometimes with the express assertion, that they had been developed *because* of their survival values. One by one, in the light of critical research, most of these 'explanations' of structure have broken down. Not only is 'survival value' almost impossible to prove in any given case, but many of these supposed adaptive structures or arrangements have been shown not to work in the way they were supposed to work. Nevertheless, the habit has remained, even up to this day, not only of looking for the 'use' or 'function' of every structural character—quite a legitimate proceeding in itself, if we are not wedded to the belief that it *must have* a 'use'—but of considering its existence sufficiently 'explained' when such a use has been experimentally established or even more or less plausibly suggested.

Round about the beginning of the present century several publications of first-rate importance began to put a new complexion on these problems. First there was De Vries's work on mutations,[10] which claimed to show that discontinuous variation, whose widespread occurrence in nature had already been demonstrated by Bateson and suggested by him as the prime cause of the discontinuity of species,[11] was *the* important factor in evolution. In 1903 Johannsen's work on 'pure lines'[12] showed in the most unmistakable manner in the case of the bean that the minimal 'fluctuating' variations, on which Wallace and the Neo-Darwinians had been accustomed to rely as the material on which natural selection operates, are *not* inherited, so that if one breeds from a group of such variations which deviate from the mean of the pure line, there is no establishment of a deviating mean in the descendants, but a regression to the original mean. Meanwhile, the rediscovery of the Mendelian phenomena and the rapid extension of the range of characters in which they were found to be exhibited had at last placed our knowledge of the mechanism of heredity and variation on a secure basis. The immense quantity of breeding and cytological work which has followed has given reality to the conception of 'genetic constitution,' or *genotype* as it is called in current terminology. We now know that an ordinary 'Linnean' species is, often at least, an aggregate or mixture of crosses from 'pure lines' in respect of different characters, each pure line with a specific genetic constitution based on the structure of the chromosome complex. New *heritable* variations of the stock are produced by redistribution of units within the chromosomes resulting from the crossing of individuals belonging to different pure lines or of their hybrid offspring. This apparently occurs in the stage of 'synapsis' of the nuclei which are just entering upon the divisions that result in the tetrads of spores and gametes; and it is followed by the 'reduction division' of the mother cell of the tetrad, resulting in segregation of unlike units so that the gametes of a single tetrad bear different characters. Other internal changes in the chromosome complex may perhaps take place, but of these we can as yet say very little.

10 Published in a series of papers culminating in his great work, *Die Mutationstheorie.* Leipzig, 1901. Vol. II, 1903.

11 Bateson, *Materials for the Study of Variations.* London, 1894.

12 Johannsen, *Ueber Erblichkeit in Populationen und reinen Linien.* Jena, 1903.

It is to be noted that these great discoveries do not *necessarily* invalidate the Neo-Darwinian position. It is still perhaps just possible to hold, so far as this new knowledge of the mechanism of variation and heredity is concerned, that in any given complex of forms which we call a species, only those variations are in the long run preserved which adapt the individuals that show them more closely to their conditions of life. But the more exact knowledge we now possess of the way in which new heritable variations in the body of the organism actually come to arise and maintain themselves has firmly established the thesis, clearly stated by Bateson nearly thirty years ago,[13] that the primary problem of evolution is the process of variation itself and not what happens to the variations in the struggle for life after they have appeared. Variations from type, more or less considerable, actually arise by new combinations of the primary chromosomal determinants—*genes* as they are now called—by the loss (dropping out) of certain genes, or perhaps by actual changes in the nature of the genes or the appearance of new ones; and the variations so produced persist, or may persist, indefinitely, without any reference to selection. It is perfectly true, of course, and must always remain true, that every organism which survives must be viable and *sufficiently* adapted to the conditions of its existence. But it is not only unproved, it is a gratuitous belief unsupported by the evidence, that all new characters, all differences between species, are of survival value or owe their origin in any way to selection.

The clearest and most plausible account of the origin of new species, in the light of our existing knowledge, is, it seems to me, that given by the Hagedoorns.[14] Any group of related individuals capable of interbreeding, so far as its somatic characters are genetically determined, owes those characters (*phenotype*) to the totality of the genes possessed by the zygotes from which they were produced (*genotype*). Some of the genes present may not, however, affect the phenotype, because they do not meet with the developmental or environmental conditions necessary to enable them to find expression in the soma, or because some other gene or genes, interaction with which is necessary to phenotypic expression, may be absent. The total actual 'genetic' variability of the group is measured by the total range of phenotypic variability: the total *potential* variability is greater than this because it includes the potential effects of the genes which are present, but which may, at any given moment, be inoperative for the reasons cited. The total potential variability is measured by the number of genes for which the group is not pure. If the whole group is pure, uniform and homozygous for all characters, it cannot, by hypothesis, vary genetically. The potential variability of the group is increased if there are taken up into it individuals which either possess a gene or genes not present in any member of the group or which lack genes that are the common property of all the original members of the group. Thus if fresh crossing takes place with fertile individuals outside the group, the potential variability of the original

[13] W. Bateson, *op. cit.*, p. 6.

[14] A. L. and A. C. Hagedoorn, *The Relative Value of the Processes causing Evolution.* The Hague, 1921.

group is increased. But in the absence of this, in fact in all cases where the group is isolated, mechanically or otherwise, the potential variability constantly tends to *decrease*, because the offspring of any generation are normally produced from a small fraction only of the individuals of that generation, and this leads to the dropping out from the breeding stock of part of the total potential group variability. In the case of a self-fertilised plant the reduction of variability will proceed even if all the individuals produce offspring, because Mendelian segregation will result in the daughter being heterozygous for only one-half the number of genes for which the mother was impure. In the absence of crossing with individuals having a different genotype, heterozygotes will produce some homozygotes, but homozygotes can never produce heterozygotes, so that the proportion of heterozygotes in such an exclusively self-fertilised race will steadily decrease. This is an intelligible view of the origin of the discontinuity of species. The mechanism will work whether natural selection is in play or not.

Suppose, for instance, that from a breeding stock with a given total potential variability a number of islands are colonised. The colony on each island will, on random selection, have a substantially smaller total variability than the original stock, because it will be derived from a much smaller number of individuals, and a good part of the original variability will be lost. Further, if the colonising groups are selected haphazard the potential variability of each colony will be different, and the offspring of the different colonies will form as many new 'species,' each of which will in successive generations increase in purity. The differences between these species may, however, have no relation whatever to adaptation, because the characters in which the new species differ from one another and from the parent species may have no survival value in any of the habitats. Many years ago J. T. Gulick called attention to the fact that the species of land molluscs on the Sandwich Islands showed differences which did not seem to be adaptive, but which were closely related to isolation.[15] More recently Crampton has arrived at similar results in regard to the forms of another land snail, *Partula*, and has actually shown that numerous new forms have arisen, as he holds by mutation and isolation, since the distribution of the forms was accurately recorded in 1884.[16] On the other hand, if the new habitats differ, and there is variability in the original genotype corresponding with phenotypic characters which have survival value in relation to the differences of habitat, selection will play its part in determining the genotypes of the new species. Thus we can understand why it is that geographically isolated but clearly allied species *may or may not* differ in 'adaptive' characters. We can also understand how it is that different closely allied species come to exist in the same geographical area but in different habitats—different 'ecological niches' as they have been called—between which the chances of crossing are at a minimum, *either with or without* specific adaptation to the habitat. It depends

[15] J. T. Gulick, 'Divergent Evolution through Cumulative Segregation,' *Journ. Linn. Soc. Zool.*, 20, 1888.

[16] H. E. Crampton, *Studies on the Variation, Distribution and Evolution of the genus* Partula. Carn. Inst. of Washington, 1917.

upon whether the random selection of individuals which originally colonised these habitats varied from the genotype of the parent stock in characters of survival value in relation to those habitats or not. Where two such habitats abut on one another and there is no specific adaptation to the two habitats intermediates of hybrid origin are often found along the line of contact.

In plants which are self-fertilised as a rule, but in which crossing is not absolutely excluded, numerous species may come to exist in the same geographical area and the same habitat, for the changes in genotype brought about by the occasional crossing will be fixed and the phenotype purified, *i.e.* rendered more homogeneous, by the subsequent isolation for many generations of the different families. It is in this way that the 'elementary species' of such a form as *Erophila vulgaris* (*Draba verna*) may be supposed to have originated. The differences between these are small but constant, and they must be regarded as true species. A variety, on this view, is a relatively transitory form which may at any time be reabsorbed by crossing into the general stock of the species.

We cannot in the present state of knowledge reject altogether the possibility of other modes of formation of new species. Geneticists differ as to the occurrence of radical alteration in the nature of a gene, or of new genes arising *de novo* in the genotype, *i.e.* as to the occurrence of 'mutations' in the narrowest sense, while the interaction of conjugating chromosomes by 'crossing over' is well recognised. We cannot, I think, exclude the *possibility* of long-continued action of the environment actually altering genes or even creating new ones. Thus we have only shifted the problem of variation back. We cannot as yet express variation in terms of chemistry and physics. We do not know what genes are. They may be definite chemical substances, they may be physico-chemical complexes, or some may be of one, some of the other nature. It is certain that a great number must always be present, and that the phenotypic 'characters' must depend on their interaction. We cannot analyse a race of organisms genetically except in respect of those genes that may be present or may be absent. Many genes must be present invariably or the working mechanism would break down—the organism would be non-viable—and these we cannot separate by breeding methods. These things being so, we cannot wholly exclude the hypotheses of orthogenesis and of epharmosis as causes of evolution, much as we may dislike them on account of their vagueness. Modern genetic research has been able to demonstrate to a very large extent the exact correspondence between changes in phenotype and the dropping out and new combinations of genes. But it is impossible at present to demonstrate exactly how such possible processes as orthogenesis or epharmosis may work. We know nothing of orthogenesis except as a phenotypic phenomenon, though we can conceive the possibility that the genotype tends to undergo continuous progressive change in one direction, change which might depend, for instance, on an orderly series of dissociations of molecular complexes, and show itself by corresponding orderly change of the phenotype in one direction. Such a hypothesis would explain certain phyletic phenomena, but we do not know that it is necessary to explain them thus: they may be brought about in other ways. Epharmosis in the widest sense means simply the continuous adjustment of the organism to its conditions of life. It is often used with reference to external conditions only, but we should not forget that adjustment to external conditions cannot be separated, except by logical abstraction, from the total adjustment of the organism, internal and external. The ontogenesis of each individual is a continuous process of adjustment of every part of the organism to its internal and external environment. So much follows from the universal law that every physical system constantly tends towards equilibrium, and the law is abundantly illustrated in the development of plants. The particular state of relative equilibrium represented by the adult individual is, however, as we know, mainly determined by the stock of genes contained in the zygote from which it is developed, though partly by the particular environment in which it grows up. Epharmosis as a theory of phylogenesis must depend on the belief that the genes themselves can be considerably, continuously, and permanently altered by forces outside themselves—their environment in the wide sense—and it must be admitted that the evidence for such a belief is neither very abundant nor very conclusive. We certainly do not know that genes cannot be so altered; but we cannot point to cases in which it is possible either to assert definitely that they are or to explain plausibly how they may be. On this side the Neo-Darwinian position has not yet, as it seems to me, been successfully attacked, though few biologists who are interested in these questions and not wedded to a particular theory of evolution would now be greatly surprised if it eventually fell.

How, then, are we to make progress to a fuller knowledge of the necessarily interlinked problems of phylogenesis and ontogenesis which together make up the problem of evolution? On the one hand we have the theoretically indispensable genes, of whose nature we have no certain knowledge, though we know a great deal now about the effect on the phenotype of various combinations and omissions of some among them. On the other we have the phenotype, built up from the genes by long and complicated processes of physical and chemical action and interaction between the genes and their derivatives, between the substances and structures of the developing organism, and between these and the environment. Of these ontogenetic processes we still know extraordinarily little. Until quite recently physiology has kept its face averted from such problems, partly as a result of that unfortunate divorce from morphology which we have seen emphasised as a cardinal principle of botanical methodology by distinguished botanists. It must be admitted that these processes are difficult to disentangle, and it is only the great development of physical chemistry, and of the so-called biochemistry which depends so closely upon it, that has opened up during the last twenty years the avenues through which we may approach the problems in this field with any prospect of success. Thirty years ago plant physiologists were mostly either occupying themselves with measuring the 'functions' of the organs of the adult plant under different conditions, or they were caught in the toils of the 'stimulus and reaction' conception, with its postulate of a series of mysterious mechanisms, supposed to have been built up by natural selection, and apparently inaccessible to further analysis. That this conception was a necessary stage in the development of plant physiology we need not deny; but some physiologists, like some of their morphological colleagues, seem to have rather mistaken a transitory stage of development for an ultimate condition of research. Within the last few years we have begun to get *developmental* physiological studies of all kinds, and some of these are at last beginning to give us some insight into the formative processes which result in the differentiated structures of the plant body. A number of years ago Goebel, in his 'Experimentelle Morphologie,' sketched the connexion between various characteristic external forms of plants and definite factors of the environment. In 1916 one of my predecessors in this chair, Professor Lang, clearly outlined the ideal of 'causal morphology,' and indicated lines on which he thought such investigations should proceed. It is, I think, quite possible to claim that 'causal morphology' in the widest sense *is* morphology proper; to say, with Professor D'Arcy Thompson, that since the problems of form are in the first instance mathematical problems, and the problems of growth are essentially physical problems, 'the morphologist is *ipso facto* a student of physical science.'[17] More recently, again, Professor Priestley and his collaborators have attacked with considerable initial success the question of the actual sequence of events leading to the differentiation of various tissues, more particularly endodermis, cork and cuticle, and have perhaps opened the way to a causal ontogenetic understanding of the whole of the tissue systems of the higher plant.[18]

It certainly seems a far cry from a causal knowledge of these ontogenetic processes, common to whole families or large groups of plants, to an understanding of the way in which the genes which determine the difference of phenotype between one species and another, or one pure line and another, bring about the development of the corresponding phenotype. Superficially at least the kind of character whose origin in the ontogeny Priestley and his fellow-workers have been investigating seems to differ in nature from the kind of character which commonly separates species and varieties. The one is built into the constitution, and helps to determine the economy not only of one species but of a wide range of related species or of great groups of plants; the other, so far as the vital economy of the plant is concerned, often seems to be of no importance at all. To use a metaphor which is perhaps just permissible, the difference is like the difference between the plumbing of a house and the decoration of its façade, or between the lay-out and

[17] D'Arcy Thompson, *On Growth and Form*, 1917, p. 8.

[18] I am aware that there are some physiologists who think that this line of attack is overbold, that our existing knowledge of biochemistry and physiology does not justify a direct attempt to grapple with such problems. I can only say that I am not in agreement with this criticism. The results reached seem to me already to justify the methods employed, though, of course, it may well be that some of Professor Priestley's first conclusions will have to be revised in the light of future knowledge.

construction of its rooms and passages and the lighting of these by a few large windows or by many small ones, where the illumination required is equally well secured by either arrangement. I cannot here undertake a discussion of the justification for separating the 'characters' of organisms into different categories, as Professor Gates, for instance, has tried to do,[19] nor of the related controversy between those who believe that a 'particulate' theory of inheritance such as that which has been worked out by the Mendelians is a sufficient basis for explaining all the phenomena, and those who advocate the claims of the organism to be considered 'as a whole,' which usually means in this connexion cytoplasmic inheritance, through the egg and perhaps sometimes also through the pollen. We cannot wholly exclude the possibility of cytoplasmic inheritance, or an eventual effect on the genotype of cytogenetic characters; but from the broad position I am now taking I see no good reason for supposing that the ontogenetic development of what, for want of a better word, I may call 'organisatory' characters differs essentially from that of the characters which are commonly used to separate species and which obey the Mendelian laws. If we define a gene as some substance contained in the zygote which is a factor in the determination of the phenotype, we must believe that all hereditary phenotypic characters alike, internal or external, separating species or common to a great many species, important, indifferent, or disadvantageous in the life economy, are developed from the genotype, *i.e.* from the total stock of genes, whether contained in the chromosomes or not, by an inevitable series of chemical and physical processes, modified, of course, by differences of environment. Now my point is this. We can only hope to connect the genotype with the phenotype by tracing out these processes in detail, by following the ontogenetic history, not only in terms of the production of organs and tissues, of cell division and growth, but in terms of physical and chemical changes, of such processes as pressures and filtrations, oxidations and reductions, hydrolyses and condensations, reversible reactions and catalyses. And I think we may perhaps begin to find a way which will ultimately lead to an understanding of how the genes produce the characters of the organism, and thus of the nature of the genes themselves, by following the trail which has recently been opened, by studying the detailed processes which lead up to the appearance of a structure, over and above, or, as one should perhaps more fittingly say, 'under and below,' that reaction of structure upon process which we have been used to call the 'function' of the structure. It is only in this way, as I believe, that we are likely, for instance, eventually to get more light on the problem of ontogenetic recapitulation, which has certainly not been rendered easier by the Mendelian results and the conception of the 'species cell.'

The botanists of seventy years ago, notably that great pioneer Sachs, in the spacious days of the new 'wissenschaftliche Botanik' in the 'fifties and 'sixties of the last century, had in some ways a view of the problems of structure clearer than that of their immediate successors. It is plain that the overwhelming effect of the theory of descent on the

[19] R. R. Gates, 'Mutations and Evolution,' *New Phyt.* 19, pp. 217 *et seq.*, 1920.

imagination of biologists, the first brilliant results of the evolutionary interpretation of the doctrine of homology, led to an interest in structure for its own sake which could have but a limited fertility. This interest has in the long run been mainly important because it has immensely increased our actual knowledge of structure. At the same time the very human but really quite irrational desire to find a 'use' for everything led to a facile and sweeping application of the theory of natural selection quite out of accord with the patent facts of nature. The physiologists, the people who really remained interested in tracing causal sequences, in finding out 'how things work,' and who retained the only sound method of discovering this—the experimental method—were rather cut off from the interpretation of structure by the assumption that it was causally 'explained' if it were shown or even plausibly believed to be useful to the organism, and tended to confine themselves to measuring and determining the conditions of processes, mainly in the adult plant. Thus there came about that separation of morphology from physiology which was no doubt a sound methodological principle for the restricted purpose of increasing our knowledge of certain series of facts, but which in its general effect on botany has, I fear, tended not only to disruption but to sterilisation. The effect of the divorce between morphology and physiology was just as bad for physiology as it was for morphology. As little accustomed as the morphologist himself to envisaging the plant in its entirety as a continuously developing complex of substances and structures, the average physiologist tended to limit himself, as has been said, to the recording and measuring under different conditions of arbitrarily selected functions or processes, with the result that his work was often at least as arid as the conventional descriptions and correlations of the morphologist. Needless to say, there were honourable exceptions in both camps.

It is instructive in this connexion to consider a work which professed to deal with tissue structure in the light of function or process—a book thoroughly characteristic of the period I have been considering, the first edition being published in 1884 and the latest (the fifth) in 1918 —I mean Haberlandt's 'Physiologische Pflanzenanatomie.' This book describes and discusses each of the tissue systems of the higher plant from the point of view of the part which it plays in carrying on the life functions of the plant as a whole, an excellent aim, and one which is, in the main, admirably carried out. The author makes a great point of adducing experimental evidence for the 'functions' of particular tissues wherever possible. But there is always the implicit assumption that every tissue must *have* a 'function,' must be of some 'use' to the plant, and in his effort to find that use Haberlandt is often compelled to rely on unconvincing argument from structure or from analogy, sometimes on little more than guesswork. It scarcely seems to occur to him that a tissue may have no specific 'use' at all, that structures are developed as the result of the processes which take place in the developing plant, and do not necessarily perform a definite function which is useful to the whole organism. Many of them do, of course; but to confine oneself to the search for such 'functions' is not the right way to get a real understanding of the structure of a plant. At last year's meeting of Section K the President, Professor Dixon, showed reason to believe that the sieve tubes of the phloem are in the cases which he considered quite inadequate for the purpose of carrying organic substances such as sugars from the leaves to the regions where they are used or stored, as, for instance, potato tubers. What, then, we may ask, is the 'function' of sieve tubes? It seems to me that we should not close our minds to the possibility that they may *have* no 'function' in this sense, that cells having the characters of what we call sieve tubes may quite conceivably be formed simply as the result of the processes going on in certain tracts of developing tissue, without subsequently playing any essential part in the economy of the plant.

The analogy of the machine made by man, in which each part is constructed with a definite object, may be very misleading if we allow ourselves to forget that an organism is not constructed in that way at all, but is the outcome of blind, inevitable processes, and may produce parts which are useless or even harmful to it, provided that the whole is still able to 'carry on' and reproduce itself in its actual conditions of life. We should always approach structure through development, the mechanics, physics, and chemistry of growth and differentiation. It is only thus that we can ever hope to 'explain' structure in any real sense. It is only thus, I believe, that we can ever hope to get back to the real nature of the genes.

The 'functions' of the various organs and tissues—'biological' and 'physiological' functions in the old sense—will then appear in their proper places as those properties or activities which actually contribute to the growth, maintenance, and reproduction of the plant—for the plant must grow, maintain, and reproduce itself, or the race will die. The main essential activities are sufficiently obvious, and we can sometimes say with confidence that if such and such a structure were absent or such and such a process did not take place, these essential activities would be fatally impaired. When a failure of this kind takes place owing to change of genotype or of environment we rarely see it, for it brings extinction in its train.[20] For the most part we cannot know that apparently useful characters could not have been dispensed with, or that metabolic processes might not equally well have taken some other course so far as the success of the plant in the struggle for existence is concerned, while in regard to a multitude of characters there is not only no proof but not the smallest reason to suppose that they have now, or ever did have, any 'survival value' at all. Like all structural features, they are simply products of the plant's activity, though they react in turn to a greater or lesser degree on that activity. Differentiation and so-called division of labour are the inevitable result of increase in size, and of the ensuing different relations of parts of the body to one another and to the surrounding medium. Every type of plant, whether it differs from its parents or not, does and must

[20] In his 'lethal factors' the Mendelian geneticist has, however, succeeded in discovering definite heritable entities which lead to such failure and thus to death. The real nature of these may be eventually ascertainable along the line of research indicated above.

'adapt itself' during its development to its conditions of life. That is to say, it does and must react to the forces, external and internal, acting upon its several parts, and the result of the reaction must be to bring it into closer equilibrium with the whole of those forces. It is sometimes forgotten that 'adaptation' in this sense is a wide physical conception which does not imply that the whole of the characters of an organism are 'useful' to it in the sense in which all the parts of a man-made machine are useful.

Thus we conclude that the central and vital part of botany as a science is, and must be, the study of process which creates and modifies structure as well as of process which is in its turn determined by structure. In reality no line can be drawn between processes of these two kinds, for the development and metabolism of the plant form a continuous connected history in which process and structure continually act and interact. Nevertheless, the 'physiological functions' of adult structures certainly have a special position in that the processes of which they consist are, like the adult structures themselves, the current *terms* of ontogenetic development, the current stages of full expression of the given genotype under the given conditions of life.

The separation of morphology and physiology no doubt ultimately takes origin from the two distinct types of human interest in living organisms, characteristic of different types of mind, the one attracted by the forms, formal relationships and classification of *objects*, the other by the understanding of *process*, the knowledge of working. The one naturally observes and classifies, the other observes and experiments. This kind of separation, clearly enough seen among the older naturalists, has been greatly enhanced on the one hand by the enthusiastic effort to trace phylogeny consequent on the acceptance of the doctrine of descent, on the other by the continuous complication of the physical and chemical knowledge and technique required by the study of physiological processes. It has had a profound effect on the teaching of botany during the past forty years. Botanists whose personal research lay in the one field have been less and less able to take an intelligent interest in the other, even if they could understand the terms in which the results were expressed. The student has perforce come to regard and to study the two fields as wholly distinct, with very few points of contact, and his attention has been directed primarily to morphology largely because it is so much easier for the beginner to examine and cut sections of plants and draw pictures of them than to study the processes which go to the making of them. Too little serious effort has been made to overcome the difficulties of teaching students to study process. The physiologists themselves have been too much absorbed in their apparatus to consider the bearing of their subject on general botany. In recent years the rise of new branches of study, such as cytology, genetics, and ecology, has added to the distraction of the student.

The result has been to separate botany into disconnected parts and failure to give the student any unified notion of the subject. It is unnecessary to say that the growth of knowledge inevitably brings in its train ever-increasing specialisation in *research*, but that fact in no way absolves the teacher who is responsible for the introduction of students to the subject from the duty of displaying it as a whole, and this he can only do by making its most vital part, the study of process, the key to his exposition, by representing all structure as the result of process, and, in its turn, as limiting and directing process, rather than by concentrating the student's interest on structure and the comparison of structure for its own sake. It seems to me most misleading to represent morphology (in the sense in which it has come to be used) and physiology as if they were equivalent branches of the subject between which the attention of students should be divided. It is only the most superficial view that can regard them as equivalent. Structures are the end results of processes, and to understand them we must study process by observation and experiment. It is unnecessary to remark that thorough and accurate acquaintance with facts of structure is incidentally essential. But to claim the larger portion of the student's time and energy for the work of becoming acquainted with the details of structure of all the various groups of plants involves, in my view, a very serious misdirection of effort.

There should be no division of elementary botany into morphology and physiology. In advanced work there must, of course, be differentiation, as there must in research, not into morphology and physiology, but into a great number of groups of connected phenomena, because of the vast number and complication of the phenomena of the plant world. Some minds find their satisfaction in studying structure for its own sake, so to speak, and in comparing the structures studied. Their research will naturally lie in that direction, and it is certain to increase, as it has in the recent past already vastly increased, our knowledge of the detailed facts of structure of the plant kingdom, to reveal unsuspected relationships, and to establish probabilities as to the lines evolution has followed. But this knowledge *in itself*, considered in relation to the science as a whole, is, and must necessarily remain, superficial. Its conclusions even in regard to the lines which evolution has followed can at the best never attain to more than a considerable degree of probability. And its methods and aims can never explain structure in any real sense. For that a study of process is essential.

The great development in morphological knowledge, especially of what I have called the middle grades of the plant kingdom, and of the great groups of fossil plants which belong to these grades, has, as we must all recognise, immensely increased our acquaintance with the structure of the plant world. It was a natural development of interest in the past history of plants, stimulated and directed by the acceptance of the doctrine of evolution. Looking back upon the history of botany during the past half-century we must be grateful to this movement, and proud of the leading and distinguished part our countrymen have played in its development. But I cannot think that it has had a wholly good influence on the progress of botany, particularly on botanical teaching and research in this country. This has remained too long dominated by the ideal of tracing phylogeny, has given far too much time to the detailed morphology of the different groups which make up the plant kingdom, and has correspondingly neglected the newer knowledge of process which must be the main avenue to a deeper understanding of plants. Fortunately there are now many signs of impending change. Meanwhile the younger workers, dissatisfied, especially during the last two decades, with the older outlook, have turned more and more to specialised physiological research, to mycology or to genetics, with their outlets on practical life, but often without the grounding that only a thorough grasp of the essentials of the subject can give. One of the results has been that botany has to a large extent become disintegrated, workers in particular parts of the subject having little understanding and less interest in the results of their fellow-workers in other parts. It may be said that this is an inevitable result of the complication of the subject, and no doubt that is partly true. There is a type of professional worker who, having once got immersed in a particular line of research, resolutely refuses ever to come out of his groove and take a broader view. The subject no doubt owes a great deal of its energetic detailed development to such workers. But if botany, as the science of plants, is to retain any meaning as a whole, somebody must retain the power of looking at it as a whole. And if, as teachers, we fail to keep touch with the newer developments, and are consequently no longer able to focus the whole subject from a viewpoint determined by current knowledge, this power will come to be possessed by fewer and fewer botanists, and the subject will definitely and finally break up into a number of specialised and unco-ordinated pursuits.

Do we want that to happen? I think that most botanists would answer 'No!' I do not think there can be any question that the most advanced research worker, as well as the student who never goes on to research, benefits substantially by having had a training which is at once the broadest and the most vital that is possible. As science continuously advances and necessarily specialises, the unexplored fields which lie between the traditional lines of research become of more and more relative importance. They cannot receive adequate attention—the student can, indeed, hardly become aware of their existence—unless his introduction to the subject is continuously informed by the widest outlook and the clearest apprehension of the essential relations of the phenomena of plant life.

THE EDUCATION OF THE PEOPLE.

ADDRESS TO SECTION L (EDUCATIONAL SCIENCE) BY

T. PERCY NUNN, M.A., D.Sc.,

PRESIDENT OF THE SECTION.

In consonance with the general aim of the British Association, the special purpose of our Section is the advancement of educational science. The Section owes its existence to a group of persons who saw clearly that in education, as in all the great fields of practice, there are, and must constantly arise, problems that can be solved only by patient application of the methods of science. The range and importance of these problems were illustrated by Sir Robert Blair in his Presidential Address to the Cardiff Meeting, but I do not propose working over any of the ground which my distinguished predecessor then surveyed. My intention is to take advantage of the customary right of a President to travel outside the strict bounds of his science and to deal with questions which the results of inquiry within its limits illuminate but do not themselves answer.

To a President of Section L the temptation to use this wider liberty must always be strong; for, however far the scope of educational science may extend, the critical educational issues will always lie beyond it. If the term 'education' is used, as it sometimes is, to include all the influences which affect mind and character, it is obviously much more than an applied science. But so it is if the term is restricted, as I shall restrict it, to those formative influences which are brought to bear with some degree of purpose upon the minds of the young. In its origin education is a biological process found not only in all human societies, however primitive, but even in a rudimentary form among the higher animals. By calling it biological I mean that it is a native, not an acquired expression of the race's life, correlative to the race's needs; that it does not wait for deliberation to call it into existence or for science to guide it, but has the inevitability of behaviour rooted in instinct. Thus, as I have argued elsewhere, educational science stands to education in much the same relation as hygiene stands to the physical life; it is a critic rather than an originator; it scrutinises and pronounces judgment upon ways and means, but does not and cannot prescribe the general direction which the educational process shall take. At most it can only help to stabilise the movement by lifting it from the level of instinctive impulse or vague opinion to the plane of ends clearly envisaged and consistently pursued.

What is it, then, that determines the general character of the educational process at a given point in the history of a human society?

The answer is, briefly, that the same *élan vital* which brought the society to that point urges it so to train its young that they may maintain its tradition and ways of life. But this statement needs an important qualification. The consensus of a society never approves of all that goes on within its borders, and among the activities it treats as admissible sets a higher value upon some than upon others. Accordingly the biological impulse which is the mainspring of education tends to select for the training of the young those activities which society judges, consciously or instinctively, to be of most worth. It follows that the education a nation gives its children is, perhaps, the clearest expression of its *ethos* and the best epitome of its scheme of life. Thus the ideas of too many of our Georgian forefathers upon the education of the masses corresponded faithfully with their belief in the great principle of subordination about which Johnson and Boswell talked so often and agreed so satisfactorily. One remembers, for instance, how hotly Miss Hannah More denied the scandalous rumour that she was teaching the poor of Cheddar to write! Similarly, the liberal curriculum of our elementary schools reflects the prevalence to-day of a widely different view of the nature and purpose of society. One is tempted to add that the misgivings with which that curriculum is, here and there, still regarded may be largely due to the ideas of the eighteenth century dying hard in the twentieth.

If what children are taught is but an expression of the general mind of their time and nation, what guarantee is there that education shall be an instrument of social progress and not of retrogression? It must be acknowledged that there is no such guarantee. Among the ideas and ideals, the modes of feeling and action current in a society, it is possible for the general mind to approve the worse rather than the better, and so to give a fatally wrong turn to the training and outlook of whole generations. Have not some of the great tragedies of history thus come about? Such disasters are, in fact, avoided only where the predominant mind of a people has a sufficient sense of the things that belong to its peace. It follows that the ideal 'educational authority' would be neither the teacher with forty years' experience nor the brilliant exponent of educational science, but the *phronimos*—the perfectly wise man who had grasped fully the meaning of man's existence, could see to the bottom of his people's life, appraise justly all its movements, and discern with sure eye its needs. Assuming that he could also communicate his vision to his fellow-citizens, we should do as well under his guidance as the imperfections of humanity would allow.

Unhappily the true *phronimos* appears but rarely, and when he comes bears no unchallengeable certificate of authenticity. If he is not at hand or is unrecognised, we ordinary men and women must apply to our problems the best insight we can attain, trusting that in the conflict of sincere opinions the soundest will in the end prevail. For example, I have referred to the great change in the conception of popular education which has taken place in our time, and have connected it with the steadily growing belief, first, that every member of society has an equal title to the privileges of citizenzship; and, secondly, that the corporate strength of society should be exerted to secure for him actual as well as theoretical possession of his title. How the movement based upon that belief will ultimately affect the happiness of our people no one can with certainty foresee; nevertheless, if one is interested in the wider educational issues one must define one's own attitude towards it. I am, therefore, bound to record my opinion that in its main tendency it ought wholeheartedly to be accepted. I think this chiefly because it seems to be inspired by the Christian principle of the immense value of the individual life, or, if you prefer to put it so, by the Kantian principle that no man ought to be treated merely as a means but always also as an end in himself. But if the movement is accepted, public education must correspondingly assume a character which would follow neither from the principle of subordination nor from the principle of *laissez faire*. The view I submit is that the education of the people should aim at enabling every man to realise the greatest fullness of life of which he is by nature capable—'fullness' being, I add, measured in terms of quality rather than of quantity, by perfection of form rather than by amount of content. That view is the basis of all I have to say.

Having adopted it, I am compelled at once to face the question, What are the essential qualities of a full life? It is just here that the judgment of the *phronimos* would be invaluable. In his absence I must hazard the conjecture that he would approve of at least the general drift of the following observations. During the last century we learnt, following Darwin, to look upon all biological phenomena as incidents in a perpetual struggle wherein the prizes to be won or lost were the survival of the individual and the continuance of his species. From this point of view there could be only one object of life, one *causa vivendi*, namely, to continue living, and the means by which it was to be attained were adaptations to environment achieved by an individual, and perhaps handed on to its offspring, fortunate germinal variations, or lucky throws of the Mendelian dice. It was natural, if not logically necessary, that the doctrine should fuse with the view, as old as Descartes, that life is but an intricate complex of physico-chemical reactions. Upon that view, even to speak of a struggle for existence, is to use a metaphor admissible only on account of its picturesque vigour; when we study the forms, processes, and evolution of living beings we are spectators merely of the operation of physical and chemical laws in peculiar forms of matter. Thus the occurrence and the phenomena of life are finally and wholly to be explained in terms of the statistical distribution of positive nuclei and their satellite electrons.

These ideas, in either their more moderate or their more drastic form, affected the attitude of men towards matters lying far outside the special province of biology. National policies have been powerfully influenced by them, and it has been widely held that the education of children should be shaped mainly if not solely with a view to 'efficiency' in the struggle for existence. It is, therefore, relevant to point out what tremendous difficulties are involved in their thorough-going application. I will not speak of those which have driven physiologists of high standing to reject the mechanistic theory of life as unworkable, for I am not competent to discuss them, and they do not bear directly upon my argument. It will be both simpler and more to our purpose to raise, as William James did in the last chapter of his great treatise on psychology, the question of the higher æsthetic, moral and intellectual qualities and achievements of man, and to ask how these are to be brought under the conceptions before us. To be fair we will not press the question how the emergence, say, of Beethoven's Fifth Symphony is to be explained in terms of physics and chemistry; for even the most stalwart mechanists hardly expect that it will actually be done; they only believe that conceivably it could be done. But it is both fair and necessary to ask how the things of which the symphony is typical can be accounted for on the principle of survival-value. James, facing this question with characteristic candour, felt bound to admit that they have 'no zoological utility.' He concluded, therefore, that the powers and sensibilities which make them possible must be accidents—that is, collateral consequences of a brain-structure evolved with reference not to them but only to the struggle for material existence. The premises granted, I do not see how the conclusion can be avoided; but surely it is extremely unacceptable. If, with Herbert Spencer, we could regard art merely as something wherewith to fill agreeably a leisure hour, we might be satisfied by the hypothesis that our sensibility to beauty in form, in colour and in sound, is an 'epiphenomenon' having no significance in relation to the real business of life. But when we think of men whose art was in truth their life, and consider how eagerly the better part of mankind cherishes their memory and their works, it is next to impossible to be satisfied with that view. Or take the case of science. Votaries of pure science often seek to justify their ways to the outer world by the argument that discoveries which seemed at first to have only theoretical interest have often disclosed immense practical utility. It is a sound enough argument to use to silence the Philistine, but would the pursuit of science lose any whit of its dignity and intrinsic value if it were untrue? For instance, would any member of this Association refuse his reverence to the great work of Albert Einstein even if it were certain that, in the words of the famous toast, it would never do anybody any good? I will not lengthen the argument by extending it to the saints and the philosophers, for its point should be already sufficiently plain. The activities of 'our higher æsthetic, intellectual and moral life' have such intrinsic worth and importance that to regard their emergence as accidental and biologically meaningless is outrageously paradoxical. They must be at least of equal significance with anything else in man's life, and may not unreasonably be held to contain the clue to life's whole meaning.

It may be helpful to put the conclusion in other language. Man's life is a tissue of activities of which many are plainly *conservative* in nature. By this I mean that their function is directly or indirectly to maintain the existence of the race and the individual. Agriculture, industry, defence, medicine, are obvious instances of the type, and the list could easily be extended. But there are other activities—I have taken art and pure science as capital instances—whose character, in contrast with the former, is best indicated by the term *creative.* The point I have tried to make is that in any sane view of human life as a whole the creative must be regarded as at least as significant and important as the conservative activities.

Having travelled so far one must perforce go farther. Purely conservative and purely creative activities, if indeed they exist, are only limiting instances; in most, if not in all activities, the two characters are interfused. For example, the motive of pure science is unmistakably creative, yet its extrinsic conservative value is unlimited; on the other hand, the vast industrial organisations of to-day exemplify activities which, though conservative in their genesis, yet have developed the creative character in an impressive degree. Considerations of this kind prepare one to see that the higher creative life, far from being merely a splendid accident, is really the clearest and purest expression of the essential character of life at all its levels. The poets are, as the Greeks called them, the supreme *makers,* for all making has in it something of the stuff of poetry. In short, there is no life, however humdrum, however crabbed by routine, which is not permeated by the self-same element whose inflorescence is literature, art, science, philosophy, religion.

The argument might rest here, but I am constrained to carry it still farther. I find it difficult to believe that what is true of human life in its conscious aspect is not in some sense true of life as a whole. Competent observers, for instance Professor Garstang, hold that in the animal world there is something strictly comparable with æsthetic creation, but I have in view an idea of wider scope. It is the idea developed with whimsical seriousness by Samuel Butler, namely, that the variations or mutations which in one form or another every theory of evolution postulates, are in essence acts of creation homologous with human inventions and works of art—that if, for example, we compare the emergence or modification of an animal organ, say, with the creation of *Hamlet* or the invention of the petrol-engine, the differences between the two things, vast as they may be, have yet less significance than the fundamental resemblances. This view, which is implicit in some of the older philosophies, is central in the speculations of M. Bergson; it is congruent with the ideas of several modern thinkers who are hardly to be called Bergsonians; and I think it is beginning to invade orthodox biology. It is certainly incompatible with the mechanistic theory of life, but nevertheless leaves room for all that the upholders of the theory are entitled, and (I venture to think) are really concerned to claim. That the life of an organism can be analysed exhaustively into physical and chemical factors is a proposition which it would be extremely rash to dispute; but it is, I think, plainly untrue that the behaviour of the organism as an integrated unit remains within the categories of physical science. Here I take my stand with Professor Alexander and Professor Lloyd Morgan, holding that life is not the mere sum of the physico-chemical reactions that occur in an organism but a constitutive quality of the complex of those reactions—a quality not 'epiphenomenal,' but substantial in the sense that it makes a difference to what Professor Stout has called the executive order of the world. In Dr. Lloyd Morgan's happy phraseology, the behaviour of an organism *involves* chemical and physical factors, but *depends* on the 'emergent' quality which may properly be distinguished as life. If that be the case, life may well exhibit throughout its range the creativeness which, I have suggested, is one of its essential characters. My educational argument does not stand or fall in accordance with the truth or the falsity of this view; but if the view were well founded the significance of the creative element in human life would be made clear beyond dispute, and the general force of the argument would be greatly strengthened.

The foregoing discussion has wandered some distance from the class-room. Nevertheless it has, I think, a close bearing upon the questions what ought to be taught and in what spirit the teaching should be given. The curriculum, we have seen, always *will* be a partial reflection of the actual life and traditions of a community, and *ought* to reflect all the elements therein which have the greatest and most permanent value and significance. Without doubt these will, in general, be the things that have the highest significance and value for the human family as a whole, but there can hardly be said to be a common human tradition. There exists, it is true, a common European tradition based mainly upon the Græco-Roman and Christianity, and it is vastly important for the happiness of the world to deepen and vivify men's consciousness of it. But even this lacks the concreteness needed to form the basis of popular education—as is seen by contemplation of France and England, two nations that have grown up in it and have influenced one another strongly for centuries, and yet have perfectly distinctive cultures. In short, a nation is the largest social unit whose *ethos* has the necessary individuality. Hence, though we should aim at making our young people 'good Europeans,' we can do so only by shaping them into that particular brand of good Europeans who are rightly to be called good Englishmen. Their education should be, in Professor Campagnac's illuminating phrase, a 'conversation with the world,' but the conversation must, in the main, be conducted in the native idiom. Hence the importance of fostering in our elementary schools the special traits of the English character at its best; of giving English letters a chief place among the studies of our youth; of cherishing the English traditions in the arts and crafts, including our once proud art of music; even (as Mr. Cecil Sharp rightly urges) of reviving the old dances which were so gracious and typical an expression of our native gaiety and manners. Lest this contention should be misunderstood I add that I preach neither the hateful doctrine that what is foreign should, as such, be excluded, nor the ignorant and presumptuous doctrine that what is our own is necessarily the best, and that we have nothing to learn from other peoples. The whole burden of my argument is that the things which have universal human value are the things of most importance in education. But the universal can be apprehended only where it lives in concrete embodiments. In the cases we are concerned with, these are elements or organs of a national culture; and the only national culture to which a child has direct and intimate access is his own. He should be taught to see, as opportunity permits, how much of it is derived from the common European tradition and how much it owes to the influences of other national cultures; but it should, in its concrete individuality, be the basis of his education.

Lastly, I have urged that among the strains or currents in a national tradition the highest value belongs to those that are richest in the creative element. These are themselves traditions of activity, practical, intellectual, æsthetic, moral, with a high degree of individuality and continuity, and they mark out the main lines in the development of the human spirit. Consider what man has made of poetry and what poetry has made of him; what a noble world he has created out of the sounds of vibrating reeds, strings, and brass; think of the expansion of soul he has gained through architecture and the arts of which it is the mother and queen; of the achievements of his thought, disciplined into the methods of mathematics, the sciences and philosophy. Do we not rightly measure the quality of a civilisation by its activities in such directions as these? And if so, must not such activities be typically represented in every education which offers the means to anything that can properly be called fullness of life?

If the force of the argument be admitted, the principles of the curriculum, about which so much has been written, take a clear and simple shape. A school is a place where a child, with his endowment of sensibilities and powers, comes to be moulded by the traditions that have played the chief part in the evolution of the human spirit and have the greatest significance in the life of to-day. Here is the touchstone by which the claims of a subject for a place in the time-table can be infallibly tested. Does it represent one of the great movements of the human spirit, one of the major forms into which the creative impulses of man have been shaped and disciplined? If it does, then its admission cannot be contested. If it does not, it must be set aside; it may usefully be included in some special course of technical instruction, but is not qualified to be an element in the education of the people.

The same criterion may be applied to the methods by which the subjects of the curriculum are taught. We are constantly told that the ‘ educational value ’ of a subject lies in the mental discipline it affords, and, from this point of view, a distinction is made between its educational value and its import as an activity in the greater world; thus geometry is taught as a training in logic, the use of tools as ‘ hand and eye training,’ and so forth. From the standpoint I ask you to adopt that distinction is unjustifiable and may be dangerously misleading; it has, I fear, often been a source of aridity and unfruitfulness in school teaching. The mistake consists in supposing that the disciplinary value can be separated from the concrete historical character of the subject as a stream of cultural tradition. The discipline of the school workshop consists in using the tools of the craftsman for purposes cognate with his and inspired by his achievements. It is because this has not always been done that methods of ‘ manual training ’ have too often falsified the expectations of their advocates. Similarly the discipline of school geometry consists not in mastering an abstract scheme or formula of argumentation, but in steeping one's mind in a certain noble tradition of intellectual activity and in gradually acquiring the interests, mental habits and outlook that belong to it. To say this is not to minimise the importance of discipline or to expel from school studies the austerity which the grave old word suggests. How, for instances, could it be said that our school mathematics represented truly the genius of real mathematics if we neglected the element of laborious accuracy and precision of thought which are essential to it? What is insisted on is that the several forms of mental discipline are characters of concrete types of creative activity, practical, æsthetic, intellectual, and that they influence the mind of the learner favourably only in so far as he pursues those activities as adventures of the human spirit, laborious yet joyous and satisfying, and pursues them after the manner of the great masters. In short, true discipline comes simply by trying to do fine things in the fine way.

The foregoing principles, stated in a necessarily brief and crude manner, are open to misconceptions against which it is desirable to protect them. In the first place, it may seem that I am designing the education of the people upon a scale which may be magnificent but is certainly impracticable. Now I recognise the need of following the advice of a wise official friend who bids one always to bear in mind the magnitude of the educational problem—to remember the slum school and the remote village school as well as the happily placed schools of rich and progressive urban authorities. It is easy, no doubt, to form extravagant expectations, and by seeking to do too much to achieve nothing solid at all. But the argument is concerned far less with the standard to which school studies may be pursued than with their proper qualities and the spirit that should inspire them. In particular, it is directed against the attitude expressed recently by a public speaker who asked what good is poetry to a lad who will spend his days in following the plough and spreading manure upon the fields. Against this attitude it urges that a man's education, whatever his economic destiny, should bring him into fruitful contact with the finer elements of the human tradition, those that have been and remain essential to the value and true dignity of civilisation. This ideal does not assume advanced scholarship or gifts beyond those of ordinary mortals; it implies merely that the normal human sensibilities and powers should be directed along the right ways.

But, it may be objected, granted the soundness of the ideal as an ideal, the shortness of school life still makes it impracticable. This is a criticism to be treated with respect. It is true that a study, to be of real value, must be carried far enough and followed long enough to make a definite and lasting impression. It is also true that some studies can hardly produce their proper effects at all until a certain level of maturity has been reached. For example, there is much of vital moment in science which evokes no response in a pupil before the age of adolescence. But what is to be deduced from these admissions? Surely the conclusion, which the public mind is slowly accepting, that so long as children leave school for good at fourteen some of the best fruits of education will be unattainable and the security of the others precarious. It is not merely a question of length of time, but also, and even mainly, of psychological development. The more carefully youth is studied the more significant for after-life the experience during the years of adolescence is seen to be. Its importance is not a modern discovery; for even the primitive races knew it, and the historic Churches have always taken account of it in their teaching and discipline. But the problems of what has ever been a fateful period have acquired under modern conditions of life a new urgency. Parents and teachers have worried over them, devoted club-workers have wrestled with them, novelists and psychologists have studied them. In connection with the psychologists, mention of Dr. Stanley Hall's monumental work is as inevitable as it is now superfluous; reference should, however, be made to the recent memoir in which Dr. Ernest Jones has freshly illuminated the old idea that the onset of adolescence marks a definite break and recommencement in mental growth. Especially interesting is the parallelism he establishes between the successive phases of childhood and the corresponding phases of youth. But though in a sense the adolescent retravels a psychological route which he has already traversed in childhood, he is, of course, capable of vastly deeper and wider vision and experience. The case for universal education beyond the age of fourteen depends ultimately upon the importance of shaping his new capabilities in conformity with the finer traditions of civilised life. Public opinion, regretting the generous gesture of 1918, has not at the moment accepted the larger view of the mission of education; but as the nation learns to care more for the quality of its common manhood and womanhood and understands more clearly the conditions upon which that quality depends, the forward movement, now unhappily arrested, will certainly be resumed. For that better time we must prepare and build.

There is another objection to which I should think it unseemly to refer if it were not a stumbling-block to so many persons of good will. A liberal public education will, they fear, make people unwilling to do much of the world's work which, though disagreeable, must still be carried on. The common sense of Dr. Johnson gave the proper reply a hundred and fifty years ago. Being asked whether the establishment of a school on his friend Bennet Langton's estate would not tend to make the people less industrious, 'No, sir,' said Johnson, 'while learning to read and write is a distinction, the few who have that distinction may be the less inclined to work; but when everybody learns to read and write it is no longer a distinction. A man who has a laced waistcoat is too fine a man to work; but if everybody had laced waistcoats, we should have people working in laced waistcoats.'

Lastly, complaint may be made that in all this discourse about the finer values nothing has been said about the ordinary utilities, and the ironical may ask whether it is an error to suppose that the education of the people should furnish them with useful knowledge and abilities. Now the test of utility which the plain man applies to education is, in principle, sound and indispensable; it is, in fact, congruent with the biological origin and function of the educational progress. The only point doubtful is whether the test is always based upon a sufficiently broad idea of utility. The only satisfactory definition of the useful is that it contributes definitely and positively to fullness of life. From that point of view it is useful to teach a ploughboy to love poetry and not useful to teach a public schoolboy to hate Greek. This is not, I remark, an argument against teaching a subject whose disappearance from our education would be an irreparable disaster. It means merely that the literatures of the ancient world, when taught, should be taught in such a way as to contribute positively to the quality of a modern life. But the term ' useful,' according to the definition, certainly includes utility in the narrower sense. The daily work of the world must be kept going, and one of the essential tasks of the schools is to fit the young to carry it on under the immensely complicated conditions of present-day civilisation. There is no incompatibility between this admission and the general line of my argument. The only relevant limitation imposed by the argument is that what is conservative in purpose shall be creative in its method and, being so, shall embody some dignified tradition of practical, æsthetic, or intellectual activity. The condition may be satisfied by a technical education based upon many of the great historic occupations of men and women—for example, upon agriculture, building, engineering, dressmaking—provided that inspiration is sought from the traditions of the industry or craft at their noblest. Anyone who has a wide acquaintance with the schools of the country will know some whose work accords with these high requirements and gives to practically minded boys or girls an education truly liberal in aim—that is, an education which tends to free their minds from bondage to sordid tastes and petty interests and to make them happily at home among large ideas and activities of wide and enduring importance. What these schools have done and are doing should be borne in mind when Article 10 of the Act of 1918 comes again to life or is replaced by legislative provisions of still bolder design. To conceive ' secondary education for all ' as meaning ' the grammar school curriculum for all ' would be to make a most serious blunder. The only mistake more serious would be to exclude adolescent boys and girls, even of the humblest station, from any essential part of the national inheritance of culture. But this error may be avoided while full account is yet taken of the far-reaching differences in the talents and *ingenium* of individuals and the rich diversity of the valuable currents, intellectual, practical, and æsthetic, in the life of the community, of which any one may be made the basis of a course truly liberal in quality.

The eminent philosopher, Professor Giovanni Gentile, now Minister of Public Instruction in the Italian Government, has in more than one brilliant work—notably in his eloquent lectures on 'The Reform of Education '—expounded views largely congruent with those expressed in this paper. I welcome his agreement not merely because it may be presumed that the principles he upholds are the principles informing his administration, but even more because the philosophical positions from which we start are widely different. Signor Gentile holds, as I do, that the proper aim of education is to shape the activities of the individual spirit in accordance with the best traditions of the human movement. In particular, he does not shrink from insisting that the simplest instruction in the primary schools should be offered in the true spirit of culture. And he also maintains that the education of the people must be national in its general setting. Indeed, I venture to think that he sometimes carries this idea too far—appearing to advocate as an end in itself what should surely be only the means to a broader end, and to forget his noble declaration that the teacher must always stand for the universal. This is an error hard to be avoided by a philosopher whose inspiration is largely Hegelian; moreover, it is easily pardonable in a patriotic speaker with the glorious cultural history of Italy behind him and before him the elementary school teachers of Trieste *redenta*. But although I regret Signor Gentile's adhesion to what I consider a false view of the relation between the individual soul and society, his book has high value, for it expresses a passionate conviction that during the last century the development of the great European peoples went in some respects sadly astray, and that their moral health can be restored only by education inspired from top to bottom by a true judgment of values. Here he is, I believe, fundamentally right. The last hundred years have greatly accentuated the gravity of a problem which was discerned by the poet Schiller and diagnosed in the famous 'Letters on Æsthetic Education' he published in 1795. To this diagnosis Dr. C. G. Jung has devoted an interesting chapter in his book on 'Psychological Types.' In Schiller's view the immense progress of the modern nations has been purchased at the expense of the development of the individual soul, so that, in spite of the greatness of our achievements, we are, man for man, inferior to the various and well-rounded Athenians of the best days. It is the division of labour essential to a large scale organisation of society which has at once made general progress possible and individual impoverishment inevitable, for it has cut individual men off from experiences that are indispensable to the full well-being of mankind. If this was true in the days of the French Revolution, how much more true it is to-day, and how much more grave the evil. We are told that before the era of industrialism the great mass of our people enjoyed a culture which, though simple, was sincere and at least kept them in touch with the springs of beauty. What truth there is in the picture I do not know, but it is certain that with what is called the industrial revolution the conditions that make it credible largely disappeared. Torn from the traditions of the old rural life and domestic industry and herded into towns where in the fight for mere existence they lost their hold on all that gave grace to the former life, and where the ancient institutions which might have helped them to build up a worthy new one were themselves submerged in the rising tide of featureless and monotonous industrial activity, the folk who now constitute the bulk of our population were cut off effectually from 'sweetness and light.' That was the situation when the task of public education was taken seriously in hand, and that, notwithstanding a great amelioration in details, is for far too many the situation to-day. There are some who think that the only remedy is to cry halt to the modern movement and return deliberately to mediævalism. This is, I fear, a counsel of despair; instead of indulging idle dreams it will be more profitable, assuming the unalterable conditions of modern life, to consider how the rest may so be modified as to place the true dignity and grace of life within the reach of all who are qualified to achieve them. That can be done only by a system of education which brings the things of enduring and universal worth to the doors of the common people. It is what has been done by many an elementary school teacher, sometimes with scant assistance from public opinion, simply because, face to face with his helpless charges, he was impelled to give them the best he had to give. It will be done with increasing happy results the more clearly it is seen that the proper function of the elementary schools is something much more than to protect the State against the obvious danger of a grossly ignorant populace or to ' educate our masters ' in the rudiments of citizenship. And unless it is done, unless the natural hunger of the people for knowledge and beauty is wisely stimulated and widely satisfied, no material prosperity can in the end save the social body from irretrievable degradation and disaster.

SCIENCE AND THE AGRICULTURAL CRISIS.

ADDRESS TO SECTION M (AGRICULTURE) BY

CHARLES CROWTHER, M.A., Ph.D.,

PRESIDENT OF THE SECTION.

In addressing the Section as President I would confess at the very outset to a pride that I should be permitted to occupy a post of such great honour, for which my chief qualification must be that of having graduated through every other office provided for in the Sectional organisation.

I could only have wished that the honour had fallen to me in any year other than the present, in which my energies have been fully absorbed by the duties of a new appointment of a peculiarly difficult character; and it is with some misgiving that I venture to address the Section to-day, being conscious of having nothing to offer but a few random thoughts, incubated at odd moments, and reduced to verbal form under conditions which have not permitted the careful revision that the occasion demands.

For the second consecutive year the Section meets in a great seaport, a city whose activities are written large across the history of British agriculture throughout the past century, and have contributed in no small degree to the anxieties with which the industry is beset at the present day. The part played by the port of Liverpool in shaping the fortunes—or misfortunes—of British agriculture might well have formed an appropriate subject for the Presidential Address to this Section, had I possessed the competence and leisure to deal with it effectively, but I must confine myself to matters falling more closely within the range of my everyday activities.

When the Section met last year British agriculture was reeling under the shock of a second disastrous year, which in large sections of the industry, notably those dependent primarily upon the direct sale of crops, seemed likely to produce a crisis of the gravest character, and greatly accentuated the existing anxiety even in sections of the industry less directly affected. This atmosphere of crisis still unfortunately persists, though permeated now perhaps by a rather more optimistic note, and it must necessarily receive the consideration of this Section of an Association which aims at intimate touch with the everyday life of the nation.

It is generally recognised that the primary causes of the present difficulties of British agriculture are strictly economic in character, and not due to any gross and general failure to apply present-day scientific knowledge to the technique of farming, although the great disparity which exists between the average production of the country and that secured by the more competent farmers on soils of the most diverse natural fertility suggests that with a higher general level of technique and education the intensity of the crisis might have been sensibly reduced. So far, however, from there having been any appreciable lowering in the general standard of our farming, as measured by the application of the teachings of agricultural science, it is the common experience of those of us who are in close touch with the farming community that recent years have witnessed a very marked and rapid development amongst farmers of interest in agricultural education and research. Throughout the more intelligent section of the older farmers and the whole body of the younger men the old antagonism between 'practice' and 'science' is rapidly disappearing. Whether it be a case of the 'sick devil' or not, the agricultural community is at present in a more receptive mood towards scientific advice than at any time I can recall in some twenty years' advisory experience, and I believe the moment to be opportune for a forward movement in agricultural education, which, if wisely developed, may remove the last vestiges of opposition and establish education and research firmly in their rightful places in our agricultural organisation.

I have referred to the causes of the present crisis as being strictly economic, and such palliative measures as have been adopted or suggested have been almost entirely aimed directly at immediate economic relief. There is, indeed, the danger that if the exponents of agricultural science remain silent the impression may get abroad that we have nothing substantial to offer towards the alleviation of the crisis, and it is my main purpose to-day, therefore, to indicate some of the directions in which I believe help can be given, and some of the lines along which development of our scientific and educational organisation is, in my opinion, more especially necessary at the present juncture.

Our agricultural educational system may be likened to a pyramid with research at the apex, elementary education and general advisory work at the base, with intermediate education, higher education, and higher advisory work occupying the intervening parts. Our pyramid has grown within the last thirty years from a very modest structure of low elevation into an imposing edifice, which perhaps appeals to the mind's eye more through its height than its spread, the upward growth having taken place at a proportionately greater rate than the expansion of the base. Such, at least, it appears to me, and I shall suggest to you later that the essential need of the moment is a broadening of the base with a view to greater stability and a more effective transmission of the results of the activities of the upper portions to the maximum basal area over which they can beneficially react.

For the purposes of my survey it will be convenient to follow the customary classification of our work into research, advisory work, and teaching. Of these three divisions I propose to deal but very briefly with the first, that of research, since the potentialities of research for the advancement of agriculture are too patent to require exposition, the ultimate object of all agricultural research being the acquisition of knowledge which will enable the farmer to comprehend his task more fully, and to wield a more intelligent control over the varied factors which govern both crop production and animal production.

Agricultural progress must be dependent upon research, and no phase of our agricultural educational system is so full of great promise for the future as the comprehensive research organisation, covering practically every field of agricultural research, which has been brought into existence during the past twelve years, and developed upon lines which ensure an attractive career to a large number of the most capable research workers coming out of our universities. In praising the Research Institute scheme I am not unmindful of the needs of the independent research worker and the spare-time research work of teaching staffs—the type of research work to which we owe so much in this country—and it is with some anxiety that I have watched the distribution by the Ministry of Agriculture of the modest resources available for the support of this class of work. I trust that my fears are groundless, but I am afraid of a tendency to deflect such resources towards the work of the Research Institutes, a tendency which in common fairness to the independent worker should be most strenuously resisted. With a sufficiently liberal conception of the class of work which can be effectively carried through by the independent worker there should be no difficulty in allocating these moneys to the purposes for which they are intended.

In suggesting, as I did a few moments ago, that in proportion to the means available agricultural research is perhaps more adequately provided for at the moment than other branches of agricultural educational activity, nothing is further from my mind than to imply that greater resources could not be effectively absorbed in this direction, but I am guided by the feeling that a due measure of proportion should be maintained between research and the organisation behind it designed to translate the findings of research into economic practice, and to secure that each advance of knowledge shall be made known quickly and effectively throughout the industry.

It is chiefly in the latter direction that agricultural science can make an immediate and effective contribution to the alleviation of the present crisis, since agricultural research in the main does not lend itself to the 'speeding-up' necessary for quick action. The same applies also to formal educational work, which must necessarily exert its influence on the industry but slowly.

The one line of approach along which agricultural science can make its influence felt quickly is that of *advisory work*, which consists in the skilful application of existing knowledge to the solution of practical problems, or at most the carrying out of investigations of a simple type, with a view to securing guidance as to the solution of the problem in time for effective action to be taken.

It is, therefore, to the possibilities of such advisory work that I propose to turn my attention in more detail. The root difficulty of agricultural educational propaganda in the past has been to secure a sufficiently intimate and widespread contact with the farmer, and for this purpose no agency at our command is so valuable as advisory work, since it ensures a contact with the individual farmer which is both direct and sympathetic, originating, indeed, in most cases out of a direct request for help. The difficulties in the way of extending advisory work greatly I shall turn to presently, but I wish first of all to outline some of the more immediately helpful forms of advisory work which have fallen within the scope of my own personal experience.

When some four years ago I undertook to develop for the late Lord Manton a research and advisory organisation to furnish guidance in his extensive farming enterprises, I was obliged in the first instance to take account of the fact that the resources at my disposal, though large, would not serve to cover the whole field of agricultural problems, and so far as specialist work was concerned it would be necessary to concentrate on two or three fields of activity, outside which only general guidance could be afforded by the departmental staff, and for specialist assistance it would be necessary to have recourse to the national advisory organisation set up by the Ministry of Agriculture. Eventually, after careful consideration, the fields of work selected for special attention were those of soils, plant nutrition, plant breeding, and animal nutrition, and it is to these that I propose to refer more particularly. No specific provision was made at the outset for dealing with diseases, either plant or animal, partly for reasons of economy, but mainly because it was felt that the outstanding disease problems could be more effectively dealt with by co-operative effort through the national organisation than by a small isolated advisory station.

In making provision for soil work as one of our principal lines of activity I was actuated by the conviction that soil investigation is the most fundamental of all forms of agricultural research. Soil factors dominate the growth of crops from germination to maturity, and must influence the utilisation of the crops by the animal, which is their ultimate destiny. In stressing the importance of soil advisory work I am not unmindful of the fact that, despite the enormous volume of investigation relating to soils which has been carried out, the task of the soil adviser still remains a very difficult one, and except in a few directions, and over a comparatively small area of the country, the interpretation of soil analytical data is rarely clear. It is a sobering thought, indeed, to recall the abounding optimism with which soil analysis was entered upon some eighty years ago, and contrast the hopes then held with the realities of soil advisory work as we find them to-day. The initial mistake—so common throughout a large part of our agricultural investigational work of the past—lay in a failure to visualise the complexity of the problem, even with due regard to then existing knowledge. The problem was approached as if the soil were to be regarded solely as a reservoir of plant food, whose capabilities for crop production should therefore admit of complete diagnosis by chemical analysis. The conception is fascinating in its simplicity, and has dominated the greater part of our soil work down to the present time, repeated endeavours being made by variation in the methods and intensity of the analytical attack to improve the persistently low degree of correlation between analytical data and crop results. Parallel with this at a later date was developed the mechanical conception which found the major part of the explanation of the differentiation of fertility in the physical properties of the soil particles, whilst still later soil biology has asserted its claim to provide the 'simple solution.' The work of recent years, however, so brilliantly led in this country by Sir John Russell and his colleagues, leaves us with no excuse for such restricted conceptions of soil fertility, which must now be regarded as the index of the equilibrium established by the mutual interactions of a highly complex series of factors, the variation of any one of which may affect the interplay of the whole, with consequent effect upon the rate or character of plant growth.

The problem of fertility being so complex, one might perhaps be inclined to despair of attaining to anything really effective in soil advisory work, which must necessarily be dependent upon rapid and somewhat superficial examination, and such apparently is the view held by the Ministry of Agriculture if one may judge by the conspicuous neglect of chemical and physical science in recent extensions of advisory facilities.

My own conception, however, of the present possibilities of soil advisory work is more optimistic, and from experience covering the most diverse parts of the country I am confident that an extension of facilities for soil advisory work would be of immediate and progressively increasing benefit to the farmer.

It is the common experience of all engaged in soil advisory work that, although what may be termed the 'average soil' offers great difficulties, there are many soils in all parts of the country which are distinctly not 'average' for the areas in which they are situate, and for which our conventional methods of chemical and mechanical analysis, crude though they be, and imperfect the premises upon which their interpretation is based, do yield guidance which on application in practice proves to have been substantially sound. The real difficulty at the moment is that for large tracts of the country we lack the necessary data to enable us to determine what is the 'average soil' for each particular area, and until provision is made for specific soil work in these areas, which comprise the whole of the great agricultural areas of the Midlands, our advisory work relating to this raw material of crop production must of necessity remain superficial, and only too frequently ineffective.

In no direction has the need for extended soil advisory work become more evident in recent years than in the revelation of the extent to which large areas of our soils have become depleted of lime. Cases come almost daily to our notice in which this lack of lime is clearly the chemical 'limiting factor,' and the annual waste due to unremunerative expenditure on fertilisers on such land must indeed be very great. In many cases, fortunately, the depletion has been detected at a stage at which it is still economically remediable, but in others, unfortunately, this is no longer the case, and unless soil-survey facilities be greatly extended it is certain that large areas of our land must steadily fall into the latter category, with the inevitable development in the near future of a problem of such magnitude as will require national action for its solution. It is worthy of note also in passing that this problem will probably be accentuated rather than diminished as a greater proportion of our arable land reverts to grass.

A further direction in which great scope remains for the work of the soil adviser is in the economic manuring of crops. More attention has probably been paid to the subject of manuring than to any other branch of agricultural science, and this branch has been perhaps more definitely systematised than any other; but inadequate and improper manuring is still widely prevalent, and the annual wastage of resources thereby incurred must represent a very large sum. A considerable part of this wastage is due to the widespread use of proprietary compound manures, more often than not compounded without any special reference to the soils upon which they are to be used, or even without intelligent adaptation to the special needs of the crops for which they are supplied. It is not uncommon, indeed, to find mixtures of identical composition offered for the most diverse crops. In far too many cases also the prices charged are extravagantly disproportionate to the intrinsic value of the ingredients of the mixture, and in all these various ways costs of production are made higher than they need be. In claiming that improved manuring achieved through extended advisory guidance might effect a sensible alleviation of the present difficulties of the arable farmer, I am not unmindful of the fact that even the best practice may result in loss when the value of produce sinks to the low levels recently touched by many crops, and the best manuring will not make it possible, for example, to grow potatoes profitably under present conditions for sale at 30*s*. per ton. Where loss is inevitable, however, this will usually be lowest at a level of production involving the reasonable and intelligent use of manures.

Passing on from soil and manuring, we come to the sphere of seed and sowing problems, presenting obviously abundant scope for advisory work. The need for good and pure seed is axiomatic and is recognised by the existence of the Seeds Act, which remains to us as a legacy, more beneficent in its operation than many others, of the war-time interest of the State in agriculture.

Seed must not only be good, however, but it must be of the right kind, sown under proper conditions and at the most suitable time, and the value of advisory guidance on these points has always been recognised, especially with reference to the choice between different varieties of each particular crop. The variety tests carried out on the various college farms and elsewhere have always proved helpful in this respect in so far as they serve to demonstrate the general characteristics of the different varieties. Whether they have been equally successful in measuring the cropping capacities of the different varieties is more than doubtful, owing to their restriction to single, or at most double plots of a kind, and this has been recognised in the more elaborate schemes devised for the purpose by the National Institute of Agricultural Botany, which it is to be hoped may furnish a practical scheme for more accurate quantitative field tests in the future.

Given good seed, the improvement of crop possible through seed selection is perhaps not in general so striking as that frequently obtainable by manuring, but it may nevertheless be substantial, especially with crops such as barley, where improvement of quality may have a special value. There is also a rapidly extending field for seed advisory work in connection with the laying down of land to grass for varying periods.

During the growth of the crop advisory work is largely restricted to the domain of diseases and insect pests, whose ravages take incalculable toll of our crops. This section of advisory work I am not competent to discuss, but I am continually impressed by its importance as I note how largely such matters bulk in the inquiries for assistance which pass through my hands, and I believe science can make no more directly effective contribution towards the removal of at least the technical difficulties of the farmer than the elaboration of effective preventive measures against pests and diseases.

In some directions, as in the circumvention of certain diseases of potatoes and cereals, very striking advances have already been made, to the great benefit of practice; but in all too many cases the adviser at present can go little beyond the stage of diagnosis, although, with the greatly increased number of research workers now available, there are good grounds to hope that the lines of preventive action may before long be worked out.

I must pass on, finally, to the utilisation of crop products as food for animals, the line of work with which my own personal interests and activities have always been most closely associated. Looking back over twenty years of advisory activity, I realise that the position of the adviser in animal nutrition is infinitely stronger to-day than when I first assumed the *rôle*.

At the outset of this period the feeding of animals was regarded simply as a matter of supply of suitable proportions of digestible protein, oils, and carbohydrates, more or less regardless of the character of the materials in which they were supplied. Little further could be done in the way of differentiating the values of different food materials beyond a comparison upon the basis of gross digestible energy, although the conclusions to which this led were notoriously unreliable and in many cases in flagrant conflict with practical experience. Material for a great advance was, however, rapidly accumulating in the work of Kellner, which was finally reduced by him to a practical system of food evaluation in his classic 'Ernäbrung der landwirtschaftlichen Nutztiere,' published in 1905, and universally acclaimed as representing a great advance in the application of nutritional science to the practical feeding of farm live-stock. The advance lay essentially in the discrimination between the available energy and the net energy of foods, and the carrying out of a sufficiently large number of determinations of the latter to furnish a fairly adequate basis for generalisation. With these to supplement his classic determinations of the values of protein, fat, and carbohydrate for the production of fattening increase, he was able to devise a practical scheme of assessing the production-values or net energy-values of foods, which he preferred for reasons of practical convenience to express in terms of starch. The significance of the great practical advance made by Kellner was not at first clearly grasped in this country, critical attention being directed, in accordance with true British conservatism, more to the admitted shortcomings of the starch-equivalent than to its merits; but as time revealed its superiority over the older methods it came generally into use, and now serves as the basis of all our advisory work in farm nutrition.

Although primarily designed for the case of the fattening animal, it has proved practically useful for other classes of stock, and even, with slight modification, for the case of the milk-producing animal.

The last twenty years has also witnessed the great developments of protein investigation which have thrown much light upon the problems of protein metabolism and the productive efficiency of the proteins of different foods. Lastly, we may recall the remarkable developments in nutritional science of recent years, consequent upon Hopkins' discovery of the 'accessory growth factor,' and also the attention which is now being directed to the importance of the mineral ingredients of foods.

With all this newer knowledge at his command, the adviser in nutrition can now approach his work with far greater confidence, and evidence of the increasing practical value of his work is rapidly accumulating. This is particularly the case with advisory work in milk production, a branch of feeding which lends itself more readily than most to carefully regulated rationing owing to the ease with which the amount of product can be determined. Few branches of advisory work have proved more directly helpful to the farmer in recent years than this advisory control of the feeding of dairy cows, the extension of which has been greatly aided by the development of milk-recording societies, in whose activities such rationing advice is rapidly becoming regarded as an indispensable feature. Much success has also been met with in advisory work in pig-feeding, and to a less extent in the feeding of cattle, the lower degree of success in the latter case being due not so much to an inferior capability of the adviser to help as to the difficulty of dispelling the tradition that beef production represents the supreme accomplishment of the British farmer, as to which there is nothing left for him to learn. The work already accomplished represents, however, but the very beginnings of economy in the feeding of live-stock, and wasteful feeding of both home-grown and purchased feeding-stuffs for lack of the necessary advisory guidance is still far too widely prevalent.

Such are only a few of the aspects of advisory work, which, if extended more widely, might exercise a very profound effect upon the economy of the industry. Such extension implies, however, greatly increased resources in men and money and more efficient means of bringing the advisory facilities to the notice of the farmer.

I am inclined, indeed, to think that a more efficient propaganda is perhaps the first need of the situation, as one finds in all parts of the country an astonishingly large number of farmers who are totally unaware of the existence of advisory facilities of any kind. A more extensive propaganda will be useless, however, unless accompanied by increased provision for advice, since the present resources are already more than fully taxed by the relatively moderate volume of calls for assistance that now arise. It is the universal complaint of the County Agricultural Organisers that they cannot secure the personal contact, which it is the most important part of their functions to establish, with more than a very small fraction of the farmers within their area, and it is for a great extension of this type of advisory assistance that there is the most clamant need. Most of our counties have, at present, only one agricultural adviser—some, indeed, have none—and yet this slender organisation represents in large measure the base of contact with the industry upon which the whole pyramid of our advisory and educational work rests. It is here where I see the most immediately profitable outlet for any further moneys that may be available for agricultural education in the near future. The facilities for organised instruction in agriculture are at present adequate for the numbers of students coming forward, or likely to come forward, in the near future, the present problem in this sphere being indeed rather that of finding suitable openings for the numbers of students passing through our courses—a matter to which I shall return presently.

I have already alluded to the chemical gaps in our specialised advisory organisation, and I might also have indicated the similar and even less comprehensible inadequacy in the provision for specialist advice in economics; but these are relatively small matters compared with the paucity of the less highly specialised but scientifically trained advisers of the County Organiser type, whose business it should be to secure the confidence of the individual farmer by personal contact, and the rendering of assistance either directly in the simpler problems or with the help of the specialist staff standing behind them in more complex cases, whereby a more widespread and real appreciation of the practical value of agricultural education and research than now prevails might quickly be developed.

A great extension of advisory work such as I suggest must necessarily involve heavy expenditure, and further, an exceptional measure of care in the selection of men, since in the direct approach to the farmer personal qualities may in the first instance count for more than technical proficiency. Furthermore, if the full measure of success is to be achieved, it is essential that a more closely organised and intimate contact should be established between the various units of the advisory organisation, from the research station through the scientific adviser, to the practical adviser. Our present organisation is too indefinite and too widely permissive in this respect and calls urgently for consideration by all concerned, both county authorities and advisory and research workers, with a view to more effective co-ordination and co-operative effort.

I have laid great stress upon the potentialities of advisory work as a contribution to the alleviation of the present crisis, but I cannot close without some reference to the far greater contribution to the future prosperity of British agriculture which we can make through our educational system, if wisely pursued, in the training of the farmers of the future.

I have already expressed the opinion that the existing facilities for organised agricultural education—at least so far as universities and colleges are concerned—are adequate to deal with the numbers of students presenting themselves. There is indeed at the moment a considerable excess output of the class of student who is either unwilling or unable to take up practical farming and must needs have a salaried post. This problem, which is becoming an increasingly serious one, especially for the non-university institution, such as my own College, hardly falls, however, within the scope of my present theme, except in so far as the extension of advisory facilities I have advocated would tend to absorb this surplus and restore the balance of the whole organisation.

Of more immediate concern is our comparative failure to secure for our educational courses more than a small fraction of the sons of farmers, upon whom the future of the industry will largely rest. I have testified to the greatly awakened interest in agricultural education which has been displayed amongst farmers in recent years, but it is yet far from having developed into a conviction that such education is to be regarded as a vitally essential part of the farmer's training. One must perhaps be content with gradual advance towards this goal by internal development, although the possibilities of more rapid advance by external pressure should not be overlooked. One such that might have a more potent influence than any other in filling our colleges with farmers' sons I would submit for the consideration of my distinguished predecessor of last year, in supplement of his able exposition of the part to be played by the enlightened landowner in the progress of agriculture. It is that in letting his farms—at any rate so far as young applicants are concerned—the enlightened landowner should show his faith in agricultural education by giving first preference—other considerations being equal—to men who have received adequate instruction in the principles of agriculture in addition to practical experience. So long as the private ownership of land continues—and I trust that it may be very long—the landowner will have it in his power to render the most powerful aid to the progress of agricultural education, and by action along the lines I have suggested might exert more good in one year than is attainable by many weary years of propaganda. Whatever the character of our land tenure system of the future, it is certain that sooner or later some guarantee of efficiency for the productive occupation of land will be demanded from the would-be farmer. We cannot continue indefinitely, on the one hand, to proclaim that the land is our greatest national asset, to be maintained with the help of, and in the interests of, the State in a highly efficient state of productivity, whilst, on the other hand, the use of the land is left open to all, regardless of fitness for its effective use. This vision of farming reduced to the status of medicine and law as a close profession regulated by an entrance examination, may perhaps be stigmatised as a horrible nightmare; but some movement in that direction I believe to be inevitable, and, with nationalisation of the land, might well come more speedily than one would venture to contemplate. None will question, at any rate, that, should such a day arrive, education in the principles underlying the calling will loom as largely as practical training in determining the standards of admission to the use of the land. I will conclude on this highly imaginative note with an expression of my firm conviction that the genius of the British race for the management of its affairs on lines of voluntary action will not desert us in this particular, and that with wise guidance and intelligent adaptation of educational curricula and methods to the changing needs of the times the penetration of our practice by science will proceed smoothly and with such rapidity as to render interference from outside not only unnecessary, but unwarrantable.

REPORTS ON THE STATE OF SCIENCE

ETC.

Seismological Investigations.— *Twenty-eighth Report of Committee* (Professor H. H. TURNER, *Chairman*; Mr. J. J. SHAW, *Secretary*; Mr. C. VERNON BOYS, Dr. J. E. CROMBIE, Sir HORACE DARWIN, Sir F. W. DYSON, Sir R. T. GLAZEBROOK, Dr. HAROLD JEFFREYS, Professor H. LAMB, Sir J. LARMOR, Dr. A. CRICHTON MITCHELL, Professors A. E. H. LOVE, H. M. MACDONALD, *and* H. C. PLUMMER, Mr. W. E. PLUMMER, Professor R. A. SAMPSON, Sir A. SCHUSTER, Sir NAPIER SHAW, *and* Dr. G. T. WALKER). [*Drawn up by the Chairman except where otherwise mentioned.*]

General.

ONCE again the Committee has to deplore the loss of one of its eminent and active members in Professor C. G. Knott, who has been associated with the work from the time (1883) when he became a colleague of John Milne in Japan. He was the author of a standard work on earthquakes, 'The Physics of Earthquake Phenomena' (Oxford University Press, 1908), which represents a series of carefully thought-out lectures on the science; and more recently he undertook a laborious investigation of the paths of earthquake rays within the earth, including the times to different points (*Proc. R.S.E.*, 1919, vol. xxxix., part II., No. 14). This important research was the starting point for the investigation of depth of focus of earthquakes, mentioned in the last Report, and in this.

The clerical work at Oxford is still being carried on in the 'Students' Observatory,' since the tenant of the house purchased by Dr. Crombie's benefaction continued to declare himself unable to find other quarters. But the situation may be modified by the recent death of this tenant. His widow is still living in the house, and it is yet too early to say how soon it will be available for Seismology.

International.

The relation of the Committee to the Seismological Section of the International Union for Geodesy and Geophysics was mentioned in the last Report, and the suggestion was made that at the end of 1917 the Bulletins of this Committee, which have aimed at giving a summary of observations of the important earthquakes, should become the official publication of the Union. Accordingly, as mentioned below, the title was altered with the year 1918 to that of 'The International Seismological Summary.' But the subsidy received from the Union (10,000 francs annually) is only sufficient for a fraction of the cost of this publication, and at the next meeting of the Union in 1924 application will be made for an increased grant. Meanwhile the extra expense is being met partly by the annual grant of 100*l.* from the Caird Fund of the British Association, and partly by a further and special grant of 200*l.* from the Royal Society. These funds (and former grants of the same kind) have been applied to the routine expenses of calculation and printing, and to the maintenance of the modest instrumental equipment (first at Shide and recently at Oxford). Supervision has been provided voluntarily by the Chairman and Secretary of the Committee; but during the last year a very welcome addition to the resources available for supervision has been made by the further generosity of Dr. J. E. Crombie, who has provided a salary during the year for Mr. J. S. Hughes, B.A., of New College, Oxford, in order that he may give his whole time to this work.

Instrumental.

The Milne-Shaw seismograph in the basement of the Clarendon Laboratory at Oxford has worked well throughout the year. It is one of the early machines of this pattern, and the scale is smaller than that on more recent machines. The question of replacing it by one with a more open scale has been considered, but it is thought better at present to supply the improved pattern to distant stations, from which there has been a succession of demands sufficient to keep Mr. Shaw closely at work.

During the year he has dispatched machines to Ottawa (2nd component), Hong Kong (2nd component), Strasbourg, Hyderabad, Perth (W.A.), and Stonyhurst. Of these only that for Perth is the property of the B.A. Committee, and represents a loan (again owing to the generosity of Dr. J. E. Crombie); the others are all purchases. But they are mentioned here to show the distribution of machines of the type which is essentially the product of this Committee; for Mr. Shaw began his experiments at the request of John Milne.

It was mentioned in the last Report that a machine had been taken to Christmas Island by the eclipse observers from the Royal Observatory, Greenwich. An accident to the time-clock on the voyage led to considerable delay in setting up the instrument, which was only erected just before the observers left, after the eclipse, for home. It was expected that records would have been received before this, but nothing has yet come, and Mr. Jones is kindly making inquiries into the matter.

Mr. Claxton has kindly sent to Oxford for examination most of the Hong Kong films which contain earthquake records, and they are naturally of great interest to us as showing the effects of disturbance at distances so much smaller than those to which we are accustomed. The record for March 24 last is specially noteworthy. The earthquake was very destructive in a region (32° N. 102° E.) not far from the destructive earthquake of December 16, 1920 (35°.5 N. 105°.5 E.).

Bulletins and Tables.

The Bulletins to the end of the year 1917 have been printed and distributed. The title of the publication was then changed, as above mentioned, to 'The International Seismological Summary,' the first number of which contains the results from January to March, 1918; the next number, April to June, 1918, is passed for press; July to November, 1918, is ready in manuscript, though some checking of the later months is still required. The work steadily increases owing to the communication of results from new stations, and the receipt of arrears from older ones.

The Tables for P and S have been expanded to give results for every tenth of a degree, and will be distributed with the next number of the Summary. This expansion has been delayed in the hope of first obtaining corrections of the tables, but it becomes clear that this may take some time owing to the complication introduced by consideration of focal depth, and in any case the present tables will be applicable to a great deal of work already in print.

Depth of Focus.

It was mentioned in the last Report that the time of arrival of the earliest disturbance at the opposite side of the earth gives valuable indication of the depth of focus. The number of instances then available was small, but several more have been found during the past year, and successfully treated by the provisional formulæ then given. As they are fully dealt with in the Bulletins and Summaries there is no need to reproduce them here, but new light has been thrown on the possibilities by a paper by the late Prince Galitzin, dated 1919 but only recently received from Petrograd. From a study of the angles of emergence he was led to infer three critical surfaces at depths 106, 232, and 492 kilometres below the earth's surface: or 0.017, 0.036, 0.077 in terms of the earth's radius. This work is quite independent of the investigation of focal depth, but the results provisionally obtained for focal depth do collect themselves roughly into three groups, which may possibly refer to foci at these critical surfaces; at any rate the intervals between the groups correspond to the intervals between the surfaces. The information about focal depth was entirely relative, and we had no means of judging the absolute focal depth. If, however, this identification is confirmed the missing constant is supplied.

In a note to this effect (*Geop. Sup. to Mon. Not. R.A.S.*, Jan. 1923) the times of arrival of [P] at the anticentre from foci actually on these surfaces are found to differ from the adopted tables by

Group	I.	II.	III.
Depth	−0·017	−0·036	−0·077
Diff. from normal	+0·019	0·000	−0·041
Time for [P]	+14s.	−3s.	−39s.

To Group I. we may assign the following :—

		d.	h.	°	°	s.
1916	Oct.	3	1	14·0 S	74·5 W	[P] = +16
1916	Oct.	20	17	18·0 S	173·0 W	= +16
1917	June	13	6	30·2 S	177·7 W	= +15
1917	May	1	18	29·2 S	177·0 W	= +13

In the last case the solution printed in the Bulletin is probably in error, as is seen by detailed comparison with June 13, 1917, probably from the same focus: and a corrected solution will be given, subtracting 25s. from the adopted T_0. To this group we may provisionally assign also

1914	June	26	4	13·0 S	166·8 E	[P] = +8
1916	Jan.	1	13	5·5	154·0 E	[P] = +7

To Group II. we assign the great majority of earthquakes. Several cases where [P] can be well determined are collected in the paper in vol. i. No. 1, of the *Geop. Sup.*; its values are as follows :—

+3s., −1s., −4s., −4s., −5s., −7s., −9s., −9s., −12s. (−17s.),

but these cases have not been yet fully revised.

To Group III. we assign the following :—

		d.	h.	°	°	s.
1913	Nov.	10	21	18·0 S	170·0 E	[P] = −26
1914	Feb.	26	4	16·0 S	61·0 W	−42
1915	Jan.	5	14	16·5 S	168·5 E	−27
1916	June	21	21	17·0 S	57·0 W	−48
1916	Sept.	3	7	7·0 S	155·0 E	−28
1917	April	21	0	37·2 N	70·4 E	−26
1918	Feb.	7	5	6·5 N	127·0 E	?
1918	April	10	2	44·0 N	131·0 E	−57
1918	May	22	6	17·0 S	177·5 W	−42
1918	May	25	19	31·0 S	91·0 W	−15?

It is admitted that at the present stage there is too much scattering within the group and too much overlap between groups; but a great deal of the material is still rough, and we may be content to await further developments. It will be seen that there is some appearance of local restriction in the groups. Thus the epicentres of Group I. are all south and west. But this may be an accident due to the distribution of observing stations. No case has been included at this stage unless there is a good determination of T_0 from stations near the epicentre and also of [P] from stations near the anticentre, and one or other of these may fail for want of observing stations (or of observations from them) in the appropriate neighbourhood. Thus the earthquake of 1918 January 30d. 21h. at 47°.5 N. 129°.0 E. has some large residuals which suggest an abnormal focal depth, but the South American stations give us no information about [P], unless we accept a single observation at La Paz iP = +18m. 6s. as an observation of [P] with residual [−104s.], which is far too large to help us. It seems more likely that the observation refers to the P wave, with residual +31s. from adopted tables as printed.

Periodicity.

A periodicity near 21m. was mentioned in the last Report. It was detected in the Jamaica earthquakes tabulated by Maxwell Hall (*Geop. Sup. M. N.*, vol. i. No. 2), and the period assigned as 21.001451m. But this led to the examination of a long series of Italian earthquakes (kindly lent by Mr. R. D. Oldham for the purpose), which very soon indicated a correction of one whole period in ten years. The discussion of the Italian series is not yet completed, but the Jamaica series was revised (*Geop. Sup. M. N.*, vol. i. No. 3), for the new period 0.014584282d. or 21.001366m., which was found to suit them better. But there were fluctuations of six months' period and of four years' period in the position of maximum, the former with a range of 7.8m. (3.9m. on either side of the mean position), the latter with an even greater range of 14.0m. (7.0 on either side). A further fluctuation of fifteen months' period was detected after the paper had been sent to press, but is discussed in a supplementary note to the paper. This fifteen months' period had already been detected in 'Earthquake Phenomena' (see the *B.A. Report* for 1912), and its elimination from the Jamaica series had the satisfactory result of removing a double maximum which previously affected the mean curve.

We thus have three new periodicities in addition to the main one of 21m.: viz. 4 years, 15 months, and 6 months. The 15 month (or 104/7 months more accurately) has independent support as above stated, though as yet we have no hint of its origin. The 6-month period, if real, is doubtless connected with the year. There remains the 4-year period which stood unsupported. But it was noticed that it affected the general frequency of Jamaica earthquakes (apart from its effect on the 21m. period); and also that of the Italian earthquakes. An examination was made of the Chinese and Japanese long series and of other shorter series, and they were all found to be affected. The results are given in a paper now in the press (*Geop. Sup. M. N.*, vol. i. No. 4). When the paper was read it had been inferred that the maximum travelled round the earth from east to west in 8 years (a double cycle, indicating a double polarity), but on checking the proof a serious error was detected in the Japanese reduction which rendered this view no longer tenable. It was found, however, that there was a travel in latitude from the Equator to the North Pole in the N. Hemisphere. What happens in the S. Hemisphere is doubtful, as we have only the single case of New Zealand to give information. But for what it is worth it indicates that the sweep is in the same direction (S. Pole to N. Pole).

But for the further elucidation of these matters more material, and more accurate material, is required: and it would appear that our best line of advance at present is to continue the identification of epicentres and times for as many earthquakes as possible. Hence this work of identification has been continually expanded (in the 'Bulletins' for 1917 and their successors the 'Summaries' for 1918) in spite of the consequent delay in catching up arrears.

The General Propagation of Earthquake Waves.

The announcement of the 21m. periodicity in the last Report had the incidental consequence of leading Dr. Jeans to undertake a new investigation of the whole question of earthquake wave propagation, and in a paper contributed to the Royal Society (*Proc. R. S.*, A, vol. 102. 1923, p. 554) he points out that in addition to the Rayleigh waves denoted by L. which travel with velocity $0.92\sqrt{(\mu/\rho)}$, there are two whole series of surface waves of which the terminal members travel with velocities of $\sqrt{(\mu/\rho)}$ and $\sqrt{[(\lambda+2\mu)/\rho]}$. Taking velocities suggested by the Oppau explosion, these waves would travel round the earth in 126m. and 222m., and Dr. Jeans suggests that returns of these waves to the epicentre (or perhaps the anticentre) may act as triggers for new earthquakes. [Since this report was sent to press a number of cases favourable to this view have been noticed.] Independently of this possibility (which chiefly concerns periodicities) the paper must be of great value for the interpretation of seismograms, though no opportunity for testing it in this connection has yet been found.

Calculation of Mathematical Tables.—*Report of Committee* (Professor J. W. NICHOLSON, *Chairman*; Dr. J. R. AIREY, *Secretary*; Mr. T. W. CHAUNDY, Professor L. N. G. FILON, Colonel HIPPISLEY, Professor E. W HOBSON, Mr. G. KENNEDY, *and* Professors A. LODGE, A. E. H. LOVE, H. M. MACDONALD, G. N. WATSON, and A. G. WEBSTER).

IN the Report for 1922 reference was made to mathematical tables calculated for the Association without the assistance of grant from the Committee. The publication of these tables was deferred; the Report for the present year includes in Part I. the tables of sin θ and cos θ for θ in circular measure from 1 to 100 radians, supplementing those computed by Dr. Doodson in the 1916 Report, viz. sin θ and cos θ to fifteen places of decimals for θ = 0 to 10 by intervals of 0·1 radian.

Tables of Bessel and Neumann functions, where the order and argument are equal or differ by unity, have been calculated to six places of decimals and published in the Report for 1916, the order and argument having integer values only. In Part II. will be found tables of these and other functions, the integrals of Schläfli and the Lommel-Weber functions, where the order and argument are not restricted in value, but contain both integral and fractional values, the order of the functions ranging from 0 to 10 by intervals of 0·25. The work of calculation, especially that of the preliminary tables required for Part II. of the Report, has been much relieved by the use of an arithmometer kindly lent to the Secretary.

Recently, Prof. A. E. Kennelly has placed at the disposal of the Committee tables—to six places of decimals—of Bessel functions for a complex variable. These functions are equivalent to the classical ber, bei, ber′ and bei′ functions of Kelvin, but are more convenient to use in electrical engineering problems. On account of their practical importance, the Committee feel justified in undertaking their publication in Part III. of this Report.

The other functions referred to in last year's Report, Bessel-Clifford functions $C_0(x)$ and $C_1(x)$ and Lommel-Weber functions $\Omega_0(x)$ and $\Omega_1(x)$, and further tables of the sine and cosine functions are reserved for later publication.

PART I.

Sines and Cosines (θ in radians).

The values of the sine and cosine of unit angle (radian) have been calculated* to 105 places of decimals by Bretschneider. Using only 30 places, the sines and cosines of the following angles (radians) were found in succession, 5, 10, 50, 100, the last calculation being correct to 25 places of decimals. To obtain the values of these functions for intermediate angles, *e.g.* 20, 30, 40, etc., it was found convenient to construct a table of the first hundred multiples of sin 10 and cos 10 to facilitate the calculation of the products when sin 10 or cos 10 is a factor. In a similar way, by employing a table of multiples of sin 1 and cos 1, the remaining values of sin θ and cos θ were obtained. Each result was checked by those already computed, sin 54 by sin 52, and so on.

A further check was made by a direct calculation of sin 71 and cos 71.

Thus 71 (radians) $= 22{\cdot}6\pi + \theta$, where

$$\theta = 0{\cdot}00000\ 60288\ 70672\ 81074\ 42595.$$

Hence $\sin\theta = 0{\cdot}00000\ 60288\ 70672\ 77422\ 20829$

and $1-\cos\theta = 0{\cdot}00000\ 00000\ 18173\ 64079\ 46837.$

Also
$$\begin{aligned}\sin 71 &= \sin 22{\cdot}6\pi\ .\ \cos\theta + \cos 22{\cdot}6\pi\ .\ \sin\theta\\ &= \cos 18^\circ\ .\ \cos\theta - \sin 18^\circ\ .\ \sin\theta\\ &= +0{\cdot}95105\ 46532\ 54374\ 63665\ 6570\\ \cos 71 &= \cos 22{\cdot}6\pi\ .\ \cos\theta - \sin 22{\cdot}6\pi\ .\ \sin\theta\\ &= -\sin 18^\circ\ .\ \cos\theta - \cos 18^\circ\ .\ \sin\theta\\ &= -0{\cdot}30902\ 27281\ 66070\ 70291\ 7494\end{aligned}$$

verifying the values in this example, and indirectly the whole table, to 24 places of decimals. Fifteen places only are given in continuation of Dr. Doodson's table.

* C. A. Bretschneider, *Archiv der Math. u. Phys.*, vol. 3, 1843, pp. 28-34.

Sines and Cosines of Angles in Circular Measure.

θ	Sin θ			Cos θ		
1	+0·84147	09848	07897	+0·54030	23058	68140
2	+0·90929	74268	25682	−0·41614	68365	47142
3	+0·14112	00080	59867	−0·98999	24966	00445
4	−0·75680	24953	07928	−0·65364	36208	63612
5	−0·95892	42746	63138	+0·28366	21854	63226
6	−0·27941	54981	98926	+0·96017	02866	50366
7	+0·65698	65987	18789	+0·75390	22543	43305
8	+0·98935	82466	23382	−0·14550	00338	08614
9	+0·41211	84852	41757	−0·91113	02618	84677
10	−0·54402	11108	89370	−0·83907	15290	76452
11	−0·99999	02065	50703	+0·00442	56979	88051
12	−0·53657	29180	00435	+0·84385	39587	32492
13	+0·42016	70368	26641	+0·90744	67814	50196
14	+0·99060	73556	94870	+0·13673	72182	07834
15	+0·65028	78401	57117	−0·75968	79128	58821
16	−0·28790	33166	65065	−0·95765	94803	23385
17	−0·96139	74918	79557	−0·27516	33380	51597
18	−0·75098	72467	71676	+0·66031	67082	44080
19	+0·14987	72096	62952	+0·98870	46181	86669
20	+0·91294	52507	27628	+0·40808	20618	13392
21	+0·83665	56385	36056	−0·54772	92602	24268
22	−0·00885	13092	90404	−0·99996	08263	94637
23	−0·84622	04041	75171	−0·53283	30203	33398
24	−0·90557	83620	06624	+0·42417	90073	36997
25	−0·13235	17500	97773	+0·99120	28118	63474
26	+0·76255	84504	79603	+0·64691	93223	28640
27	+0·95637	59284	04503	−0·29213	88087	33836
28	+0·27090	57883	07869	−0·96260	58663	13567
29	−0·66363	38842	12968	−0·74805	75296	89000
30	−0·98803	16240	92862	+0·15425	14498	87584
31	−0·40403	76453	23065	+0·91474	23578	04531
32	+0·55142	66812	41691	+0·83422	33605	06510
33	+0·99991	18601	07267	−0·01327	67472	23059
34	+0·52908	26861	20024	−0·84857	02747	84605
35	−0·42818	26694	96151	−0·90369	22050	91507
36	−0·99177	88534	43116	−0·12796	36896	27405
37	−0·64353	81333	56999	+0·76541	40519	45343
38	+0·29636	85787	09385	+0·95507	36440	47295
39	+0·96379	53862	84088	+0·26664	29323	59937
40	+0·74511	31604	79349	−0·66693	80616	52262
41	−0·15862	26688	04709	−0·98733	92775	23826
42	−0·91652	15479	15634	−0·39998	53149	88351
43	−0·83177	47426	28598	+0·55511	33015	20626
44	+0·01770	19251	05414	+0·99984	33086	47691
45	+0·85090	35245	34118	+0·52532	19888	17730
46	+0·90178	83476	48809	−0·43217	79448	84778
47	+0·12357	31227	45224	−0·99233	54691	50929
48	−0·76825	46613	23667	−0·64014	43394	69200
49	−0·95375	26527	59472	+0·30059	25437	43637
50	−0·26237	48537	03929	+0·96496	60284	92113

Sines and Cosines of Angles in Circular Measure.

θ	Sin θ	Cos θ
51	+0·67022 91758 43375	+0·74215 41968 13783
52	+0·98662 75920 40485	—0·16299 07807 95705
53	+0·39592 51501 81834	—0·91828 27862 12119
54	—0·55878 90488 51616	—0·82930 98328 63150
55	—0·99975 51733 58620	+0·02212 67562 61956
56	—0·52155 10020 86912	+0·85322 01077 22584
57	+0·43616 47552 47825	+0·89986 68269 69194
58	+0·99827 26480 84537	+0·11918 01354 48819
59	+0·63673 80071 39138	—0·25810 16359 38267
60	—0·30481 06211 02217	—0·95241 29804 15156
61	—0·96611 77700 08393	—0·25810 16359 38267
62	—0·73918 06966 49223	+0·67350 71623 23586
63	+0·16735 57003 02807	+0·98589 65815 82550
64	+0·92002 60381 96791	+0·39185 72304 29550
65	+0·82682 86794 90103	—0·56245 38512 38172
66	—0·02655 11540 23967	—0·99964 74559 66350
67	—0·85551 99789 75322	—0·51776 97997 89505
68	—0·89792 76806 89291	+0·44014 30224 96041
69	—0·11478 48137 83187	+0·99339 03797 22272
70	+0·77389 06815 57889	+0·63331 92030 86300
71	+0·95105 46532 54375	—0·30902 27281 66071
72	+0·25382 33627 62036	—0·96725 05882 73882
73	—0·67677 19568 87308	—0·73619 27182 27316
74	—0·98514 62604 68247	+0·17171 73418 30778
75	—0·38778 16354 09430	+0·92175 12697 24749
76	+0·56610 76368 98180	+0·82433 13311 07558
77	+0·99952 01585 80731	—0·03097 50317 31216
78	+0·51397 84559 87535	—0·85780 30932 44988
79	—0·44411 26687 07508	—0·89597 09467 90963
80	—0·99388 86539 23375	—0·11038 72438 39048
81	—0·62988 79942 74454	+0·77668 59820 21631
82	+0·31322 87824 33085	+0·94967 76978 82543
83	+0·96836 44611 00185	+0·24954 01179 73338
84	+0·73319 03200 73292	—0·68002 34955 87339
85	—0·17607 56199 48587	—0·98437 66433 94042
86	—0·92345 84470 04060	—0·38369 84449 49742
87	—0 82181 78366 30823	+0·56975 03342 65312
88	+0·03539 83027 33661	+0·99937 32836 95125
89	+0·86006 94058 12453	+0·51017 70449 41669
90	+0·89399 66636 00558	—0·44807 36161 29170
91	+0·10598 75117 51157	—0·99436 74609 28202
92	—0·77946 60696 15805	—0·62644 44479 10339
93	—0·94828 21412 69947	+0·31742 87015 19702
94	—0·24525 19854 67654	+0·96945 93666 69988
95	+0·68326 17147 36121	+0·73017 35609 94820
96	+0·98358 77454 34345	—0·18043 04492 91084
97	+0·37960 77390 27522	—0·92514 75365 96414
98	—0·57338 18719 90423	—0·81928 82452 91459
99	—0·99920 68341 86354	+0·03982 08803 93139
100	—0·50636 56411 09759	+0·86231 88722 87684

PART II.

Bessel and other related functions of equal order and argument.

(A). Tables of the Bessel function $J_n(x)$ and the Neumann functions $G_n(x)$ and $Y_n(x)$, where the order and argument are equal or differ by unity, have been published in the 1916 Report, the values of n and x increasing by unit intervals in the earlier part of the tables. There does not appear to be any record of the computation of these functions for fractional values of the order and argument. The values of the argument of the Bessel functions $J_\nu(x)$, $J_{\nu-1}(x)$ and the Neumann functions $N_\nu(x)$ and $N_{\nu-1}(x)$, tabulated below, range from 0 to 10 by intervals of 0·25, the order of the functions being equal to the argument or less by unity.

For small values of the argument, the functions $J_{\pm\frac{1}{4}}(x)$ and $J_{\pm\frac{3}{4}}(x)$ were calculated from the ascending series, $J_{\frac{1}{4}}(x)$ and $J_{-\frac{3}{4}}(x)$ together, the terms of these series being simply related.

$$J_{\frac{1}{4}}(x) = \frac{2}{\Gamma\left(\frac{1}{4}\right)\left(\frac{x}{2}\right)^{\frac{3}{4}}} \cdot \left(x - \frac{x^3}{5} + \frac{x^5}{2.5.9} - \frac{x^7}{2.3.5.9.13} + \ . \ . \ . \ \right)$$

$$J_{-\frac{3}{4}}(x) = \frac{1}{\Gamma\left(\frac{1}{4}\right)\left(\frac{x}{2}\right)^{\frac{3}{4}}} \cdot \left(1 - x^2 + \frac{x^4}{2\cdot5} - \frac{x^6}{2\cdot3\cdot5\cdot9} + \ . \ . \ . \ . \ \right) \text{ etc.}$$

The use of the recurrence formula, $J_{\nu+1}(x) = \frac{2\nu}{x}J_\nu(x) - J_{\nu-1}(x)$, gave the values entered in the following table.

The Neumann functions were easily obtained from the relations

$$J_{-\nu}(x) = J_\nu(x) \ . \ \cos\nu\pi - N_\nu(x) \ . \ \sin\nu\pi$$
$$N_{-\nu}(x) = J_\nu(x) \ . \ \sin\nu\pi + N_\nu(x) \ . \ \cos\nu\pi.$$

For large values of the order and argument, the functions were directly calculated from the asymptotic series, viz. :

$$J_\nu(\nu) = \frac{1}{2\pi\sqrt{3}}\left[\left(\frac{6}{\nu}\right)^{\frac{1}{3}}\Gamma\left(\frac{1}{3}\right) - \frac{1}{420}\left(\frac{6}{\nu}\right)^{\frac{5}{3}}\Gamma\left(\frac{2}{3}\right) - \frac{1}{8100}\left(\frac{6}{\nu}\right)^{\frac{7}{3}} \cdot \Gamma\left(\frac{1}{3}\right) + \ . \ . \ \right]$$

with similar series for $J_{\nu-1}(\nu)$, $N_\nu(\nu)$ and $N_{\nu-1}(\nu)$. The results were checked by $N_{\nu-1} \ . \ J_\nu - N_\nu \ . \ J_{\nu-1} = \frac{2}{\pi x}$.

4ν	$J_\nu(\nu)$	$J_{\nu-1}(\nu)$	$-N_\nu(\nu)$	$-N_{\nu-1}(\nu)$
0	1·000000	0·000000	∞	∞
1	0·647832	1·230518	1·252815 :	—1·551122
2	0·540974	0·990245 :	0·990245 :	—0·540974
3	0·480568	0·855013	0·861905 :	—0·232820 :
4	0·440051	0·765198	0·781213	—0·088257
5	0·410288 :	0·699974 :	0·724036	—0·006067 :
6	0·387142	0·649838	0·680560	0·046083
7	0·368420	0·609742	0·644714 :	0·081608
8	0·352834	0·576525	0·617408	0·107032 :
9	0·339572 :	0·548919	0·593338 :	0·125900
10	0·328091	0·525080	0·572630 :	0·140293 :
11	0·318012 :	0·504345	0·554541	0·151510
12	0·309063	0·486091	0·538541 :	0·160400 :
13	0·301038	0·469858 :	0·524243	0·167544
14	0·293783 :	0·455298 :	0·511351 :	0·173345 :
15	0·287179	0·442140	0·499642	0·178099 :
16	0·281129	0·430171	0·488937	0·182022
17	0·275557	0·419222 :	0·479094 :	0·185276
18	0·270401 :	0·409155	0·470000	0·187986
19	0·265610	0·399856 :	0·461559 :	0·190249 :
20	0·261141	0·391232	0·453695	0·192142 :

4ν	$J_\nu(\nu)$	$J_{\nu-1}(\nu)$	$-N_\nu(\nu)$	$-N_{\nu-1}(\nu)$
21	0·256957	0·383205	0·446340 :	0·193725
22	0·253028 :	0·375708	0·439441	0·195047
23	0·249329	0·368684 :	0·432949 :	0·196148
24	0·245837	0·362087	0·426825 :	0·197061
25	0·242532	0·355873 :	0·421034 :	0·197812 :
26	0·239398	0·350007 :	0·415545 :	0·198425
27	0·236419 :	0·344458	0·410332	0·198918
28	0·233584	0·339197	0·405371	0·199307
29	0·230879	0·334199 :	0·400641 :	0·199605
30	0·228295 :	0·329445	0·396125 :	0·199824 :
31	0·225823 :	0·324914	0·391806 :	0·199974 :
32	0·223455	0·320589	0·387670	0·200064
33	0·221183	0·316455	0·383703	0·200100
34	0·219000 :	0·312498	0·379893	0·200089
35	0·216901 :	0·308706	0·376231	0·200036
36	0·214881	0·305067	0·372705 :	0·199947
37	0·212933	0·301571 :	0·369309	0·199825
38	0·211054	0·298210	0·366033	0·199674
39	0·209239 :	0·294974	0·362870	0·199498
40	0·207486	0·291856	0·359814	0·199299

(B). When the order of $J_\nu(x)$ is not an integer, the function can be represented by

$$J_\nu(x) = \frac{1}{\pi}\int_0^\pi \cos(\nu\theta - x\sin\theta)d\theta - \frac{\sin\nu\pi}{\pi}\int_0^\infty e^{-x\sinh\theta}e^{-\nu\theta}.\ d\theta,$$

as shown by Schläfli.

Tables of the second integral, $F_\nu(x)$ for both positive and negative values of ν have been computed, for small values of the argument, from the ascending series, viz.

$$F_\nu(x) = S_{0\cdot\nu}(x) + \frac{S_{1\cdot\nu}(x)}{\nu} - \frac{1}{\nu} + \frac{\pi}{\sin\nu\pi}\cdot J_{-\nu}(x),$$

where $S_{0\cdot\nu}(x) = \dfrac{x}{(1^2-\nu^2)} - \dfrac{x^3}{(1^2-\nu^2)(3^2-\nu^2)} + \dfrac{x^5}{(1^2-\nu^2)(3^2-\nu^2)(5^2-\nu^2)} - \ldots$

and $S_{1\cdot\nu}(x) = \dfrac{x^2}{(2^2-\nu^2)} - \dfrac{x^4}{(2^2-\nu^2)(4^2-\nu^2)} + \dfrac{x^6}{(2^2-\nu^2)(4^2-\nu^2)(6^2-\nu^2)} - \ldots$

and for large values of the argument, where $x = \nu + \kappa$, from the asymptotic series,†

$$F_\nu(x) = \frac{1}{3}\left[\left(\frac{6}{x}\right)^{\frac{1}{3}}\Gamma\left(\frac{1}{3}\right) - \sigma_1\left(\frac{6}{x}\right)^{\frac{2}{3}}\Gamma\left(\frac{2}{3}\right) + \sigma_2\left(\frac{6}{x}\right) - \frac{\sigma_3}{3}\left(\frac{6}{x}\right)^{\frac{4}{3}}\Gamma\left(\frac{1}{3}\right) + \ldots\right]$$

the functions σ_n. having the following values :

$$\sigma_1 = \kappa$$

$$\sigma_2 = \frac{\kappa^2}{2} - \frac{1}{20}$$

$$\sigma_3 = \frac{\kappa^3}{6} - \frac{\kappa}{15}$$

$$\sigma_4 = \frac{\kappa^4}{24} - \frac{\kappa^2}{24} + \frac{1}{280},\ \text{etc.}$$

$$\text{and } F_{-\nu}(x) = \left[\frac{1}{2x} + \frac{s_1}{(2x)^2} + \frac{2s_2}{(2x)^3} + \frac{6s_3}{(2x)^4} + \frac{24s_4}{(2x)^5} + \ldots\right]$$

† 'The Lommel-Weber Ω function and its application to the problem of electric waves on a thin anchor ring.' *Proc. Roy. Soc.* A., vol. 94, 1918, pp. 313-4.

where $s_1 = \kappa$

$$s_2 = \frac{\kappa^2}{2} - \frac{1}{4}$$

$$s_3 = \frac{\kappa^3}{6} - \frac{\kappa}{3}$$

$$s_4 = \frac{\kappa^4}{24} - \frac{5\kappa^2}{24} + \frac{1}{12}, \text{ etc.}$$

The recurrence formula is $F_{\nu+1}(x) = \frac{2\nu}{x} F_\nu(x) - F_{\nu-1}(x) + \frac{2}{x}$.

4ν	$F_\nu(\nu)$	$F_{\nu-1}(\nu)$	$F_{-\nu}(\nu)$	$F_{-\nu+1}(\nu)$
0	∞	1·000000	∞	∞
1	2·299108	0·869189	1·323320 :	4·725067
2	1·889991 :	0·817059 :	0·817059 :	1·889991 :
3	1·677630 :	0·781670	0·590469	1·101069
4	1·548758	0·754610	0·451242	0·754610
5	1·437873 :	0·732641	0·377600	0·566189 :
6	1·359567	0·714131 :	0·319299	0·449854
7	1·292436	0·693696	0·285219 :	0·371698 :
8	1·243478	0·684060	0·243478	0·315940
9	1·198512	0·671492 :	0·217500	0·274327 :
10	1·159994	0·660545	0·196682 :	0·242332
11	1·125211	0·649803 :	0·179120 :	0·216627 :
12	1·094702	0·640316 :	0·164557 :	0·195872
13	1.067289 :	0·631550	0·152172	0·178688
14	1·042462 :	0·623419	0·141457	0·164277 :
15	1·019839 :	0·615799	0·132221 :	0·151932
16	0·999076	0·608678	0·124076	0·141322
17	0·979924 :	0·601976 :	0·116872 :	0·132082 :
18	0·962179	0·595652 :	0·110455	0·123968 :
19	0·945664 :	0·589666 :	0·104703 :	0·116787
20	0·930242	0·583986 :	0·099518	0·110386 :
21	0·915788	0·578584	0·094820 :	0·104647 :
22	0·902200 :	0·573434	0·090545	0·099472
23	0·889393 :	0·568548	0·086637	0·094782 :
24	0·877290	0·563808	0·083051 :	0·090513
25	0·865826	0·559296	0·079750	0·086610
26	0·854943 :	0·554965 :	0·076700 :	0·083029
27	0·844593	0·550802	0·073875	0·079731
28	0·834730 :	0·546794	0·071250	0·076684
29	0·825317	0·542930 :	0·068804 :	0·073861
30	0·816317 :	0·539204	0·066521	0·071237 :
31	0·807701	0·535604	0·064384	0·068793 :
32	0·799440 :	0·532121	0·062380	0·066511 :
33	0·791510	0·528751	0·060496 :	0·064375 :
34	0·783887 :	0·525486	0·058723	0·062372 :
35	0·776552	0·522320	0·057050 :	0·060490
36	0·769486	0·519248	0·055471	0·058717 :
37	0·762672 :	0·516264 :	0·053976	0·057045 :
38	0·756095	0·513364 :	0·052559 :	0·055466
39	0·749741	0·510544 :	0·051215 :	0·053972
40	0·743596	0·507800	0·049938	0·052555 :

(C). The Lommel-Weber Ω function, defined by the integral

$$\Omega_\nu(x) = \frac{1}{\pi}\int_0^\pi \sin(\nu\varphi - x\sin\varphi)\,d\varphi,$$

when the order and argument are equal or differ by unity occurs in the problem of the electro-magnetic waves on a thin anchor ring. In addition to the Royal Society paper already cited, reference may be made to two papers by C. W. Oseen.‡ No method of evaluating these functions is given, however.

The function has been calculated from the expression

$$\Omega_\nu(x) = \frac{1-\cos\nu\pi}{\nu\pi} \cdot (1 - S_{1\cdot\nu}) + \frac{1+\cos\nu\pi}{\pi} \cdot S_{0\cdot\nu}$$

for small values of ν and x: and from

$$\Omega_\nu(x) = N_\nu(x) + \frac{1}{\pi}\int_0^\infty e^{-x\sinh\theta}(e^{\nu\theta} + \cos\nu\pi \cdot e^{-\nu\theta})d\theta$$

for large values.

By means of the recurrence formula,

$$\Omega_{\nu+1}(x) = \frac{2\nu}{x} \cdot \Omega_\nu(x) - \Omega_{\nu-1}(x) + \frac{4\sin^2\frac{\nu\pi}{2}}{\pi x},$$

functions of higher or lower order may be found from the table below.

4ν	$\Omega_\nu(\nu)$.	$\Omega_{\nu-1}(\nu)$.	4ν	$\Omega_\nu(\nu)$.	$\Omega_{\nu-1}(\nu)$.
0	0·000000	+0·636620	20	—0·189267 :	+0·028883 :
1	—0·223134	+0·764280	21	—0·176178	+0·013998
2	—0·388643	+0·801051 :	22	—0·152262	—0·012517 :
3	—0·460801	+0·729461	23	—0·130347	—0·036507
4	—0·438162 :	+0·568656 :	24	—0·121139 :	—0·046406 :
5	—0·351335 :	+0·366713	25	—0·127483 :	—0·039277
6	—0·247796 :	+0·181232	26	—0·143408 :	—0·021774
7	—0·171114	+0·056955	27	—0·158117 :	—0·005646 :
8	—0·144095	+0·010144	28	—0·162347 :	—0·000847 :
9	—0·162886	+0·026096 :	29	—0·153421 :	—0·010160
10	—0·203545 :	+0·069837	30	—0·136283 :	—0·028190 :
11	—0·236690 :	+0·104088	31	—0·120215 :	—0·044970 :
12	—0·242467 :	+0·105767	32	—0·113344	—0·051856
13	—0·218764 :	+0·073703	33	—0·118141	—0·046283
14	—0·179525	+0·025095	34	—0·130374	—0·032821 :
15	—0·145256 :	—0·016280 :	35	—0·141887 :	—0·020161 :
16	—0·131426	—0·033258	36	—0·145427 :	—0·015975
17	—0·140869	—0·023390	37	—0·138692	—0·022653
18	—0·163728 :	+0·001615 :	38	—0·125360 :	—0·036265
19	—0·184111 :	+0·023733 :	39	—0·112693	—0·049134 :
20	—0·189267 :	+0·028883 :	40	—0·107224 :	—0·054390 :

PART III.

Bessel Functions of negative semi-imaginary argument.

Bessel functions of a negative semi-imaginary argument $z\sqrt{-i}$, $J_0(z\diagdown 45°)$ and $J_1(z\diagdown 45°)$, from $z=0$ to $z=10$, by intervals of 0·1; communicated by A. E. Kennelly, Harvard University and the Massachusetts Institute of Technology; also of their application to the determination of the alternating-current skin-effect impedance ratio Z′/R, of straight uniform round copper wires, remote from other active conductors, according to the formula

$$\frac{Z'}{R} = \frac{z\diagdown 45°}{2} \cdot \frac{J_0(z\diagdown 45°)}{J_1(z\diagdown 45°)}$$

‡ (*a*) Über die Elektromagnetischen Schwingungen an dünnen Ringen.
(*b*) Über das Elektromagnetische Spektrum eines dünnen Ringes.
Archiv. f. Matematik, Astronomi och Fysik—Vol. 9. Nos. 12 and 28 1913-4.

where $z = X\sqrt{4\pi\gamma\mu\omega}$ and numeric $\angle$

Z' = linear impedance of the wire to alternating current, abohms·cm. $\angle$

R = linear resistance of the wire to continuous current, abohms/cm.

X = radius of wire, cm.

$i = \sqrt{-1}$

$\pi = 3{\cdot}14159\ldots$

$\gamma = \frac{1}{\rho}$ = conductivity of the wire, abmhos/cm., taken as $0{\cdot}580 \times 10^{-3}$.

$\rho = \frac{1}{\gamma}$ = resistivity of the wire, abohm-cm.

μ = magnetic permeability of the wire, taken as unity.

$\omega = 2\pi f$ = angular velocity of alternating current, radians/sec.

f = frequency of alternating current, cycles/sec.

X' = linear reactance of the wire to alternating current, abohm-cm.

If $\frac{Z}{R} = \frac{R'}{R} + i\frac{X'}{R}$,

then the real term $\frac{R'}{R}$ is taken as the skin-effect resistance ratio and the imaginary term, $i\,.\,\frac{X'}{R}$ is taken as the skin-effect reactance ratio.

$$\text{Thus, for } z = 3{\cdot}0\diagdown 45^\circ,\ J_0(3{\cdot}0\diagdown 45^\circ) = 1{\cdot}950192\underline{\angle 96^\circ\,.\,51810}$$

$$J_1(3{\cdot}0\diagdown 45^\circ) = 1{\cdot}799908\underline{\angle 15^\circ\,.\,71317}$$

$$\text{and } 1{\cdot}318095 + i\ 0{\cdot}950812 = 1{\cdot}625244\underline{\angle 35^\circ\,.\,80493}$$

$$\text{and } \frac{Z'}{R} = \frac{3{\cdot}0\diagdown 45^\circ}{2} \times \frac{1{\cdot}950192\ \underline{\angle 96^\circ\,.\,51810}}{1{\cdot}799908\ \underline{\angle 15^\circ\,.\,71317}} = 1{\cdot}625244\underline{\angle 35^\circ\,.\,80493}$$

$$= 1{\cdot}318095 + i\ 0{\cdot}950812.$$

In this case, the wire would offer an apparent resistance 31·8095 per cent. in excess of its continuous-current resistance. For the purposes of engineering practice, a much lower arithmetical precision would ordinarily suffice.

The table was computed by Mr. P. L. Alger, in the electrical-engineering department of the Massachusetts Institute of Technology.

References :

(1) Jahnke and Emde 'Funktionentafeln,' Berlin, 1909, p. 147, and (2) 'Experimental Researches on Skin Effect in Conductors,' by A. E. Kennelly, F. A. Laws and P. H. Pierce, *Proc. Am. Inst. Elec. Engrs.*, September 16, 1915, p. 1795.

From $z = 0$ to $z = 5·0$.

	$\rho_0 \angle \theta_0° = J_0(z\,\overline{\diagdown 45°})$				$\rho_1 \angle \theta_1° = J_1(z\,\overline{\diagdown 45°})$			
z	ρ_0	Δ_4	$\angle \theta_0$	Δ_4	ρ_1	Δ_4	$\angle \theta_1$	Δ_4
0	1·000000		0°·00000		0·000000		—45°·00000	
·1	1·000002		0°·14324		0·050000		—44°·92838	
·2	1·000025	+ 38	0·57295	— 16	0·100000	+ 1	— 44·71352	+ 1
·3	1·000126	+ 34	1·28908	— 33	0·150003	+ 7	— 44·35543	— 4
·4	1·000400	40	2·29142	— 58	0·200013	3	— 43·85411	— 4
·5	1·000976	36	3·57943	90	0·250041	12	— 43·20960	— 4
·6	1·002023	33	5·15199	124	0·300101	6	— 42·42198	— 8
·7	1·003746	36	7·00708	167	0·350219	12	— 41·49137	12
·8	1·006383	29	9·14144	204	0·400427	12	— 40·41797	15
·9	1·010208	29	11·55014	247	0·450769	16	— 39·20210	15
1·0	1·015524	20	14·22621	274	0·501301	12	— 37·84423	25
1·1	1·022663	+ 14	17·16021	292	0·55209$\bar{5}$	19	— 36·34498	23
1·2	1·031977	+ 14	20·33996	296	0·60323$\bar{5}$	17	— 34·70522	30
1·3	1·043832	— 2	23·75036	275	0·654824	20	— 32·9260$\bar{5}$	34
1·4	1·058608	— 4	27·3733$\bar{5}$	229	0·706982	20	— 31·00887	40
1·5	1·076683	16	31·18812	—163	0·759849	20	— 28·95542	39
1·6	1·098431	19	35·17157	— 85	0·81358$\bar{5}$	23	— 26·76784	44
1·7	1·124210	22	39·29897	+ 6	0·868370	25	— 24·44866	48
1·8	1·154359	29	43·54474	+103	0·924407	18	— 22·00085	47
1·9	1·189195	26	47·88336	182	0·981924	28	— 19·42786	49
2·0	1·229006	25	52·29034	246	1·041167	22	— 16·73361	44
2·1	1·274054	21	56·74301	293	1·102410	22	— 13·92251	45
2·2	1·324576	15	61·22116	315	1·165949	24	— 10·99941	42
2·3	1·380788	— 9	65·70751	312	1·232102	23	— 7·96961	32
2·4	1·442891	— 2	70·18793	296	1·301211	23	— 4·83883	27
2·5	1·511077	+ 3	74·65141	266	1·373641	20	— 1·61311	—23
2·6	1·585536	+ 14	79·08990	230	1·449780	21	+ 1·70124	— 9
2·7	1·666461	17	83·49801	186	1·530036	23	+ 5·09768	— 3
2·8	1·754059	22	87·8726$\bar{5}$	150	1·614838	20	+ 8·56957	+ 6
2·9	1·848554	31	92·21259	110	1·704638	19	12·11027	16
3·0	1·950192	31	96·51810	77	1·799908	22	15·71317	23
3·1	2·059250	36	100·79055	52	1·901139	23	19·37183	29
3·2	2·176036	42	105·03208	+ 26	2·008844	20	23·08004	37
3·3	2·300894	44	109·24535	+ 10	2·123559	26	26·83188	43
3·4	2·434210	43	113·43328	— 3	2·245840	25	30·62180	41
3·5	2·576414	52	117·59889	— 12	2·376269	27	34·44468	46
3·6	2·727979	49	121·74517	23	2·515453	31	38·29581	46
3·7	2·889430	56	125·87499	23	2·664026	32	42·17094	46
3·8	3·061341	55	129·99099	25	2·822653	39	46·06628	44
3·9	3·244342	59	134·09558	28	2·992031	38	49·97850	40
4·0	3·439118	61	138·19092	25	3·172896	44	53·90471	39
4·1	3·646413	65	142·27889	27	3·366022	49	57·84242	35
4·2	3·867032	68	146·36112	23	3·572227	52	61·78953	31
4·3	4·101845	73	150·43897	19	3·792378	57	65·74429	27
4·4	4·351790	70	154·51357	21	4·027394	65	69·70526	24
4·5	4·617878	78	158·58586	16	4·278251	67	73·67127	20
4·6	4·901190	87	162·65657	15	4·545990	73	77·64139	18
4·7	5·20288$\bar{5}$	86	166·72627	10	4·831719	78	81·61489	13
4·8	5·524210	91	170·79538	11	5·136619	91	85·59122	12
4·9	5·866494	+ 98	174·86422	— 8	5·461949	+89	89·56996	+ 9
5·0	6·231163	+104	178·93300	— 7	5·809059	+99	93·55081	+ 6

From $z=0$ to $z=5 \cdot 0$.

z	$M \angle \beta^{\circ}$ = Impedance Ratio = $M (\cos\beta + i \sin\beta) = \frac{z}{2} \diagdown 45^{\circ} \frac{J_0}{J_1}$							
	M	Δ_4	$\angle \beta$	Δ_4	Resistance Ratio. $M \cos\beta$	Δ_4	Reactance Ratio. $M \sin\beta$	Δ_4
0	1·000000		0°·00000		1·000000		0·000000	
·1	1·000002		0°·07162		1·000001		0·001250	
·2	1·000021	+31	0·28647	− 17	1·000009	+15	0·005000	−1
·3	1·000105	+29	0·64451	− 29	1·000042	+10	0·011250	−1
·4	1·000333	32	1·14553	54	1·000133	14	0·019999	−1
·5	1·000813	30	1·78903	86	1·000325	10	0·03124$\bar{5}$	4
·6	1·001685	26	2·57397	116	1·000675	13	0·04498$\bar{5}$	4
·7	1·003119	28	3·49845$\bar{5}$	154	1·001250	12	0·061212	5
·8	1·005311	23	4·55941	193	1·002130	13	0·07991$\bar{5}$	9
·9	1·008485	+16	5·7522$\bar{5}$	226	1·003407	7	0·101078	7
1·0	1·012888	+10	7·07044	253	1·005186	+10	0·124676	12
1·1	1·018783	+ 2	8·50519	269	1·007579	6	0·150677	13
1·2	1·026443	− 4	10·04518	263	1·010708	+ 8	0·179037	15
1·3	1·036143	19	11·67640	243	1·014701	+ 1	0·209699	16
1·4	1·048154	27	13·38221	191	1·019694	+ 1	0·242591	17
1·5	1·062728	37	15·14354	−121	1·025824	− 4	0·27762$\bar{5}$	21
1·6	1·080090	50	16·93941	− 42	1·033229	− 6	0·314696	17
1·7	1·100428	51	18·74763	+ 54	1·042043	−12	0·353678	18
1·8	1·123880	62	20·54559	+150	1·052394	−13	0·394428	21
1·9	1·150533	59	22·31122	231	1·064398	19	0·436785	13
2·0	1·180412	57	24·02395	290	1·078158	24	0·480567	13
2·1	1·213483	58	25·66552	338	1·093758	24	0·525579	11
2·2	1·24965$\bar{5}$	46	27·22057	357	1·111258	27	0·571613	−3
2·3	1·288779	37	28·67712	344	1·130694	31	0·618450	0
2·4	1·330660	34	30·02676	323	1·15207$\bar{5}$	26	0·665868	+5
2·5	1·375066	17	31·26452	289	1·175379	31	0·713645	14
2·6	1·421731	− 7	32·38866	239	1·200558	24	0·761563	15
2·7	1·470372	− 4	33·40033	190	1·227533	22	0·809418	18
2·8	1·520699	+ 9	34·30307	141	1·256201	21	0·857021	25
2·9	1·572418	+17	35·10232	97	1·286437	11	0·904201	29
3·0	1·625244	20	35·80493	+53	1·31809$\bar{5}$	−10	0·950812	27
3·1	1·678909	25	36·41872	+23	1·351018	− 1	0·996737	25
3·2	1·73316$\bar{5}$	30	36·95204	−11	1·385039	+ 1	1·041886	31
3·3	1·787789	28	37·41347	−33	1·419990	+ 5	1·086194	23
3·4	1·842588	28	37·81148	44	1·455704	13	1·129627	23
3·5	1·897397	32	38·15421	58	1·492019	12	1·172174	20
3·6	1·952079	25	38·44936	69	1·528786	14	1·213847	15
3·7	2·006529	26	38·70405	69	1·565868	20	1·254678	13
3·8	2·060667	19	38·92471	69	1·603142	15	1·294714	+5
3·9	2·114439	21	39·11708	68	1·640505	17	1·33401$\bar{5}$	+8
4·0	2·167810	14	39·28621	64	1·677869	16	1·372646	+1
4·1	2·220766	13	39·43647	62	1·715163	14	1·410680	0
4·2	2·273307	9	39·57159	54	1·752332	16	1·448191	−3
4·3	2·325446	9	39·69468	46	1·78933$\bar{5}$	9	1·485253	−6
4·4	2·37720$\bar{5}$	+ 3	39·80831	45	1·826147	11	1·521937	−2
4·5	2·42861$\bar{5}$	0	39·91459	36	1·862752	7	1·558308	−9
4·6	2·479710	+ 5	40·01518	33	1·899145	7	1·594429	−6
4·7	2·530524	− 3	40·11138	23	1·935328	4	1·630354	−6
4·8	2·581096	− 1	40·20416	23	1·971310	+ 2	1·666131	−8
4·9	2·631462	− 1	40·29426	−17	2·007104	+ 6	1·701802	−5
5·0	2·681657	− 5	40·38219	−13	2·04272$\bar{5}$	− 2	1·737401	−5

From $z=5{\cdot}1$ to $z=10$.

	$\rho_0 \angle \theta_0^\circ = J_0(z\diagdown 45^\circ)$				$\rho_1 \angle \theta_1^\circ = J_1(z\diagdown 45^\circ)$			
z	ρ_0	Δ_4	$\angle \theta_0$	Δ_4	ρ_1	Δ_4	$\angle \theta_1$	Δ_4
5·1	6·619737	+110	183°·0018$\bar{5}$	−2	6·179388	+109	97°·53356	+8
5·2	7·033841	+120	187°·07083	−7	6·574474	+113	101°·51806	0
5·3	7·475210	123	191·13998	−1	6·995964	123	105·50424	+5
5·4	7·945699	133	195·20927	−1	7·445618	133	109·49203	+1
5·5	8·447286	144	199·27866	−2	7·925319	138	113·48141	+2
5·6	8·982082	151	203·34810	0	8·437083	152	117·47237	0
5·7	9·552342	164	207·41752	+1	8·983064	160	121·46492	−1
5·8	10·16047	17	211·48685	−1	9·565568	173	125·45907	0
5·9	10·80904	20	215·55603	+1	10·18706	17	129·45482	−1
6·0	11·50079	17	219·62499	+1	10·85018	20	133·45217	+1
6·1	12·23866	24	223·69367	+2	11·55775	20	137·45111	−1
6·2	13·02576	21	227·76202	−2	12·31279	24	141·45164	−2
6·3	13·86544	25	231·83001	+3	13·11852	23	145·45375	0
6·4	14·76126	27	235·89759	+1	13·97840	25	149·45741	−1
6·5	15·71703	27	239·96474	−1	14·89612	28	153·46259	+1
6·6	16·73683	29	244·0314$\bar{5}$	+1	15·87562	29	157·4692$\bar{5}$	−1
6·7	17·82501	32	248·09770	+3	16·92112	31	161·47736	−2
6·8	18·98621	35	252·16348	−3	18·03713	35	165·48688	+1
6·9	20·22539	37	256·22881	+2	19·22847	33	169·49775	+1
7·0	21·54786	37	260·29368	+1	20·50031	40	173·50992	−1
7·1	22·95930	43	264·35810	−1	21·85815	40	177·52335	0
7·2	24·46576	44	268·42209	+1	23·30789	43	181·53799	−2
7·3	26·07372	49	272·48566	−1	24·85583	48	185·55379	+3
7·4	27·79010	50	276·54883	+1	26·50870	49	189·57068	−1
7·5	29·62231	55	280·61161	0	28·27371	53	193·58862	+1
7·6	31·57826	57	284·67402	0	30·15856	56	197·60756	−2
7·7	33·66641	65	288·73608	−1	32·17148	62	201·62746	+1
7·8	35·89579	65	292·79781	+1	34·32126	68	205·64826	+2
7·9	38·27608	73	296·85922	−1	36·61731	65	209·66991	−2
8·0	40·81761	75	300·92033	+2	39·06972	75	213·69238	0
8·1	43·53144	81	304·98115	−2	41·68923	81	217·71562	+3
8·2	46·42938	89	309·04171	−1	44·48733	85	221·73958	−3
8·3	49·5240$\bar{5}$	95	313·10202	+1	47·47632	90	225·76424	+1
8·4	52·82896	97	317·16208	+2	50·66935	97	229·7895$\bar{5}$	+1
8·5	56·35857	108	321·22190	−2	54·08047	104	233·81547	−1
8·6	60·12831	115	325·28151	−2	57·72470	110	237·84197	+1
8·7	64·15469	123	329·34092	+3	61·61810	119	241·86901	+1
8·8	68·45537	131	333·40012	−1	65·77783	124	245·89656	−1
8·9	73·04924	137	337·45913	−1	70·22224	135	249·92460	0
9·0	77·95650	152	341·51796	+1	74·97092	143	253·95310	+2
9·1	83·19872	163	345·57661	+1	80·04481	153	257·98203	+1
9·2	88·79899	169	349·63509	−3	85·46628	160	262·01138	−1
9·3	94·78203	184	353·69342	+1	91·25923	176	266·04115	+3
9·4	101·17425	195	357·75159	+2	97·44916	181	270·07133	0
9·5	108·00390	212	361·80960	−2	104·06333	197	274·10194	+2
9·6	115·30118	224	365·86747	0	111·13081	206	278·13300	+2
9·7	123·09841	+240	369·92520	+1	118·68264	222	282·1645$\bar{5}$	+3
9·8	131·4301$\bar{5}$	+260	373·98279	−1	126·75192	232	286·19665	+3
9·9	140·33336		378·04025		135·37397		290·22939	
10·0	149·84760		382·09758		144·58643		294·26289	

From $z=5{\cdot}1$ to $z=10$.

	$M \angle \beta^\circ$ = Impedance Ratio = $M(\cos\beta + i \sin\beta) = \frac{z}{2}\diagdown 45^\circ \frac{J_0}{J_1}$							
z	M	Δ_4	$\angle \beta$	Δ_4	Resistance Ratio. M cos β	Δ_4	Reactance Ratio. M sin β	Δ_4
5·1	2·731715	−2	40°·46829	−10	2·078194	+1	1·772957	−6
5·2	2·78166$\bar{5}$	−4	40°·55277	−7	2·113530	−2	1·808494	−6
5·3	2·831534	−4	40·63574	−6	2·148753	+1	1·844030	−1
5·4	2·88134$\bar{5}$	−1	40·77124	−3	2·183881	−2	1·879577	−6
5·5	2·931117	−4	40·79725	−1	2·218933	−1	1·915146	−3
5·6	2·980868	−5	40·87572	−2	2·253926	−4	1·950742	0
5·7	3·030612	0	40·95259	+1	2·288876	+1	1·986367	−2
5·8	3·080358	−3	41·02778	−1	2·323795	−3	2·022023	−3
5·9	3·13011$\bar{5}$	−2	41·10122	+3	2·358696	−2	2·057710	−1
6·0	3·179889	0	41·17283	+2	2·393589	−1	2·093425	+1
6·1	3·229684	−5	41·24256	0	2·428482	−3	2·129164	0
6·2	3·279504	0	41·31038	+1	2·463382	−1	2·164924	−3
6·3	3·329348	+1	41·37626	+4	2·498293	+2	2·200702	+2
6·4	3·37921$\bar{5}$	0	41·44018	−2	2·533218	−4	2·236492	+1
6·5	3·429105	−3	41·50216	+3	2·568162	0	2·272290	+1
6·6	3·479018	+1	41·56220	+2	2·603126	−1	2·308093	−3
6·7	3·528951	−1	41·62033	0	2·638111	−1	2·343899	+2
6·8	3·578902	+1	41·67660	−1	2·673117	0	2·379703	+1
6·9	3·628868	+1	41·73106	+3	2·708143	+1	2·415502	0
7·0	3·678847	−3	41·78375	−1	2·743188	−2	2·451294	0
7·1	3·728838	+3	41·83474	+1	2·778252	+1	2·487077	+2
7·2	3·778837	−1	41·88409	0	2·813333	−1	2·522849	0
7·3	3·828843	0	41·93187	−1	2·848430	−1	2·558610	−2
7·4	3·878854	0	41·97815	+1	2·883541	+3	2·594360	+1
7·5	3·928868	−2	42·02299	0	2·918663	−1	2·630097	+3
7·6	3·978883	+1	42·06646	−2	2·953796	+1	2·665820	−1
7·7	4·028899	−3	42·10863	+3	2·988939	−3	2·701531	−1
7·8	4·078917	0	42·14955	−1	3·024092	0	2·737231	0
7·9	4·128935	+3	42·18930	−3	3·059252	+5	2·772920	+1
8·0	4·178951	0	42·22795	+1	3·094416	−3	2·808598	+1
8·1	4·228966	−1	42·26554	+3	3·129586	−1	2·844266	−1
8·2	4·278981	0	42·30212	−4	3·164761	+2	2·879926	+1
8·3	4·328996	+2	42·33777	0	3·199939	0	2·915579	0
8·4	4·379011	0	42·37253	0	3·235120	+1	2·951227	0
8·5	4·429028	−2	42·40644	0	3·270304	−2	2·986872	0
8·6	4·479049	+3	42·43954	+1	3·305492	+2	3·022516	0
8·7	4·529074	0	42·47191	−1	3·340683	0	3·058161	+2
8·8	4·579106	+1	42·50356	0	3·375879	+3	3·093809	−2
8·9	4·629148	0	42·53453	−1	3·411080	−3	3·129464	+2
9·0	4·679204	0	42·56486	−1	3·446290	+3	3·165128	0
9·1	4·729278	+4	42·59458	−1	3·481510	+1	3·200805	0
9·2	4·779374	−2	42·62371	+1	3·516744	+1	3·236499	0
9·3	4·829500	+2	42·65226	−4	3·551997	+1	3·272214	−1
9·4	4·879662	+1	42·68025	0	3·587275	+2	3·307954	+2
9·5	4·929868	+3	42·70766	−1	3·62258$\bar{5}$	+2	3·343722	−1
9·6	4·980127	0	42·73447	−3	3·657936	+3	3·379523	−1
9·7	5·030451	0	42·76065	−2	3·693339	+2	3·415361	−1
9·8	5·080852	+6	42·78614	−3	3·728808	+3	3·451239	+2
9·9	5·131342		42·81086		3·764359		3·487159	
10·0	5·181939		42·83470		3·800011		3·52312$\bar{5}$	

Tides.—*Report of Committee to assist work on the Tides* (Professor H. Lamb, *Chairman*; Dr. A. T. Doodson, *Secretary*; Col. Sir C. F. Close, Dr. P. H. Cowell, Sir H. Darwin, Dr. G. H. Fowler, Admiral F. C. Learmonth, Professor J. Proudman, Major G. I. Taylor. Professor D'Arcy W. Thompson, Sir J. J. Thomson, Professor H. H. Turner). *(Drawn up by the Secretary.)*

1. The process of reduction of the tide-gauge records at Newlyn has not been carried much further than is indicated in the Report for 1921, except that ' residues ' from a complete year's record are now available. Further analyses have been carried out in the manner indicated in 1921 and revised harmonic constants for the usual Darwinian constituents are given later in §6. The residual semi-diurnal oscillations are not yet reduced to law and direct analyses of these have not been attempted, but two hypotheses concerning them have been considered. Further consideration has been given to the shallow water problem, and some conclusions have been formulated in §5.

Friction.

2. The first hypothesis concerning the residue of unknown origin was suggested by Professor Proudman, and he contributes an appendix dealing with the effects of friction on tidal motion. The effect of friction is definitely to introduce harmonic constituents which are not in the original tidal motion or among the ordinary ' shallow water constituents.' Application of the law suggested by him has been made to the Newlyn tides, but so far without much result, the reason for which is probably the difficulty of isolating this frictional effect from other and larger perturbations. Powerful support for such a hypothesis, however, has been obtained from a study of the tides at St. John, N.B., in the Bay of Fundy. Attention was called to the relevant features of these by Dr. Bell Dawson, Superintendent of the Canadian Survey of Tides and Currents.

The M_2 Constituent at St. John, N.B.

3. The results of analyses for M_2 for over nineteen years were available, and these showed that the amplitude (R) of the constituent varied in a period of nineteen years from 9·45 ft. to 9·99 ft. Darwin's factor f should give $H=R/f$ as the amplitude of the principal term of this constituent and H should be constant from year to year. It was found, however, that H varied in a period of nineteen years from 9·54 ft. to 10·07 ft. so that the factor f was futile. Dr. Bell Dawson suggested that the theoretical factor should not be used for St. John, but that the variation actually found should be used to give a new factor for local use. This, of course, would meet the case in practice, but the explanation of the behaviour is very important. Investigations showed that this constituent M_2 is effectively composed of three terms of speeds, $\sigma, \sigma+\dot{N}, \sigma-\dot{N}$, where σ is the speed of the principal term, and $\dot{N}$ is the rate of revolution of the moon's nodes. Now the full development of the potential* gives no indication of the term with speed $\sigma-\dot{N}$, but an explanation of the occurrence in actual tides is immediately furnished by Professor Proudman's theory.

Unfortunately, there are no long sequences of analyses for British waters, but the evidence tends to show that Liverpool ' constants ' are affected similarly to those of St. John, while the ' constants ' for Indian Ports show the effect in a smaller degree. These and other perturbations of harmonic constants due to deficient analyses and to secular changes of unknown origin are to be discussed by the Secretary in a separate paper.

* ' The Harmonic Development of the Tide-generating Potential,' by A. T. Doodson, D.Sc., *Proc. Roy. Soc.* (A), vol. 100, 1921.

Meteorological Tides.

4. The second hypothesis mentioned in §1 deals with the effects of the varying distribution of atmospheric pressure, both statically and by the operation of wind, on sea level and tides. A paper is being written by the Secretary on this subject, to be published elsewhere; the main results are recorded in the Journal of Section A and also in the Tidal Institute Reports for 1922 and 1923. A great deal of numerical work has been done and the Newlyn residues have been of very great value; in fact, much of the work would have been impossible without them.

Definite evidence of *perturbations* of *tidal motion* has been obtained, but the law of operation is somewhat complex. It is clear, however, that these effects are second-order effects, and are governed by the product terms in the equations of motion and continuity in just the same way as are the shallow water effects discussed in 1921. The product terms involve currents as well as heights, and since the meteorological current and height are probably fairly well represented by linear combinations of atmospheric pressure and its gradients in two directions, it is obvious that the product terms will give a rather complex law for meteorological tides. This law has not yet been obtained. It is, however, possible that contributions of importance arise from the long period changes in the distribution of atmospheric pressure, in which case the law will be simplified. The effect will show itself as a perturbation of harmonic 'constants,' or, alternatively, as new harmonic constituents, and this may be the explanation of a part of the residual semi-diurnal oscillation at Newlyn. It may possibly account for a perturbation of 0·5 foot and period of half a year in the M_2 constituent at Liverpool for the year 1918. Further analyses, however, will be necessary before this matter can be adequately considered.

Shallow Water Effects.

5. It was shown in the Report for 1921 that a simple relation exists between the quarter-diurnal tide and the square of the semi-diurnal tide. The sixth-diurnal tide, according to the theory of motion in a shallow canal, should be proportional to the sixth-diurnal part of the cube of the semi-diurnal tide, with a constant factor and constant phase shift, while tests on tidal records at Liverpool confirm this law and also a similar law for the eighth-diurnal tide. We can investigate the shallow water effects, therefore, as follows.

Taking the time-origin at High Water of the semi-diurnal tide and writing ζ_n for the nth diurnal tide, we have the compound tide given by

$$\left.\begin{aligned} \zeta &= \zeta_2 + \zeta_4 + \zeta_6 + \zeta_8 + \quad \cdots \\ \text{with} \qquad \zeta_2 &= \mathrm{R} \cos \sigma t \\ \zeta_4 &= c_4 \mathrm{R}^2 \cos (2\sigma t + \chi_4) \\ \zeta_6 &= c_6 \mathrm{R}^3 \cos (3\sigma t + \chi_6) \\ \zeta_8 &= c_8 \mathrm{R}^4 \cos (4\sigma t + \chi_8) \end{aligned}\right\} \quad \cdots \quad (1)$$

where c_n, χ_n are constants.

High Water of the compound tide will occur when

$$\sin \sigma t = -2c_4 \mathrm{R} \sin (2\sigma t + \chi_4) - 3c_6 \mathrm{R}^2 \sin (3\sigma t + \chi_6) - 4c_8 \mathrm{R}^3 \sin (4\sigma t + \chi_8) - \cdots \quad (2)$$

The constants c_n, χ_n can be determined from the harmonic constants for the principal lunar constituents, for when R is equal to the amplitude of M_2 then the tide is correctly represented by M_2, M_4, M_6, M_8, . . .

The data for Liverpool are

M_2 :	H = 9·975 ft.	$\kappa = 320^\circ{\cdot}7$		
M_4 :	H = ·691 ft.	$\kappa = 211$	$10^2 c_4 = {\cdot}695$	$\chi_4 = 70^\circ$
M_6 :	H = ·196 ft.	$\kappa = 331$	$10^3 c_6 = {\cdot}197$	$\chi_6 = 271$
M_8 :	H = ·068 ft.	$\kappa = 255$	$10^4 c_8 = {\cdot}069$	$\chi_8 = 308$

whence we can construct the following table:

R	5	10	15
$c_4 R^2$	·174	·695	1·564
$c_6 R^3$	·025	·197	·665
$c_8 R^4$	.004	·069	·350
$2c_4 R$	·070	·139	·209
$3c_6 R^2$	·015	·059	·133
$4c_8 R^3$	·004	·028	·093

The upper part of the table gives the amplitudes in feet of the contributions to ζ, while the lower part gives the coefficients of the sine terms contributing to sin σt for determining the time of High Water. Since σt is small for High Water then approximately 1 minute in time is represented by ·01 in sin σt. We can draw the following conclusions from this table, supplementary to those given in 1921 :—

I.—The use of M_6 and M_8 as sole representatives of ζ_6 and ζ_8 is entirely inadequate ; for

(1) at spring tides ζ_6 and ζ_8 are thereby under-estimated in amplitude to the extent of 0·47 ft. and 0·28 ft. respectively, while at neap tides ζ_6 is over-estimated in amplitude to the extent of 0·15 ft. ;

(2) the time of H.W. cannot be given accurately at spring tides, the error being about 10 minutes, and if navigators use interpolation methods for heights at times other than H.W., the error resulting from this 10 minutes may mean nearly a foot at half tide.

II.—The use of the partial tides ζ_2 to ζ_8 alone, even if these are correctly represented, cannot give accurate representation of spring tides ; for

(1) the slow convergence of the sequence of amplitudes of ζ_4, ζ_6, ζ_8, at springs indicates a possible error of 0·3 ft., and this expectation is confirmed by tests on Liverpool tide records.

(2) the slow convergence of the amplitudes of the contributions to sin σt also show that ζ_{10} and ζ_{12} cannot be neglected even if we desire to predict only H.W. times and heights.

III.—The large number of constituents required by the harmonic method to express at all adequately even the partial tide ζ_4 and the necessity for partial tides of higher order, render the harmonic method unsuitable for the adequate representation of the shallow water effects. It is necessary, therefore, to consider alternative methods.

One method which avoids the use of constituents, but which deals with partial tides, is that used in the Report for 1921, where the tide is dealt with as a whole. This method uses the forms given in (1) but the calculations become very intricate, and experience on Liverpool records leads to the conclusion that the use of partial tides is unsatisfactory.

The formula (2) for the time of H.W. shows, however, that t is essentially a function only of R and σ, and as σ is practically constant for the semi-diurnal tide we may consider t as a function of R alone. Similarly the height of H.W. is a function only of R, and consequently a simple table is possible giving the necessary corrections to the time and height of the H.W. of ζ_2 alone to give the compound H.W. data.

It is necessary to state, however, that the form of (1) is based upon theoretical work on non-reflected waves in a canal of infinite length, and some care might have to be exercised on dealing with actual tides. At the worst, however, it might only be necessary to take into account the rate of increase of R. A further word of caution needs to be given, for friction will give sixth-diurnal tides whose amplitudes vary as R^2 and not as R^3 (see Appendix) ; on this point the general principle, however, remains true, that the shallow water effect is essentially a function of the range of tide.

Further, the *shape* of the tide curve is also a function of the range of tide, and if hourly ordinates are required this principle can be used.

The work required for the construction of these tables is comparatively small ; the tide curves should be grouped according to range and the average shape determined as a function of the time, measured from H.W. in each case. Analyses of the resulting curves by the usual methods with the appropriate period for each value of R will give the semi-diurnal part, and thence the tables required are easily constructed.

Though there are difficulties yet to be overcome in the application of this method, especially when the diurnal tide is large, yet it is suggested that it offers some hope of solution of this difficult problem.

Revised Harmonic Constants for Newlyn.

6. The analysis explained in the 1921 Report has been applied to the residues from the whole of the year 1918 at Newlyn, and the following table of harmonic constants replaces that given in the 1921 Report. An error of sign with f'' in the formula for B_n of §17 has been found, and consequently the exposition given later in that paragraph is only correct for $f''=0$. In dealing with the residues and with N=30 the effect of f'' is entirely negligible, and the results of analyses are unaffected by this error.

The values of κ given in 1921 are not correctly given. In order to reduce to κ as defined by Darwin 22°·18 should be subtracted from the phase lags for semi-diurnals and 11°·09 from the phase lags for diurnals. For a given constituent we denote the lag of its phase behind the simultaneous phase of the corresponding equilibrium constituent

(*a*) at Newlyn, by κ
and (*b*) at Greenwich, by γ

Thus $$\gamma = \kappa + pL$$

where L is the Longitude in degrees West of Greenwich and $p=0, 1, 2$, for long period, diurnal and semi-diurnal constituents respectively. It may be remarked that γ is much more useful than κ both for analysis and prediction, as we need only use Greenwich Mean Time and the 'astronomical arguments' only need to be evaluated for the Greenwich Meridian. This is essentially the U.S.A. practice.

Newlyn: Latitude : $\lambda = 50°\ 6'{\cdot}1$N.
Longitude : $L = 5°\ 32'{\cdot}6$W.

Tide-gauge record : one year for semi-diurnal constituents, six months for diurnal constituents, commencing 0h., Jan. 0·1, 1918, G.M.T.

Method of analysis : special, as in B.A. Report, 1921.
Amplitudes : in feet.

	H	κ °	γ °		H	κ °	γ °		H	κ °	γ °
S_2 :	1·867	168·5	179·5	M_2 :	5·620	124·7	135·8	S_1 :	·010	329·5	335·0
R_2 :	·021	238·2	249·3	$2SM_2$:	·087	22·8	33·9	P_1 :	·071	102·6	108·2
T_2 :	·082	149·1	160·2	ν_2 :	·226	111·3	122·4	K_1 :	·200	102·2	107·7
K_2 :	·491	165·8	176·9	N_2 :	1·066	103·1	114·2	O_1 :	·180	334·2	339·7
L_2 :	·189	122·7	133·8	μ_2 :	·197	159·8	170·9	Q_1 :	·060	281·3	286·8
λ_2 :	·102	100·7	111·8	$2N_2$:	·089	89·5	100·6				

APPENDIX.

By J. Proudman.

(*Being part of Adams' Prize Essay*, 1923.)

In constructing the dynamical equations of the tides it is necessary to introduce terms representing the forces of friction of external origin, due mainly to the retarding effect of the sea-bottom.

T. Young (1813), followed by W. Ferrel (1874), made the hypothesis that the magnitude of the external frictional force is proportional to the square of the speed of the current, and adapted this hypothesis to the consideration of harmonic constituents in the way indicated below. Ferrel pointed out, as an important result, that one of the effects of friction on the tides produced by a harmonic disturbing force was to give rise to another constituent of speed three times as great.

In his work on tidal friction in the Irish Sea, G. I. Taylor (1918) made the same hypothesis as Young, and in extending Taylor's work, H. Jeffreys (1920) remarks that even in the empirical prediction of tides, friction may have to be taken into account.

If u, v denote rectangular components of the current, and F, G the corresponding components of external friction, then the hypothesis gives

$$\left.\begin{aligned} F &= ku\,|(u^2+v^2)^{\frac{1}{2}}| \\ G &= kv\,|(u^2+v^2)^{\frac{1}{2}}| \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (1)$$

where k is a constant.

First suppose that

$$u = u_0 \cos \sigma t \quad , v = 0 \quad . \quad . \quad . \quad . \quad (2)$$

so that

$$|(u^2+v^2)^{\frac{1}{2}}| = u_0\,|\cos \sigma t|.$$

Then

$$F = ku_0^2 \mid \cos \sigma t \mid \cos \sigma t$$

$$= \frac{8}{\pi} ku_0^2 \left\{ \frac{\cos \sigma t}{3} + \frac{\cos 3\sigma t}{1.3.5} - \frac{\cos 5\sigma t}{3.5.7} + \ldots \ldots \right.$$

$$\left. + (-1)^{n+1} \frac{\cos (2n+1)\sigma t}{(2n-1)(2n+1)(2n+3)} + \ldots \right\} \quad . \quad . \quad (3)$$

The term involving cos $3\sigma t$ corresponds to the remark of Ferrel.

Each term in the frictional force will, of course, generate a tidal constituent of equal speed, so that the relations (2) will be disturbed, but such disturbance will usually be relatively small.

Now all the constituents indicated by (3) have usually been allowed for in the practical harmonic analysis of observations, though often under the heading of shallow water constituents. But we next proceed to indicate the existence of constituents which do not appear to have been considered hitherto.

Suppose that

$$u = u_0 \cos \sigma t + u'_0 \cos \sigma' t \quad , v = 0 \quad , \quad . \quad . \quad . \quad . \quad (4)$$

while

$$\sigma t = n\theta, \quad \sigma' t = (n+1)\theta \quad , \quad . \quad . \quad . \quad . \quad . \quad (5)$$

n being an integer; then

$$F = k \mid u_0 \cos n\theta + u'_0 \cos (n+1)\theta \mid \{u_0 \cos n\theta + u'_0 \cos (n+1)\theta\}$$

and this is periodic in θ, so that

$$F = \tfrac{1}{2}a_0 + a_1 \cos \theta + b_1 \sin \theta + \ldots . + a_r \cos^r \theta + b_r \sin^r \theta + \ldots . \quad . \quad (6)$$

It is a straightforward matter to elaborate formulæ for the coefficients of (6), but we will restrict ourselves to the approximate form where u_0'/u_0 is small. We have

$$u = (u_0^2 + 2u_0u_0' \cos \theta + u_0'^2)^{\frac{1}{2}} \cos (n\theta + \varepsilon) \quad ,$$

where

$$\tan \varepsilon = \frac{u_0' \sin \theta}{u_0 + u_0' \cos \theta} \quad ,$$

and if we neglect ε we obtain

$$F = k(u_0^2 + 2u_0u'_0 \cos \theta + u'^2_0) \mid \cos n\theta \mid \cos n\theta$$

$$= \frac{8}{\pi} k(u_0^2 + u_0'^2) \left\{ \frac{\cos n\theta}{3} + \frac{\cos 3n\theta}{1.3.5} - \ldots . \right.$$

$$\left. + (-1)^{r+1} \frac{\cos (2r+1)n\theta}{(2r-1)(2r+1)(2r+3)} + \ldots \right\}$$

$$+ \frac{8k}{\pi} u_0u'_0 \left\{ \frac{\cos (n-1)\theta + \cos (n+1)\theta}{3} \right.$$

$$\left. + \frac{\cos (3n-1)\theta + \cos (3n+1)\theta}{1.3.5} - \ldots \right\}$$

$$. \quad . \quad . \quad . \quad . \quad (7)$$

The constituent of (7) of speed σ has the coefficient

$$\frac{8k}{3\pi}(u_0^2 + u_0'^2),$$

a result which is of value in calculating, for example, the frictional force of M_2 speed due to a combination of M_2 and S_2 currents.

But some of the constituents of (7), e.g. that involving cos $(n-1)\theta$, may have speeds other than those present in the astronomical disturbing forces or in the constituents associated with the product terms in the equation of continuity and the expressions for acceleration (see §3).

Such constituents were revealed by Dr. Doodson as shown in the Report for 1921, and the present considerations suggest a hypothesis as to at least part of Doodson's residue for Newlyn. His work on shallow water constituents at the same station indicates that the currents are roughly proportional to the elevations, and assuming this to be the case we get the following rule for the frictional constituents of a small range of speed.

'Square the actual elevations, attach the sign of the elevation itself, multiply by an empirical factor and apply an empirical time-lag.'

It is, of course, necessary to remove from the result all the 'Darwinian' constituents in order to reveal the presence of new constituents. Fig. 1 gives the results

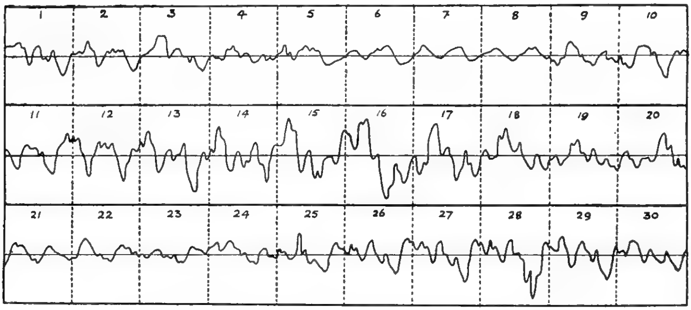

Fig. 1.—Residue from $|\zeta|\zeta$, Newlyn, January, 1918.

of calculating $|\zeta|\zeta$ for 30 days' Newlyn observations and then removing the constituents S_2, T_2, K_2, L_2, λ_2, M_2, $2SM_2$, ν_2, N_2, μ_2, $2N_2$, together with the greater part of the sixth diurnal portion. It will be seen that there is a well-marked residue, reaching about 16 per cent. of the original, and consequently the law of friction we have assumed will produce constituents of speeds other than those present in the disturbing forces or due to shallow water.

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1918.	G. I. Taylor.	*Phil. Trans Roy. Soc.* (A), v. 220, pp. 1-33.
1920.	H. Jeffreys.	*Ibid.*, v. 221, pp. 239-264.

Colloid Chemistry and its General and Industrial Applications.—*Summary Report of the Committee* (Professor F. G. DONNAN, *Chairman*; Dr. W. CLAYTON, *Secretary*; Dr. E. ARDERN, Dr. E. F. ARMSTRONG, Sir W. M. BAYLISS, Professor C. H. DESCH, Dr. A. E. DUNSTAN, Mr. H. W. GREENWOOD, Mr. W. HARRISON, Mr. E. HATSCHEK, Mr. G. KING, Professors W. C. McC. LEWIS *and* J. W. McBAIN, Dr. R. S. MORELL, Professors H. R. PROCTER *and* W. RAMSDEN, Sir E. J. RUSSELL, Mr. A. B. SEARLE, Dr. S. A. SHORTER, Dr. R. E. SLADE, Mr. F. SPROXTON, Dr. H. P. STEVENS, Mr. H. B. STOCKS, Mr. R. WHYMPER).

THE Fifth Report was published by the Department of Scientific and Industrial Research, and contains an index to the five reports now issued. Six papers have been contributed, of which the following are brief abstracts :—

(I.) *The Measurement of Surface Tension.* By Allan Ferguson, M.A., D.Sc. (East London College).

'This report deals with recent advances in the methods and technique used in the determination of surface tensions. It advisedly concerns itself with methods rather than results, for it is now clearly recognised that an accurate knowledge of the tension in surfaces separating a liquid from a vapour phase, and, more especially, of the tension in a liquid-liquid or a liquid-solid interface, is a first condition for the quantitative discussion of many of the problems of colloid chemistry and physics.'

The very important subject of the measurement of contact-angles is first dealt with, and then the various methods for determining the surface tension at a liquid-gas interface, special attention being paid to the capillary-rise method.

The methods used in determining interfacial tensions are discussed, the modern work of Harkins and his collaborators receiving detailed treatment. The great defects in the drop-number method are clearly pointed out, and attention is directed to a promising new method of determining interfacial tensions now being investigated by the author.

(II.) *Report on Collagen and Gelatin.* By Professor H. R. Procter, D.Sc., F.R.S. (University of Leeds), and J. A. Wilson, D.Sc. (Chief Chemist, Messrs. A. F. Gallun & Sons Co., Milwaukee, U.S.A.).

The authors present separate accounts of the work done in Europe and America, the latter being dealt with first.

The comprehensive work of Loeb on gelatin is well summarised, his experiments seeming to indicate that proteins combine only with cations on the alkaline side of the iso-electric point, and only with anions on the acid side. According to the Procter-Wilson theory, the combination of protein and hydrogen ion is governed by the law of mass action, and Loeb's experiments are in keeping with the theory. The work of Loeb and of Procter and Wilson on the Donnan membrane equilibria is briefly dealt with.

In connection with the European work, discussion is made of the researches of Miss D. L. Lloyd on the swelling of gelatin in relation to the p_H of the medium, and of Atkins' papers on the same subject.

The elucidation of the ultimate structure of jellies, and especially of gelatin jelly, occupies considerable space, dealing with the work of Hatschek, Procter and Wilson, McBain, von Gaza, Bradford, Barratt, and others; incidentally, the Liesegang phenomenon is dealt with. Kubelka's important work on collagen concludes the paper.

(III.) *Colloid Phenomena in Bacteriology.* By Eric K. Rideal, M.A., D.Sc. (University of Cambridge).

The subject is treated under the headings : Bacteria as colloidal systems; bacterial growth; surface adsorption; chemical constitution and adsorption; selective action; conclusions.

The author concludes : 'In addition to the factors such as the presence of suitable food materials, optimum temperature, p_H and the like, the growth rate of micro-organisms is greatly influenced by the concentration at the bacterium surface of the various substances present. The surface concentrations may already be considerable, even when scarcely detectable amounts are present in the bulk of the medium. The conditions necessary for favouring high-surface concentrations are shown to depend on the action of the substance on the interfacial surface tension. The magnitude of this action can in many cases be estimated by the effect of the solute on the air/liquid interface. Adsorption appears to be a chemical process, reaction occurring between reactive groups in the material adsorbed and the one (acceptors) in the micro-organism. Single-point reaction leads to a simple differentiation between acid and alkaline reactive groups, whilst multi-point action increases the selective nature of the reaction, which ultimately became entirely specific.'

(IV.) *Industrial Applications of Wetting Power.* By W. H. Nuttall, F.I.C. (The Ioco Rubber and Waterproofing Co., Ltd., Glasgow.)

The ability of a liquid to wet a solid surface—*i.e.* to give an even, continuous film over it—is dependent upon three surface tensions : the surface tension liquid/air (T_1), the surface tension solid/air (T_2), and the interfacial tension liquid/solid ($T_{1.2}$). For the liquid to wet, T_2 must be greater than $T_1+T_{1.2}$. The explanation of 'wetting' is, however, still obscure, and our views on the subject are in a state of transition, largely as the result of the work of Langmuir and Harkins on molecular orientation at interfaces.

The industrial applications described are : Mineral separation by flotation, separation of bitumen from rock, cattle dips and horticultural medicaments, anti-dimming preparations, and lubrication.

(V.) *Colloids in Relation to the Manufacture of Inks.* By C. A. Mitchell, M.A., F.I.C.

This is a short paper, drawing attention to a little-discussed aspect of applied colloid chemistry. The ordinary writing inks of the present day consist of a more or less soluble tannate of iron, and, on exposure to air, there is a gradual change into a black colloidal tannate, which remains in suspension and imparts a dark colour to the ink. The use of acids in the 'blue-black' inks is explained.

(VI.) *The Manufacture of Artificial Silk in Relation to Colloid Chemistry.* By Edward Wheeler, A.C.G.I., A.I.C.

'The four processes for the manufacture of artificial silk in use to-day are :—

(*a*) Cuprammonium process (also known as Glanzstoff or Pauly process).
(*b*) Nitrocellulose process (Chardonnet process).
(*c*) Viscose process (invented by Cross and Bevan).
(*d*) Cellulose acetate process.'

The bearing of colloid chemistry on each of these processes is discussed in relation to the raw materials used, the preparation of the solutions, the coagulation of the thread in spinning, and the after-treatment necessary in each case. The properties of artificial silk as a colloid system are then considered in relation to the requirements of the textile industry.

Photographs of Geological Interest.—*Twenty-first Report of Committee* (Professors E. J. GARWOOD, *Chairman, and* S. H. REYNOLDS, *Secretary*; Mr. G. BINGLEY, Dr. T. G. BONNEY, Mr. C. V. CROOK, Dr. R. KIDSTON, Mr. A. S. REID, Sir J. J. H. TEALL, Professor W. W. WATTS, Mr. R. WELCH *and* Mr. W. WHITAKER). *Drawn up by the Secretary.*

SINCE the issue of the previous report (Edinburgh, 1921) 238 photographs have been added to the collection, which now numbers 6,310.

The Committee are glad to welcome new contributors in Mr. H. T. Harry, who sends a set illustrating raised beaches on the south coast of Cornwall; in Mr. F. H. Edmonds and Mr. F. B. A. Welch, both of whom contribute prints from the Bristol district and elsewhere; in Mr. F. G. Jenkins, who illustrates Read's Cavern, Burrington, which has been studied by the University of Bristol Spelæological Society; in Mr. P. B. Roberts, who sends a set of exceptional interest illustrating marine erosion at Bexhill-on-Sea; and in Mr. J. B. Philip, who illustrates the coast of Kincardine and Aberdeen. Dr. Woolacott sends an excellent set illustrating raised beaches and boulders from Durham, and Dr. T. O. Bosworth subjects from Llangollen.

Mr. C. J. Gilbert contributes prints illustrating his paper (Q. J. G. S. vol. lxxv.) on certain Glacial and other strata from Little Heath, near Berkhamsted.

Among former contributors Mr. J. W. Tutcher sends a few excellent photographs illustrating the Lias of Somerset, Mr. J. J. Hartley a fine series from the Lake District, and Mr. B. Hobson some from the Channel Islands. Other photographs from various localities are contributed by the Secretary. Special mention should be made of a fine series of Irish photographs from Prof. Grenville Cole; no less than thirteen counties are represented in this set.

The negatives of the published series of geological photographs which had been missing since before the war have fortunately been recovered, and prints and lantern slides are obtainable through the Secretary at the following rates :—

				£	s.	d.
1st issue—22 Bromide Prints,	with letterpress,	unmounted ...	...	1	13	0
,, 22 ,,	,, ,,	mounted on cards	...	2	4	0
,, 22 Lantern Slides	,, ,,	... ...	...	2	4	0
2nd issue—25 Bromide Prints	,, ,,	unmounted ...	...	1	18	0
,, 25 ,,	,, ,,	mounted on cards	...	2	10	0
,, 25 Lantern Slides	,, ,,	... ...	...	2	10	0
3rd issue—23 Bromide Prints	,, ,,	unmounted ...	...	1	14	6
,, 23 ,,	,, ,,	mounted on cards	...	2	6	0
,, 23 Lantern Slides	,, ,,	... ...	...	2	6	0

The Committee recommend that they be reappointed.

TWENTY-FIRST LIST OF GEOLOGICAL PHOTOGRAPHS.

FROM SEPTEMBER 1, 1921, TO AUGUST 31, 1923.

List of the geological photographs received and registered by the Secretary of the Committee since the publication of the last report.

Contributors are asked to affix the registered numbers, as given below, to their negatives, for convenience of future reference. Their own numbers are added in order to enable them to do so. Copies of photographs desired can, in most instances, be obtained from the photographer direct. The cost at which copies may be obtained depends on the size of the print and on local circumstances over which the Committee have no control.

The Committee do not assume the copyright of any photograph included in this list. Inquiries respecting photographs, and applications for permission to reproduce them, should be addressed to the photographers direct.

Copies of photographs should be sent, unmounted, to

Professor S. H. REYNOLDS,
The University, Bristol,

accompanied by descriptions written on a form prepared for the purpose, copies of which may be obtained from him.

The size of the photographs is indicated as follows :—

L=Lantern size.	1/1=Whole plate.
1/4=Quarter-plate.	10/8=10 inches by 8.
1/2=Half-plate.	12/10=12 inches by 10, &c.

E signifies Enlargement.

ACCESSIONS.

England.

CORNWALL.—*Photographed by* H. T. HARRY, *B.Sc.*, *Northleigh, Tywardreath, Par Station.* Postcard size.

Regd. No.		
6072	(1) W. of Par Harbour Pier, St. Austell Bay	Raised Beach on Devonian. 1922.
6073	(2) W. of Par Harbour Pier, St. Austell Bay	,, ,,
6074	(3) W. of Par Harbour Pier, St. Austell Bay	,, ,,
6075	(4) W. of Par Harbour Pier, St. Austell Bay	,, ,,
6076	(5) W. of Par Harbour Pier, St. Austell Bay	,, ,,
6077	(6) W. of Par Harbour Pier, St. Austell Bay	,, ,,

Photographed by S. H. REYNOLDS, *M.A.*, *Sc.D.*, *The University, Bristol.* 1/4.

6078	(1923·31) Trelissick, Falmouth Harbour	Minette dyke in killas. 1923.
6079	(1923·32) Pen Voose, Lizard .	Kennack gneiss enclosing coarse gabbro. 1923.
6080	(1923·33) Pen Voose, Lizard .	Kennack gneiss. 1923.
6081	(1923·34) Carn Brea, near Camborne	Granite hill. 1923.

CUMBERLAND.—*Photographed by* J. J. HARTLEY, *Church Walk, Ambleside.* Postcard size.

6082	(B6) Pooley Bridge, Ullswater	Mell Fell Conglomerate. 1921.

DERBYSHIRE.—*Photographed by* S. H. REYNOLDS, *M.A.*, *Sc.D.*, *The University, Bristol.* 1/4.

6083	(1921·46) Knot Low, Millersdale	Spheroidal weathering of basalt (Upper Toadstone). 1921.
6084	(1921·47) ,, ,,	Spheroidal weathering of basalt (Upper Toadstone). 1921.
6085	(1921·49) ,, ,,	Spheroidal weathering of basalt (Upper Toadstone). 1921.
6086	(1921·50) ,, ,,	Spheroidal weathering of basalt (Upper Toadstone). 1921.
6087	(1921·51) ,, ,,	Spheroidal weathering of basalt (Upper Toadstone). 1921.
6088	(1921·40) W. of Longstone Station	Cutting in D_3. 1921.
6089	(1921·38) N. of Great Longstone	Chert in D_3. 1921.
6090	(1921·39) ,, ,,	Chert in D_3. 1921.
6091	(1921·42) Qu. 1 mile N. of Headstone Head	*Lithostrotion irregulare* in D_2. 1921.

Regd. No.

6092 (1921·43) Qu. 1 mile N. of Headstone Head — Clisiophyllids in D_2. 1921.

6093 (1921·36) Ashford, near Bakewell — 'Black marble quarry' (D_3). 1921.

DEVON.—*Photographed by* H. C. GRIGG, *B.Sc., 47 Hillfield Avenue, Fishponds, Bristol.* 1/2.

6094 ( ) Sharkham Point, Brixham — Exposure of Schalstein. 1922.

Photographed by S. H. REYNOLDS, *M.A., Sc.D., The University, Bristol.* 1/4.

6095 (1921·2) Saltern Cove, near Paignton — Unconformity, New Red on Devonian. 1921.

6096 (1921·3) Saltern Cove, near Paignton — Shattered and veined rock. 1921.

6097 (1921·4) Saltern Cove, near Paignton — Buckled Upper Devonians. 1921.

6098 (1921·5) Hunter's Tor, Lustleigh — Weathering of granite. 1921.

6099 (1921·6) Horsham Steps, Lustleigh — Granite boulders forming natural causeway across stream. 1921.

6100 (1921·7) Packsaddle Bridge, near Lustleigh, Dartmoor — Granite intrusion in Culm. 1921.

6101 (1921·13) Livermead, Torquay . — Marine erosion of Permian breccias. 1921.

6102 (1921·14) ,, ,, — Marine erosion of Permian breccias. 1921.

6103 (1921·15) ,, ,, — Marine erosion of Permian breccias. 1921.

6104 (1921·16) ,, ,, — Marine erosion of Permian breccias. 1921.

6105 (1921·17) ,, ,, — Permian breccias. 1921.

Photographed by F. B. A. WELCH, *6 Paragon Parade, Cheltenham.* $3\frac{1}{4} \times 2\frac{1}{4}$.

6106 (A13) Skainer's Hole, Lee Bay — Relation between bedding and cleavage. 1922.

DORSET.—*Photographed by* S. H. REYNOLDS, *M.A., Sc.D., The University, Bristol.* 1/4.

6107 (1922·20) Pondfield Cove, Worberrow — Contemporaneous brecciation in Lower Purbecks 40 ft. above Broken beds. 1922.

6108 (1922·9) Man of War Cove, Lulworth — Man of War rock (vertical Portlandian) from W. 1922.

6109 (1922·22) Bacon Hole, Lulworth — Lower Purbecks and Upper Portlands. 1922.

6110 (1922·31) Lulworth Cove, W. side — Disturbed Cypris freestone. 1922

6111 (1922·32) ,, ,, — Faulted 'Cockle beds.' 1922.

6112 (1922·27) Holworth House, near Osmington — Portlandian section. 1922.

6113 (1922·25) Osmington . . . — Bencliff grit 'doggers' on shore. 1922.

DURHAM.—*Photographed by* D. WOOLACOTT, *D.Sc., 8 The Oaks West, Sunderland.* 1/4.

6114 (1) Easington . . . . — 60 ft. Raised Beach.

6115 (2) ,, — ,, ,,

6116 (3) ,, — ,, ,,

6117 (4) Warren House Gill . . — Lauvigite boulder.

6118 (5) ,, ,, — Gneiss boulder.

GLOUCESTER.—*Photographed by* S. H. REYNOLDS, *M.A., Sc.D., The University, Bristol.* 1/2 *and* 1/4.

Regd. No.		
6119	(1922·54) Sodbury railway cutting	Grit masses in D_1. 1/4. 1922.
6120	(1922·53) ,, ,,	Grit or sandstone mass in D_1. 1/4. 1922.
6121	(1922·56) ,, ,,	Weathered surface of Concretionary Beds (S_2). 1/4. 1922.
6122	(1922·60) ,, ,,	*Spongiostroma* layers in S_1. 1/4. 1922.
6123	(1922·61) ,, ,,	Shattered Z_1 limestone. 1/4. 1922.
6124	(1922·62) ,, ,,	Algal nodules in C_2. 1/4. 1922.
6125	(1922·64) ,, ,,	*Spongiostroma* layers S_1. 1/4. 1922.
6126	(1922·1) Hallen railway cutting	Gypsum in Keuper. 1/2. 1922.
6127	(1922·2) ,, ,,	,, ,,
6128	(1922·3) ,, ,,	,, ,,
6129	(1922·48) Tytherington railway cutting	Z_1 and Z_2 beds. 1/2. 1922.
6130	(1922·49) Grovesend qu., Tytherington railway section	Z_2 and top of Z_1. 1/2. 1922.
6131	(1922·50) Hardwicke qu., Tytherington railway section	C_1 (sub-oolite and Caninia-oolite). 1/2. 1922.
6132	(1922·51) Tytherington railway cutting	C_2. 1/2. 1922.
6133	(1922·52) Church Quarry, Tytherington	S_1 and S_2. 1/2. 1922.

Photographed by J. W. TUTCHER, 57 *Berkeley Road, Bristol.* 1/2.

6134	(5c) Willsbridge lime works, near Bitton	L. Lias with A. bucklandi *Sow.* in situ. 1902.

Photographed by F. S. WALLIS, *Ph.D., Bristol Museum.* 1/2.

6135	(A) Fishponds Asylum, Bristol	*Sigillaria* trunk in Pennant Sandstone. 1923.
6136	(B) ,, ,,	*Lepidodendron* trunk in Pennant Sandstone. 1923.

Photographed by F. B. A. WELCH, 6 *Paragon Parade, Cheltenham.* 1/4.

6137	(C.N.2) Cuckoo-pen quarry, near Air Balloon, Birdlip	Current bedding in Upper Freestone. 1922.
6138	(C.N.8) Cleeve Hill, near Cheltenham	Faulted Pea Grit. 1922.

HANTS (ISLE OF WIGHT).—*Photographed by* F. H. EDMUNDS, *B.A.,* 28 *Jermyn Street, London, S.W.* 1/4.

6139	( ) High Down . . .	Coast erosion of chalk cliffs. 1922.
6140	( ) Walpen Chine . .	Commencement of wind erosion. 1920

Photographed by E. R. MARTIN, 114 *Southlands Road, Bromley.* 1/4.

6141	(2) Ladder Chine	Wind erosion. ($2\frac{1}{4}$ pl. joined). 1920.
6142	(4) Alum Bay	Rain eroded gullies in vertical Reading beds. 1920.

Photographed by S. H. REYNOLDS, *M.A., Sc.D., The University, Bristol.* 1/4.

6143	(1923·9) Brook	'Pine Raft.' 1923.
6144	(1923·12) Compton Bay . .	Carstone and Sandrock series. 1923.
6145	(1923·15) Gore Cliff, Niton .	Chert beds of Up. Greensand. 1923.

Regd. No.		
6146	(1923·18) Cowleaze Chine . .	Chine formation. 1923.
6147	(1923·21) Culver and Redcliff section	Succession Wealden to Chalk. 1923.
6148	(1923·23) The Crackers, Atherfield	Concretionary masses of calcareous and ferruginous sandstone. 1923.
6149	(1923·25) Colwell Bay, N.W. end	Fold in Headon beds. 1923.
6150	(1923·26) Cliffs above 'Crackers,' Atherfield	Recession of cliffs by foundering. 1923.
6151	(1923·27) Culver	Shore platform and storm beach. 1923.
6152	(1923·28) Culver	Storm beach. 1923.

HERTS.—*Photographed by* J. T. NEWMAN, *Berkhamsted, and presented by* C. J. GILBERT, *F.G.S.* 1/2.

6153	(6) Little Heath, near Berkhamsted	Glacial beds on 'loamy sands.' 1919.
6154	(7) Little Heath, near Berkhamsted	Glacial beds on 'loamy sand' on ?Pliocene gravel. 1919.
6155	(8) Little Heath, near Berkhamsted	Glacial beds on 'loamy sand' on ?Pliocene gravel. 1919.
6156	(10) Little Heath, near Berkhamsted	Glacial beds on 'loamy sand' on ?Pliocene gravel. 1919.

LANCASHIRE.—*Photographed by* J. J. HARTLEY, *Church Walk, Ambleside.* Postcard size.

6157	(B1) Tilberthwaite	Glacial river channels. 1921.
6158	(B8) Birk Fell	Erratics of Harrath tuff. 1921.
6159	(2·22) Hill Fell road section .	Concretions in L. Coniston Flags. 1922.

NORTHAMPTON.—*Photographed by* B. G. CHILCOTT, *Guernsey.* 1/4.

6160	(30) Brixworth	Glacial gravel on Inferior Oolite ironstone on Upper Lias. 1921.
6161	(31) Brixworth	Chalky boulder clay overlying Glacial sand with small erratics. 1921.
6162	(32) Cranford, near Kettering .	Anticline in Upper Lias to Lower Estuarine beds. 1921.
6163	(33) S.W. of Islip . . .	Cornbrash on Great Oolite, clay above, limestone below. 1921.

SOMERSET.—*Photographed by* L. BARROW, *c/o* MESSRS. J. S. FRY & SONS, *Bristol.* 1/2.

6164	( ) Keynsham Hams, Messrs. J. S. Fry & Sons' new factory site	Fold in Lower Lias. 1922.
6165	( ) Keynsham Hams, Messrs. J. S. Fry & Sons' new factory site	Lower Lias section with 'calcicosta bed.' 1922.

Photographed by F. H. EDMUNDS, *B.A.*, 28 *Jermyn Street, London, S.W.* 1/4

6166	( ) Woodspring, Weston-super-Mare (2nd exposure)	Tuff showing lapilli. 1922.
6167	( ) Woodspring, Weston-super-Mare (2nd exposure)	Pipe rock structure in sandstone overlying tuff. 1922.

Photographed by F. G. JENKINS, 6 *Brandon Villas, Park Street, Bristol.* $3\frac{1}{4} \times 2\frac{1}{4}$ and 1/4.

Regd. No.		
6168	(2) Read's Cavern, Burrington	Mushroom-shaped stalagmite. 1919. $3\frac{1}{4}$ by $2\frac{1}{4}$.
6169	(3) ,, ,,	Breaking and distortion of stalactites. 1/4. 1919.
6170	(4) ,, ,,	Folded limestone slabs fallen from roof of cave. 1/4. 1919.
6171	(5) ,, ,,	Anticlinal fold in roof of cave. 1/4. 1919.

Photographed by S. H. REYNOLDS, *M.A., Sc.D., The University, Bristol.* 1/2 *and* 1/4.

6172	(1921·81) Cadbury Hill, Yatton	Seminula pisolite. 1/2. 1921.
6173	(1922·44) Fore Hill quarry, Portishead	Lower Zaphrentis beds. 1/2. 1922.
6174	(1922·46) Weston Big Wood, E. quarry	Vertical Z_2. 1/2. 1922.
6175	(1922·47) Weston Big Wood, W. quarry	,, ,,
6176	(1923·2) Charlcombe Bay, N. of Clevedon	Dolomitic Conglomerate unconformable on O.R.S. 1/4. 1923.
6177	(1923·3) Redcliff Bay, N. of Clevedon	Dolomitic Conglomerate unconformable on O.R.S. 1/4. 1923.

Photographed by J. W. TUTCHER, 57 *Berkeley Road, Bristol.* 1/2.

6178	(20) Quarry at Dunkerton colliery, 3 miles N. of Radstock	Fold in Lower Lias. 1912.
6179	(46b) Keynsham Hams, Messrs. J. S. Fry & Sons' new factory site. The railway siding	Fold in Lower Lias (angulatus zone). 1922.
6180	(47a) Keynsham Hams, Messrs. J. S. Fry & Sons' new factory site. The railway siding	L. Lias, lower part angulatus zone. 1922.
6181	(46a) Keynsham Hams, Messrs. J. S. Fry & Sons' new factory site. The railway siding	Folds in L. Lias (lower Bucklandi and upper angulatus zone). 1922.

Photographed by F. B. A. WELCH, 6 *The Paragon, Cheltenham.* 1/4.

6182	(c.n.11) Portishead, new road round lake	Anticline in K-beds. 1922.
6183	(c.n.12) Portishead, Woodhill Bay	Old Red Conglomerate showing rounded nature of pebbles. 1922.
6184	(c.n.14) Portishead, Woodhill Bay	Small thrust in O.R.S. and thinning out of grit. 1922.

SUSSEX.—*Photographed by* P. B. ROBERTS, 9 *Westbury Hill, Westbury-on-Trym, Bristol.* 1/2.

6185	(1) Bexhill-on-Sea . . .	Marine erosion. Winter 1909-10.
6186	(2) Bexhill-on-Sea, W. end of W. Promenade	Marine erosion. Winter 1909-10.
6187	(3) Bexhill-on-Sea . . .	Marine erosion. Winter 1909-10.
6188	(4) Bexhill-on-Sea W. Promenade	Before 'erosion wave' had reached this point. Winter 1909-10.
6189	(5) Bexhill-on-Sea W. Promenade	Beginning of removal of beach. Winter 1909-10.
6190	(6) Bexhill-on-Sea W. Promenade	Further stage in removal of beach. Winter 1909-10.

Regd. No.		
6191	(7) Bexhill-on-Sea W. Promenade	Beach all removed; threat to Parade bastion. Winter 1909-10.
6192	(8) Bexhill-on-Sea W. Promenade	Woodwork erected to protect bastion. Winter 1909-10.
6193	(11) Bexhill-on-Sea W. Promenade	Eating away of Parade and outflanking bastion. Winter 1909-10.
6194	(12) Bexhill-on-Sea W. Promenade	Destruction of Parade beyond bastion. Winter 1909-10.
6195	(13) Bexhill-on-Sea W. Promenade	Bastion shattered; ineffective barrier of hurdles. Winter 1909-10.
6196	(14) Bexhill-on-Sea W. Promenade	Destruction of hurdle barrier and shifting of massive blocks down the beach. Winter 1909-10.
6197	(15) Bexhill-on-Sea W. Promenade	Remains of bastion and widespread destruction of Parade beyond (to E). Winter 1909-10.
6198	(16) Bexhill-on-Sea W. Promenade	Preparations to meet erosion. Spring 1910.

WESTMORLAND.—*Photographed by* J. J. HARTLEY, *Church Walk, Ambleside.* Postcard size.

6199	(B2) The Park, Ambleside .	Roche moutonnée. 1921.
6200	(B3) Kirkstone Pass . . .	Moraines in Stock Gill Valley. 1921.
6201	(B4) Whitemoss, near Grasmere	Pot-holed junction of andesite and bedded tuff. 1921.
6202	(B7) Grisedale Pass . . .	Flow-brecciated andesite. 1921.
6203	(1·22) Ambleside, 200 yards S. of gasworks	Thick-bedded tuff in Borrowdale series. 1922.
6204	(3·22) Wrynose Pass . . .	Fault in bedded tuff (Scafell ash group). 1922.
6205	(4·22) The Helm, Grasmere .	Bedded tuff in Borrowdale series. 1922.
6206	(5·22) Bowfell, between summit and 'Three tarns'	Bedded tuff (Scafell ash group). 1922.
6207	(6·22) Ambleside, 200 yards S. of gasworks	Thick-bedded tuffs in Borrowdale series. 1922.
6208	(7·22) Bowfell, between summit and 'Three tarns'	Bedded tuff (Scafell ash group). 1922.
6209	(8·22) The Helm, Grasmere .	Bedded tuff in Borrowdale series. 1922.
6210	(9·22) Bridge over Brathay, N. of Wrynose Pass .	Bedded tuff in Borrowdale series. 1922.
6211	(10·22) Patterdale, 50 yards S. of Post Office	Coarse felsitic tuff. 1922.

YORKSHIRE.—*Photographed by* GODFREY BINGLEY, *Thorniehurst, Headingley, Leeds.* 1/2.

6212	(6968) Red Cliff, Caytor Bay .	Boulder Clay on Middle Oolite. 1905.
6213	(6933) Osgodby Nab . .	Boulder Clay on Lower Oolite. 1905.
6214	(6939) N. of White Nab, near Scarborough	Section in Estuarine series (L. Oolite) 1905.
6215	(7389) Cliff near Holbeck Gardens, Scarborough	Estuarine series (L. Oolite). 1906.
6216	(7390) Cliffs S. of Spa, Scarborough	Joint caves in Up. Estuarine series. 1906.

Photographed by F. B. A. WELCH, 6 *The Paragon, Cheltenham.*

6217	(1914) Filey Brig . . .	Boulder Clay on Calcareous Grit series.

Wales.

ANGLESEY.—*Photographed by* S. H. REYNOLDS, *M.A., Sc.D., The University, Bristol.* 1/4.

Regd. No.			
6218	(1923·36)	Newborough . . .	Blown sand with protruding ridges of spilite. 1923.
6219	(1923·38)	,, ...	Pillow lava (spilite). 1923.
6220	(1923·37)	,, ...	Spilitic ellipsoids. 1923.
6221	(1923·39)	,, ...	Pillow lava (spilite). 1923.
6222	(1923·40)	,, ...	Exceptionally large spilitic ellipsoid. 1923.
6223	(1923·41)	,, ...	Spilite spheroids with interstitial chert or jasper. 1923.
6224	(1923·42)	,, ...	Interstitial jasper between spilitic ellipsoids. 1923.
6225	(1923·43)	,, ...	Interstitial limestone between spilitic ellipsoids. 1923.
6226	(1923·44)	,, ...	Contorted Tyfry beds. 1923.

DENBIGH.—*Photographed by* T. O. BOSWORTH, *M.A., Sc.D., 12 Giles Street, Northampton.* 1/2.

6227	(1)	Craig Arthur, Eglwyseg, N. of Llangollen	Carboniferous Limestone on Ludlow slates.
6228	(2)	World's End, Plas Uchaf, 4 miles N. of Llangollen	Carboniferous Limestone transgressing on to Ordovician grit.
6229	(3)	N. of Plas Uchaf, 4 miles N. of Llangollen	Carboniferous Limestone on Ordovician grit.

RADNOR.—*Photographed by* S. H. REYNOLDS, *M.A., Sc.D., The University, Bristol.* 1/2.

6230	( )	Block of Woolhope Limestone, Old Radnor Churchyard	Patches of *Solenopora gracilis.* 1922.

Scotland.

ABERDEEN.—*Photographed by* J. B. PHILIP, 8 *Belvedere Crescent, Aberdeen.* 1/2.

6231	(10)	Dunbuy Rock, N.E. of Cruden Bay	Marine erosion of granite.

AYR.—*Photographed by* S. H. REYNOLDS, *M.A., Sc.D., The University, Bristol.* 1/4.

6232	(1921·53)	Near S. end of Loch Doon	Inclusions of grit in granite. 1921.
6233	(1921·56)	Near S. end of Loch Doon	Peat on granite. 1921.
6234	(1921·54)	Near S. end of Loch Doon	'Felsite' vein in granite. 1921.
6235	(1921·58)	Craigmulloch, near S.W. corner of Loch Doon	Altered grit inclusions in granite margin. 1921.
6236	(1921·59)	Craigmulloch, near S.W. corner of Loch Doon	Altered grit inclusions in granite margin. 1921.
6237	(1921·62)	Craigmulloch, near S.W. corner of Loch Doon	Altered grit inclusions in granite margin. 1921.
6238	(1921·63)	Craigmulloch, near S.W. corner of Loch Doon	Grit altered by granite. 1921.
6239	(1921·55)	Near S. end of Loch Doon	Glaciated rock. 1921.

FIFE.—*Photographed by* S. H. REYNOLDS, *M.A., Sc.D., The University, Bristol.* 1/4.

Regd. No.		
6240	(1921·67) E. of St. Andrews .	Agglomerate of vent and adjacent sediments. 1921.
6241	(1921·80) Elie Ness . .	Agglomerate of vent. 1921.
6242	(1921·70) St. Andrews, W. of Buddo Rock	Hæmatite in sandstone. 1921.
6243	(1921·71) Lion Rock, St. Andrews	Agglomerate of vent. 1921.
6244	(1921·73) St. Andrews, E. of Rock and Spindle	Current bedded Calciferous Sandstone. 1921.
6245	(1921·74) St. Monans . .	Basalt dyke. 1921.
6246	(1921·75) Ardross Castle, St. Monans	Erratics on shore. 1921.
6247	(1921·78) Chapel Ness, Elie .	'White trap' margin of basalt. 1921.
6248	(1921·72) St. Andrews, E. of Rock and Spindle	Part of vent and adjacent sediments. 1921.
6249	(1921·81) S. of Cambo Ness, St. Andrews	Erratic on shore. 1921.
6250	(1921·82) S. of Cambo Ness, St. Andrews	Current bedded Calciferous Sandstone. 1921.
6251	(1921·83) S. of Cambo Ness, St. Andrews	Hæmatite in current-bedded Calciferous Sandstone. 1921.
6252	(1921·84) S. of Cambo Ness, St. Andrews	*Stigmaria* in Calciferous Sandstone. 1921.
6253	(1921·87) Wormit, S. end of Tay Bridge	Erratic on shore. 1921.
6254	(1921·88) Wormit Bay . .	Volcanic conglomerate. 1921.

KINCARDINE.—*Photographed by* J. B. PHILIP, 8 *Belvedere Crescent, Aberdeen.* 1/2.

6255	( ) ½ m. S. of Cove Bay station	Roches moutonnées and Boulder clay.
6256	(2) Nigg Bay	Boulder clay section. 1920 or 1921.
6257	(3) Nigg Bay and Girdleness .	Shingle Beach.
6258	(4) Shore ⅓ m. S. of Cove Bay station	Dalradian rocks with granite intrusion. 1921.
6259	(6) Coast at Muchalls . .	Coast erosion of Dalradian rocks. 1920.
6260	(8) Muchalls	A sea stack of gneiss, the 'Old Man' of Muchalls. 1920.
6261	(9) Shore near Muchalls . .	Marine erosion of gneiss. 1920.

Ireland.

ANTRIM.—*Photographed by* GRENVILLE A. J. COLE, *F.R.S., Carrickmines, Co. Dublin.* L.

6262	(16) Coast W. of Fair Head .	Coal Seam in L. Carboniferous Sandstone
6263	(17) N. of Ballymena . .	Tree-stumps in bog.

ARMAGH.—*Photographed by* G. A. J. COLE, *F.R.S., Carrickmines, Co. Dublin.* L.

6264	(19) near Armagh . . .	Tertiary basalt dyke in Carboniferous Limestone.

DONEGAL.—*Photographed by* G. A. J. COLE, *F.R.S., Carrickmines, Co. Dublin.* L.

Regd. No.		
6265	(22) Quarry N. of Fintown, E. of Glenties	Granite dyke in composite Dalradian gneiss.
6266	(24) Mullaghderg, Inishfree Bay	Orbicular granite.
6267	(24) N. of Gweebara River and of Glenties	Bog-covered lowlands.
6268	(25) W. of Doocharry Bridge .	Sheets of mica-schist, residues of Dalradian sediment, in granite.

DOWN.—*Photographed by* G. A. J. COLE, *F.R.S., Carrickmines, Co. Dublin.* L.

6269	(18) N. slope of Slieve Donard	Joints in granite controlling course of stream.

DUBLIN.—*Photographed by* G. A. J. COLE, *F.R.S., Carrickmines, Co. Dublin.* L.

6270	(1) Lowland S.E. of Dublin from Three Rock Mountain	Granite Tor and drift-covered Carboniferous plain.
6271	(2) Carrickgallogan, N.W. of Bray	Dome of Cambrian quartzite with foreground of Ordovician.
6272	(3) The Scalp (Dublin and Wicklow border)	Gorge cut across granite spur by overflow-water from glacial lake.
6273	(4) By River Dodder, N. of Rathfarnham	Vertical Boulder Clay cliff.
6274	(5) Greenhills, N. of Tallaght .	Section in esker.
6275	(6) River Dodder, Tallaght Bridge	River-channel cut in Boulder Clay.
6276	(7) Dodder valley, Tallaght .	iver-terraces cut in glacial drift.

GALWAY.—*Photographed by* G. A. J. COLE, *F.R.S., Carrickmines, Co. Dublin.* L.

6277	(28) Joyce's river valley, S. of Leenane	Silurians on nearly vertical Dalradians.
6278	(29) W. of Oughterard . .	Overfolded and contorted Dalradian crystalline Limestone.

KERRY.—*Photographed by* G. A. J. COLE, *F.R.S., Carrickmines, Co. Dublin.* L.

6279	(32) S. side of Valencia Id. .	Subsoil forming from massive Devonian slate.
6280	(33) E. of Kenmare . . .	The Cloghvorra, an erratic of Carboniferous Limestone on O.R.S.

KILKENNY.—*Photographed by* G. A. J. COLE, *F.R.S., Carrickmines, Co. Dublin.* L.

6281	(31) N. bank of the Suir, Waterford	Old Red Sandstone unconformable on Ordovician.

MAYO.—*Photographed by* G. A. J. COLE, *F.R.S., Carrickmines, Co. Dublin.* L.

6282	(26) Pontoon Bridge, W. of Foxford	Roches moutonnées.
6283	(27) Croaghpatrick . . .	Characteristic weathering of quartzite mountain.

ROSCOMMON.—*Photographed by* G. A. J. COLE, *F.R.S., Carrickmines, Co. Dublin.* L.

Regd. No.		
6284	(21) View W. from Slieve Bawn, S. of Carrick-on-Shannon .	Characteristic lake-set Carboniferous Limestone plain.

SLIGO.—*Photographed by* G. A. J. COLE, *F.R.S., Carrickmines, Co. Dublin.* L.

6285	(20) Ben Bulben	Carboniferous Limestone flat-topped hill.

WATERFORD.—*Photographed by* G. A. J. COLE, *F.R.S., Carrickmines, Co. Dublin.* L.

6286	(30) Lough Coumshingaun, Comeragh Mts. . . .	Tarn at base of cirque-cliff of O.R.S.

WICKLOW.—*Photographed by* G. A. J. COLE, *F.R.S., Carrickmines. Co. Dublin.* L.

6287	(8) Upper Lough Bray . .	Moraine separating the two lakes.
6288	(9) Lough Nahanagar, Leinster granite chain	Block-moraine holding up lake.
6289	(10) Fall of Dargle river, Powerscourt	Fall is determined by junction of relatively soft schists with hard granite.
6290	(11) R. Liffey above Pollaphuca fall (Wicklow and Kildare border)	Post-glacial ravine in Ordovician slates.
6291	(12) Pollaphuca fall of R. Liffey (Wicklow and Kildare border)	Central shelf due to andesite bar in Ordovician slates.
6292	(13) Near head of Glenmacnass	Roots of trees in peat on granite 600 ft. above present tree limit.
6293	(14) E. of Luggela above Roundwood	Granite erratics on mica schist.
6294	(15) Ovoca Valley . . .	Mines (Cu and Fe pyrites and ochre).

Channel Islands.

JERSEY.—*Photographed by* S. H. REYNOLDS, *M.A., Sc.D., The University, Bristol.* 1/4.

6295	(1921·20) La Moye . . .	Basic dyke. 1921.
6296	(1921·21) Belval Cove, St. Catherine's Bay	Coarse Cambrian and Conglomerate. 1921.
6297	(1921·22) Anne Port . . .	Columnar rhyolite. 1921.
6298	(1921·24) Mt. Orgueil . .	Mica trap dyke. 1921

GUERNSEY.—*Photographed by* B. HOBSON, *M.Sc., Thornton, Hallamgate Road, Sheffield.* 1/4.

6299	(F1) Looking E. from Corbière promontory	Basic dykes cutting gneiss. 1921.
6300	(E4) Les Tielles (S. coast) .	Basic dykes in gneiss. 1921.
6301	(E·6) Moulin Huet Bay . .	Marine erosion of gneiss. 1921.

Photographed by S. H. Reynolds, *M.A., Sc.D., The University, Bristol.* 1/4.

Regd. No.			
6302	(1921·26) Belle Grève . .	Coarser diorite veined by finer.	1921.
6303	(1921·29a) N. of St. Peter's Port	Felsite enclosing gneiss lenticle.	1921.
6304	(1921·30) St. Sampson's . .	Worm castings.	1921.
6305	(1921·32) L'Eree	'Submerged forest.'	1921.
6306	(1922·39) S. of Grand Havre .	Raised beach on granite.	1922.
6307	(1922·43) Grand Havre . .	Microgranite veins in diorite.	1922.

Sark.—*Photographed by* B. Hobson, *M.Sc., Thornton, Hallamgate Road, Sheffield.* 1/4.

6308	(F·3) Port du Moulin . .	Lenticles of hornblendic rock.	1921.
6309	(F·5) Les Autelets (W. coast) .	Sea stack of gneiss.	1921.
6310	(F6) Les Autelets . . .	Sea stacks of gneiss.	1921.

Naples Table.—*Report of Committee* (Professor E. S. Goodrich, *Chairman*; Professor J. H. Ashworth, *Secretary*; Dr. G. P. Bidder, Professor F. O. Bower, Dr. W. B. Hardy, Sir F. S. Harmer, Professor S. J. Hickson, Sir E. Ray Lankester, Professor W. C. McIntosh) *appointed to aid competent investigators selected by the Committee to carry on definite pieces of work at the Zoological Station at Naples. [Drawn up by the Chairman and Secretary.]*

The British Association Table was occupied by Dr. Cresswell Shearer, F.R.S., from April 10 to June 21, 1923, and he has sent in a report as follows :—

'I was engaged on the problem of the respiration of the growing parts of embryos. The main result of my work was a confirmation (by direct manometer measurements) of Child's work on the determination of oxidation-gradients of the embryo, by the susceptibility methods, using cyanide and other chemical agents. I was able to carry the problem a step farther than Child, in that I was able to find the acetone powders of parts of the embryo still retained (in a reduced form) the different (respiratory) relationships they showed in the living embryo, in that an acetone powder of the embryo head had four to six times the oxidation-rate of a similar quantity of powder prepared from the trunk and tail region of the same embryo.'

We understand that Dr. R. Dohrn has been appointed Administrative Director of the Zoological Station, but we have as yet no details of the other changes involved.

The Chairman and Secretary believe they are interpreting the wishes of the Committee in applying for reappointment of the Committee with a grant of 100*l*.

Zoological Bibliography and Publication.—*Report of Committee* (Prof. E. B. POULTON, *Chairman*; Dr. F. A. BATHER, *Secretary*; Mr. E. HERON-ALLEN, Dr. W. EVANS HOYLE, Dr. P. CHALMERS MITCHELL).

SEVERAL requests from workers both at home and far away for the Circulars and Reports of the Committee have been received during the year, and have in some cases given rise to a useful correspondence. Advice was given on the following questions:—

(*a*) *Mode of reference to previous publications*: see Report for 1916, and Circular Letter. Emphasis was laid on the need for contracting the titles of periodicals in a way intelligible to workers in all branches of science; *e.g.*, *Ber. Annalen*, *Beiträge*, *Monatsb.*, without further qualification, are quite meaningless. Too many workers ignore all fields outside their own garden-plot; but with the transgression of the old boundaries now so frequent, as for instance in Biochemistry, this attitude is an obstacle to would-be readers. For similar reasons it is advisable to give initials of authors, at least in the case of such surnames as Smith, Jones, Müller, Meunier, Perrin, and Peterson.

It is always permissible to employ brief contractions composed *ad hoc*, provided that a list of them with their interpretation accompanies the memoir.

(*b*) *Repetition of the Title and other details on each leaf.*—A case arose in which one or two leaves were issued at intervals, and bore no reference to the volume of which they were supposed to form part. The ideal is attained (and attained without difficulty) when every page-opening shows the title, volume-number, and month of publication.

(*c*) *Insertion of unnecessary or even misleading dates.*—In attempting to ascertain the date of publication of a new species, it was found necessary to contend not only with the date of reading the paper, and with the month and year for which the part was ostensibly issued, but also with various dates inserted by the printers, presumably indicating the actual day on which each sheet or cover was worked off on the press. None of these dates can be of any value, except as yielding one date before which the part cannot have been published. The Committee would, therefore, insist once more that the actual date of issue should be definitely indicated, as closely as possible, upon each separate part of a periodical or serial publication. It is, however, equally important that this date, when given, should be correct, and should not, like that on a recent volume of *Palæontographica italica*, be three years out. A letter on this subject has been sent to the *Revue critique de Paléozoologie*.

(*d*) *What constitutes Publication?*—This question was raised by Dr. Henry Fairfield Osborn in August, 1922, in consequence of the private issue of a pamphlet containing a number of new names. The Secretary of this Committee expressed the principles consistently guiding its recommendations for the past twenty-five years, and his observations were included by Dr. Osborn in his paper entitled 'Publication Standards in Vertebrate Palæontology' (Feb. 1923, *Proc. Biol. Soc.*, Washington, xxxvi., pp. 1-6). Since, however, this is a matter of importance to all systematic biologists, and consequently to all the other workers who must follow their lead in nomenclature, it seems advisable that the views of this Committee should be published here in definite form.

(1) The term 'private publication,' though frequently used, is self-contradictory, for that which is private cannot be public, and that which has been made public is no longer private. A writer must make up his mind: *il faut qu'une porte soit ouverte ou fermée.*

(2) The term 'private printing,' though often used erroneously, has no application to this question. A privately printed book is one printed by an amateur on his private press; and such a book may subsequently be published or distributed privately. On the other hand, a work printed at a press so public as, say, the Clarendon, may be rigidly kept from publication.

(3) A correct term to express the procedure under discussion is 'private issue,' and this, adopted by Dr. Osborn, will be used here. It may be defined as the presentation by the author, or authors, of a limited number of copies

of a work, multiplied by any mechanical process, to his, or their, personal acquaintance. This definition, however, lacks precision in respect of the words 'limited' and 'acquaintance.' The practical interpretation is that the ordinary person is liable to be refused a copy.

(4) The publication of a written work must consist in the multiplication of copies, and in their distribution either to all who demand (as in the case of certain Government issues, or other matter scattered *urbi et orbi*), or to all who pay the price asked. Here, again, the practical interpretation is that no unavoidable difficulty shall be placed in the way of a would-be acquirer. The ordinary dictionary definition and the trade custom agree with this definition by insisting on either sale or universal distribution.

(5) It is now clear that a work may be written, printed, and placed on sale by an individual who is not by profession a publisher, and that such work will none the less be published, provided that the law of the country of production is in other respects complied with, *e.g.* the Copyright Act of Great Britain. It is, however, most desirable that in all cases, whether by Governments or individuals, in which publication is not through ordinary trade channels, reasonable announcement of the fact should be made through that section of the public press which may be expected to reach parties interested.

(6) There are certain limitations of distribution which create difficulties. When a number of people club together and subscribe to produce a book for themselves and themselves alone, it seems clear that this does not constitute publication; and proof of this is that the method is sometimes adopted to escape police prosecution. If this be accepted, however, a difficulty seems to arise in the case of the few learned societies which refuse to sell any part or volume of their serials to one who is not a member; we hold that this action is in restriction of the advance of knowledge, and that it should therefore not be regarded as publication.

(7) We have in our second Report (Toronto, 1897, Recommendation No. 3) dealt with the private distribution of authors' separates before publication of the part or volume; many societies have since acted on our recommendation, and have placed a price on such pre-prints, as well as on their own abstracts of proceedings, formerly distributed to members only.

(8) The application of the foregoing principles to zoological (and botanical) nomenclature brings us up against a fresh difficulty. It is generally recognised that for our purposes publication must be limited to such books and serials as our fellow-workers may reasonably expect to contain such matter. Consequently a new specific name cabled to *The Times*, or printed in a trade-journal or a literary review, would, rightly, be ignored by systematists. If there is any doubt in a particular instance it should be decided by the International Commission on Zoological Nomenclature.

(9) We have not dealt here with the other conditions required to validate a new systematic name. Publication is only one condition. So far as that is concerned we may sum up thus :—

Publication of a new systematic name is effective only when the volume, paper, or leaflet in which it appears is obtainable at a price in the way of trade by any applicant, or is distributed widely and freely to circles interested, it being always of a character suitable to the publication of such matter.

Your Committee asks for its reappointment, with a grant of 1*l.* to meet incidental expenses, and requests that this Report be published.

Geography Teaching.—*Report of Committee* (Professor T. P. Nunn, *Chairman*; Mr. W. H. Barker, *Secretary*; Mr. L. Brooks, Professor H. J. Fleure, Mr. O. J. R. Howarth, Sir H. J. Mackinder, Professor J. L. Myres, and Professor J. F. Unstead, *from Section E*; Mr. Adlam, Mr. D. Berridge, Mr. C. E. Browne, Sir Richard Gregory, Mr. E. Sharwood Smith, Mr. E. R. Thomas, and Miss O. Wright, *from Section L*).

Prefatory Note.

At the Edinburgh Meeting of the British Association the discussion, in both Sections E and L, on the effect of the Regulations of the Board of Education upon the position of geography in secondary schools, was followed by the appointment by the General Committee of a Research Committee 'to formulate suggestions for a syllabus for the teaching of geography both to matriculation standard and in advanced courses; to report upon the present position of the geographical training of teachers, and to make recommendations thereon; and to report, as occasion arises, to Council, through the Organising Committee of Section E, upon the practical working of Regulations issued by the Board of Education affecting the position of geography in training colleges and secondary schools.' The members of the Committee were Professor T. P. Nunn (Chairman), Mr. W. H. Barker (Secretary), Mr. C. E. Browne, and Sir Halford J. Mackinder.

During the period that the Committee carried on its investigations the Council had correspondence with the Board of Education on the subject, and obtained from the Board a statement relating to *Revised Regulations for Secondary Schools, England, 1921*, as follows :—

(1) The effect of Article 7 is to make it necessary that the course of work should be arranged as to secure that every pupil who remains in the school till the age of sixteen shall during his school life have passed through an adequate course of graduated instruction in each one of the subjects named in the Article.

(2) In a circular issued in 1919 it was stated that Geography 'necessarily holds, as an essential part of all proper study of history, an important place in all courses belonging to Group B and Group C; and that the definition of Group C embodied in the current Regulations affords special opportunity for increased attention to Geography in connection with the work in history.' This view is also applicable to the new Group D courses allowed under the recent Regulations.

(3) Geography is not accepted as a main subject in Group A (Science and Mathematics).

The groups B, C, and D, referred to in (2) above, refer to main subjects of study in advanced courses and, as defined in the Regulations, consist respectively of '(B) Classics, viz. the civilisation of the ancient world as embodied in the language, literature, and history of Greece and Rome; (C) Modern Studies, viz. the language, literature, and history of the countries of Western Europe in modern and mediæval times; (D) the civilisation (i) of Greece or Rome and (ii) of England or another country of Western Europe in modern times as embodied in their language, literature, and history.'

The correspondence embodying the above statement was published in the press by order of the Council, with the consent of the Board.

The Council, after further correspondence with the Board, were gratified to learn from the draft *Regulations for Secondary Schools, 1922*, that the position of geography in the curriculum was to be materially strengthened, and that it was to be included as a principal subject in advanced courses (Group E).[1]

The new regulations referred to in the above Report (see also 'Higher School Certificate,' p. 335) so materially altered the position of geography in schools that the Committee decided to withhold its report and to recommend

[1] See Report of the Council, 1921-22, pp. xiv-xv.

that a new and larger Committee be appointed with the same terms of reference. This recommendation was carried out by the General Committee at the Hull Meeting, 1922.

In the course of its deliberations the Committee has had frequent occasion to consult with the heads of schools, teachers of geography, examinations boards, and universities, and desires to express its appreciation of the help which invariably has been given.

Introduction.

The definition of Geography as the study of the surface of the earth has by its very vagueness made both for progress and for retrogression. On the one hand, the various possible interpretations have encouraged the inclusion of the subject within the curriculum; on the other, the same considerations have given rise to criticism which has urged the inclusion of geography, wholly or in part, within the teaching scope of another subject, this inclusion to begin at some period ranging from the middle forms of the secondary school to the university stage.

For these reasons, difficult though it is to define the scope of any subject in few words, especially when, as in school work, educational discipline and co-ordination of knowledge must also be considered, any attempt to carry out the Committee's terms of reference demands a restatement of the content of the subject. Conceived on a world scale, the earth's surface constitutes a sphere whose physical form arises from the interpenetration and interplay of the lithosphere, hydrosphere, and atmosphere. Physical forms and forces, however, are but part of the constituents of the earth surface, and organic life—flora and fauna—enter into its composition. In addition, man, with his ability to transmit experience and knowledge, has an accumulating power to influence the other concomitants, physical and biological, of his existence. Some of his work, indeed, is of the magnitude of the works of Nature—*e.g.* the Suez Canal, the Forth Bridge, the Simplon Tunnel, the irrigation of Egypt, &c. Though he cannot alter to any appreciable extent the major phenomena, yet in almost every small region the evidence of his work may be seen. The 'surface' of the earth is, therefore, at any moment the resultant of many complex processes, each of which is in a constant state of change, of greater or less rapidity. Structure, relief, climate, vegetation, human agency, and many other factors operate together, modifying the action of one another continually as change takes place in any of them. From the earth as a whole to the smallest hamlet, movement and change of form constantly and continuously take place, imparting to a region many of the characteristics of an organism, and giving life to the subject of geography. Only an all-embracing intelligence could comprehend even for one region all the interweavings of all the phenomena and calculate the relative values of each, which makes the knowledge of the region full and complete.

Nevertheless, it is not only possible but necessary for an appreciation of world conditions to-day to make a synthetic study of certain major phenomena. Such phenomena, for example, are the effects of the rotation and revolution of the planet with its axis at $66\frac{1}{2}°$ to the plane of the ecliptic; the character and interpenetration of lithosphere, hydrosphere, and atmosphere; the major distributions of land and water: the circulations of air and water: the distribution of vegetation zones; the distribution of peoples and their control by and eventual control over the complete and resultant conditions under which they live.

In the first place, geographical study is necessarily descriptive of the regional life as it is, though with the consciousness that in very few areas is there even an approximation to stability. The one area where scholars may see and observe this multiplicity of phenomena in geographical unity is that of the home—*i.e.* the district whose limits are defined by its accessibility for direct observation by them. Here may be seen the various forces operating to give the characteristic life of the region—the altitude of the sun, weather changes, relief and soils, vegetation, buildings, works, public utilities, and the contacts with the larger world. For the learner 'home' is the centre of his world. It is also the laboratory in which geographical observations and records are made. It is here that the pupil must obtain measures and standards by which to estimate the other regions of the earth

The continuous study of the home gives the best possible training not only in geographical thought but also in geographical method. The record of observations, besides furnishing the basis for synthetic study, gives the training in map and chart interpretation—the reading of the geographical alphabet—upon which the study of other regions must be based.

Necessarily the regional study of the world will be less intensive than that of the home, but the character of the study remains the same. Mere description develops into an analysis and synthesis of the major components with the view of establishing their relationships, and for those studies the pupil must learn to use maps and diagrams and to understand how they are made. From the study of the major regions it is possible to establish certain world-generalisations which may be regarded as the highest aim of geographical study.

It is well to notice that man with his power to transmit the results of experience and knowledge is becoming increasingly a factor which makes for change and consequent readjustment. The application of science to modify the conditions of life constitutes, along with the production of charts and maps and their manipulation, the closest bond between the fields of geographical and scientific studies.

Thus far, geography has been defined as the study of the earth's surface as it is. Description of regions as they are develops into an analysis and synthesis of the components with a view to establish reasons for the special and peculiar relationships, and essential to this study are the reading and interpretation of maps. But the present is the outcome of the past, and though much that has been is displaced by that which is, certain events continue their influence markedly into the present and must be regarded as concomitant factors. Such, for example, is the upfolding of the Pennines which has resulted in the special relationship of the northern coalfields of England and their connecting routes, and has influenced present occupations through the effect of the uplift on such other components as climate, drainage, &c. The effects of the West African slave trade of the sixteenth, seventeenth, and eighteenth centuries operate to-day in the geography both of the United States and of West Africa. Indeed, for almost all regions the effects of certain outstanding events of the past continue to operate, and must be considered by the geographer.

As applications of modern science connote the affinity of geography with the sciences, so this bringing forward of the past to help in the interpretation of the present connotes links between geography and historical studies, including geology and archæology. It should be noted that this is not historical geography, but pure geography in which present conditions are considered as fully as possible in order to appreciate the reasons why a region is as it is.

Historical geography may be defined as a sequence of geographies to which the conception of historical development is applied. At any period of the past each place had its 'geography,' defined as the balance or resultant of forces then operating. So might be reconstructed, for example, the geography of Britain in the Stone Age, the Bronze Age, the periods of the Romans, Saxons, Normans, &c., until we arrive at our own times. By a process of evolution the passage of these 'geographies' one into the next gives that combination of geographical and historical processes which is the subject-matter of historical geography.

Geography, as ordinarily understood, deals with the world of to-day, proceeding from the description of a region by map, chart, or words to an investigation into those causes of which the present geographical 'form' or 'shape' of the region may be regarded as the result. Some, indeed most, of these causes have their origin in the past, and this is specially true of man and his work. Moreover, because man is able to transmit his knowledge and experience from generation to generation and from one group to another, the importance of the human factor in any region is steadily and rapidly increasing. For this reason, geography, especially as interpreted and limited for the purposes of school work, occupies a special position in the study of human conditions at present obtaining in the various parts of the earth and the tendency of the changes taking place therein.[2]

[2] For a scientific statement on the content of geography see the forthcoming *Geographical Essays* by Sir Halford J. Mackinder.

The Aim and Functions of Geography in Education.

The claim of a subject to a place in the school curriculum must ultimately be measured by the value of its contribution to the history of the human spirit, the development of culture and civilisation, and what may be called the educated mind of the age. The principle assumed here is that the development of the individual mind and character is best fostered by the moral, intellectual, and æsthetic traditions which have been, or promise to be, of most significance in the upward movement of the race. The criterion guarantees the position of the older disciplines, and also justifies the admission of others, such as natural science and geography, which have only in modern times attained to the distinctness of aim, the individuality of method, and the coherence of content which have made them important elements in the life of civilised peoples. It points, moreover, to a practical maxim of great weight. A subject, to have its full educational value, must be so taught as to represent faithfully in the class-room the spirit and character of the corresponding movement in the wider intellectual world. This means, for instance, that school geography must be the geography of geographers : not the mere learning of geographical data and results, but a training in the geographer's characteristic methods and principles of interpretation and an assimilation of his characteristic point of view. Only when a subject is taught in this way are the items of knowledge communicated given their true relations and significance, so that the subject as a whole makes its special contribution to the pupil's outlook and habits of thought.

In the preceding section an attempt has been made to characterise geography as the modern geographer conceives it. It must, however, be recognised that this conception is not one which can be placed before pupils at the outset, but is rather a goal towards which their teacher should direct their studies as they pass from stage to stage of mental growth and experience. In the earlier phases of their progress it will be appropriate to emphasise aspects which will fall into subordinate positions when the subject has reached its full systematic development. These will include the romantic and descriptive elements which may properly predominate in the earliest lessons, and the utilitarian or 'human' elements which naturally occupy the focus of interest in the middle school period.

With regard to the latter it should be remarked that a knowledge of geographical facts is important for men and women in all walks of life, and the utilitarian value of the subject should never be overlooked in school teaching. But the main aim of the teaching should be to enable pupils, by study of the regions of the world, to realise how the peoples of the world live and work, and how their life and their work are related. This aim coincides with the nature of the contribution which geography can make to the training of future citizens, estimated in relation to the fundamental needs of our time. In studying the world and its regions the geographer must pay attention to the distribution and inter-relations of all the relevant phenomena of land, water, and air, and of the life of plants, animals, and men, but for school purposes, at least below the stage of the advanced course, the emphasis should be on man. In view of the comparatively short time that is given to geography in most schools there must be a careful selection of subject-matter and a concentration upon essentials. It is also necessary that the material selected should appeal to the interests of young people of school age, should equip them with adequate geographical knowledge so that they may be able to take an intelligent interest in the world and its affairs, and should make them familiar with the working of great geographical principles. These objects can best be achieved by emphasising the distribution and activities of man, and, in the main, by restricting what is taught concerning the other geographical distributions to what is necessary in order to understand the life of man.

Thus, whilst a school course of geography should provide for adequate work of an observational character, for practical work in the making, use, and understanding of maps, and for an examination of those geographical distributions and special processes necessary to understand the life of a region, the main aim should be to show the distribution and activities of man in relation to his physical environment. If this aim is accepted it is clear that schemes of geographical instruction in schools, at least up to and including the stage of the First Examination, should not show separate schemes of physical geography. The groundwork of the physical basis must be covered during the four years' course, but the treatment should be incidental and the topics arranged according to the needs of the regional studies and the age and ability of the pupils.

The Stages of School Life.

The success of any scheme of instruction depends largely upon a scientific adjustment of teaching and training to the natural movement of mental development. The total school period may be taken to run from the age of six to the age of eighteen. In this period there occurs one life-change of the greatest importance—the advent of adolescence. The physical, intellectual, and spiritual developments of that critical period constitute the division between primary and post-primary education. Adolescence cannot be fixed at any particular date or year. It is a period or epoch which appears at different times in different children, and therefore for administrative purposes it is necessary to fix upon some date. The age of 11+ has been generally adopted as the dividing line between the two main periods of school life. It is at this age that the scholarship holders leave the elementary school for the secondary school. Each of the main periods 6 to 11+ and 11+ to 18 may be subdivided for the purposes of administration. In the first period occurs the transfer from infants' school or kindergarten to the junior or preparatory school. In the second it is possible for education to cease at 14+ for the great majority of the pupils of the elementary schools. The majority of the pupils in secondary schools remain until the end of the 'four years' course,' which covers the period 11 + to 16, and some remain for an 'advanced course' followed from 16 to 18. This report is concerned with secondary schools, and principally concerned with the post-primary or secondary period from 11 + onwards, the period of the 'four years' course,' and the 'advanced course,' but many schools have also pupils belonging to the later years of the primary stage. This report is not concerned with pupils belonging to the earlier years of that period.

The School Course.

The principles which should guide the formation of a syllabus of geographical instruction in secondary schools may be stated briefly.

I. The Later Primary Stage—ages 9 to 11+.

Pupils of this age will, in most cases, have heard stories of the lives of children in typical environments. They will also have been introduced through nature study to the simple facts of natural phenomena. They are, however, still children, and cannot appreciate instruction of too formal a character. They love outdoor activities, they are full of imagination and adventure, and they revel in the wonderful things of the world in which they live. It is then the period for a wide basis of instruction, for the deepening of impressions of the homeland and of lands and peoples far away, and for an abundance of work having the concreteness and freshness of open-air experience. It is the period in which are laid the foundations upon which a consciousness of imperial and world citizenship may later be built.

The Secondary Period.

II. The 'Four Years' Course'—ages 11+ to 16.

This stage covers the main part of the secondary school, and includes the most important of the years of adolescence. It is a common mistake to make the work of the earlier years too formal and bookish, thus neglecting the fact that young people passing through the years of early or pre-adolescence show, though on a higher level, many of the characteristics usually associated with children, *e.g.* the love of make-believe. Thus while the work gradually becomes more formal in character and the pupils are trained to rely more and more upon their own resources and less on those of their teacher, there should be no abrupt change from the methods of the primary stage.

During the four years' course the groundwork of the general and regional geography of the world should be covered. The method of work will be illustrated by a first-hand study of the home district to which reference will be made at all stages. In the study of the home district and the British Isles direct experience and observation play an important part, and maps and charts, such as the maps of the Ordnance Survey, weather charts, &c., should be read and interpreted.

The emphasis on the human factor in all the teaching will be welcomed and eagerly developed by pupils passing through the experience of adolescence proper.

III. The Advanced Course—ages 16 to 18.

At this stage the adolescent has begun to surmount his difficulties, and steadying influences appear. In this stage the beginnings of specialisation can be introduced with profit, and the pupil can be thrown more and more upon his own initiative. In geography he is now able to engage in more detailed regional studies, and to pursue courses in specialised branches of geographical instruction, *e.g.* meteorology, geomorphology, surveying, historical geography, &c.

Outline Schemes for each Stage.

I. The Later Primary Stage.

Formal geography cannot be taken in these years, but the principles which underlie geographical study should serve as a guide in the selection of story and description. One group of lessons should be preparatory to the study of the 'home.' It should be related to familiar things, and involve a good deal of observation. The complexity of the 'home' arises from—

(i) its position on the surface of the earth;
(ii) the local conditions of relief, soil, climate, &c.;
(iii) the activities of man in field or factory, on road or railway.

All these may be introduced by a teacher who possesses a geographical 'sense.' The farmer, the woodlands, a winter's day, the thunderstorm, the market cross, old street names, these and a thousand other circumstances may be selected round which to weave the threads of a geographical study. The farm with meadowland by the river should be contrasted with the farm consisting mainly of hill pasture. Seed time must ultimately be coupled with harvest time, and both with the seasonal change of climate, and the cattle market with the shops in the High Street.

The home district must also be used to teach the elements of geographical notation by means of simple maps. Similarly, in the choice of descriptions and stories of other lands and peoples, the basis must be as fine a geographical conception as possible. Eskimo life in winter must have as complement the life in summer. The prairie, as the former home of the Indian, needs another picture of the prairies as the home of the present wheat cultivator. The wheat farm of Canada needs as its corollary the factories of the Black Country, and both involve the romance of the ship by which the wheat and manufactures are exchanged.

The story of explorer and adventurer in Africa and Australia needs to be linked with the story of the development of these same lands under modern conditions. Folk-lore, not as isolated stories but carefully selected as to area and with points referring to local conditions, faithfully related, can be made to render valuable aid in these early years of instruction.

As the work proceeds so it becomes possible to 'locate' the scenes of the stories. For local setting the first rough map may be built and orientated on the floor or table, showing the position of school, church, market, farm, wood, &c. Distant scenes should be located on a black-surfaced globe, the character of the region being indicated so that on completion the major regions of the earth —climatic, vegetational, and industrial—have been placed, and great world ocean and railway routes of commerce have been marked.

Thus by the end of the primary stage the pupil has some elementary conception of the 'home' and of the world, and has been introduced to the use of map and globe as a means of localising his ideas.

II. The Four Years' Course.

This period of four (or five) years is the one in which the foundations of formal and advanced geographical studies are laid. It is terminated as a rule by the School Leaving Examination, which as determined by most examination syllabuses tests a knowledge of the world in general, and of one or more important regions in somewhat greater detail. It is obvious that the work done, say, at age 12, on any particular area would not be of the character or standard required for the examination at the age of 16. Equally obvious is it that the whole work for the examination cannot be done in one year. Were either of these possible the position of geography in secondary education would be seriously prejudiced, and rightly so.

Experience has shown the possibility of most diverse treatment of the subject during these years, but, ignoring for the moment the sequence of study, the underlying principles in the teaching of the home district, the British Isles, and the world may be set out thus :—

The 'Home.'

The home district, which includes the whole of the area which can be studied on the spot by a whole class, forms the first geographical laboratory in which, while the formal study proceeds, observations are made and recorded, including the measurement of the length of the day, rainfall, wind direction, altitude of the sun, the time of the budding of trees, hay and corn harvest, &c. These form the beginnings of the study of the synoptic (weather) chart, one of the valuable documents of geographical study. Relief, rivers, soils, villages, roads, &c., plotted at first as the study proceeds and always orientated when additions are made, lead to the study of the Ordnance Survey maps, and of the geological maps in so far as they help the study of the relationship of structure to relief and vegetation and of cultivation to the general character of soils. The distribution and activities of man are studied in relation to all these factors, and the whole is made as far as possible a model for the regional study of lands which cannot be visited.

This home study may be followed either by :

(i) A descriptive study of the British Isles where the lessons, observations, maps, and diagrams of the 'home' may readily be applied; or

(ii) The simple study of general world phenomena for which the local study of variability of the day and seasons, the climate, &c., forms a suitable introduction.

The World.

The use of the globe and generalised maps of relief, climate, &c., enable elementary ideas to be acquired according to the principles already enunciated. These world conceptions lead readily to regional subdivisions, though there is much variation in the manner of subdivision. Whether the teacher selects for treatment the land-masses lying in an east and west direction (*e.g.* the Southern Continents, North America, and Europe or Eurasia), or in a north and south direction (*e.g.* the Americas, Asia and Australasia, Africa and Europe), or in any other order, it is imperative that the order should be thought out carefully so that it permits of a proper development of the teaching. The land-masses must not be selected for detailed regional study in haphazard fashion.

Whatever method is adopted the data are supplied largely by generalised maps, charts, and diagrams. It is, therefore, an integral part of geographical work at this stage to continue the study of the ordnance maps, weather charts, and meteorological charts of the great oceans, both as correctives to these generalisations and to give proficiency in the expression of geographical knowledge through the notation of geography.

One important value of geography in education is the opportunity it gives to express thought in diagram and sketch no less than in words.

The British Isles and the World.

Towards the end of the third year the elementary principles of world geography and the interpretation and use of maps and diagrams have been acquired. In the 'home' study the geographical complex could be realised because of the smallness of the area. In the world study the emphasis becomes more particularly the influence of natural conditions. In the last year or so the other viewpoint may be given—*viz.* the activities of man as he utilises the resources of nature. The economic study of the British Isles, for example, enables the previous study to be considerably amplified; and, moreover, by the links of all kinds which bind Britain to her overseas Dominions and to other parts of the world, the previous regional studies both of Britain and of the world may be revised and completed.

At this stage the use of graphs and diagrams for statistical purposes should be used along with the map and diagram studies begun in the first and second periods.

The Secondary Stage: The Advanced Course.

The present system of advanced courses under the Regulations of the Board of Education demands that each principal subject must satisfy the following conditions :—

(i) That the study may be usefully carried to an advanced stage within the school, and occupy approximately six hours per week of the time-table.

(ii) That it should be capable of forming a co-ordinated and uniform body of study with the other principal subjects (generally two in number).

During the ordinary school course the outline of general and regional geography, with a fairly detailed study of the British Isles, has usually been attempted. As a general rule there have been no separate courses in the physical basis of geography, and the relations between geography and history have only been illustrated in a general way.

The lines of the direction of advanced study in school are thus clear. In the first place, there should be a more advanced treatment of the world as a whole, and also of the regional geography of selected areas in which a more comprehensive analysis and synthesis is possible than at an earlier stage. In the second place, especially if history is one of the other main subjects, there should be some examination of the influences which geography has had upon the course of history, and this may take the form of studies either in historical geography or the history of geographical discovery, or both. Thirdly, and particularly where a science forms one of the main subjects, it is possible to take an extended course of study on some geographical phase for which the scientific subject makes a suitable preparation, *e.g.* the physical basis of geography where physics or geology are taken, or the distribution of plant and animals in connection with studies in biology, botany, or zoology. In most cases studies of both kinds would be included.

Although advanced studies of three kinds are mentioned only the regional studies would form a necessary part of every course, although it is highly desirable that all three aspects should be represented. Where either the second or the third is omitted, special attention should be given to its leading features in the teaching of the regional studies.

As the regional studies are of special importance it is necessary to indicate their character. In the first place, the world as a whole should be studied in more detail and with more understanding than was possible during the four-years' course. The emphasis could be on the economic conditions of the modern world. In the second place, there should be a more detailed regional study of two or more smaller areas from some particular point of view—for example, an area such as the 'Land of the Five Seas,' where the rise and fall of ancient civilisations has been followed by centuries of desolation and decay, with a revival under modern economic conditions; or France, in which there has been continuous development, and in which internal economy and external contacts offer a wide circle of study; or an area such as one of the British

Dominions, the United States, or Argentina, which has developed comparatively recently under the conditions of modern times. Thirdly, wherever suitable the home district, or a district which is within easy reach and can be visited on several occasions, should be studied in considerable detail and by personal investigation, and the results of the study should be assembled on maps. All three types of regional studies should be accompanied by cartographical studies of an order comparable with the detail given to their study.

Geography in Relation to other Subjects of the Curriculum.

Science.

The various forces or phenomena which, as previously stated, may be regarded as components whose resultant is the 'life' of any region, may in a general way be divided into three groups: (i) physical, (ii) biological, and (iii) human. Though this division cannot be pressed too far, it serves to indicate that geography may have important relationships with studies belonging to each group. Forced correlation should never be attempted, but such harmony as may reasonably be observed by the simultaneous study of two or more subjects should be carefully maintained. The natural and biological sciences, applied science, and history, as well as literature, art, and the social sciences, often demand or reflect a geographical setting.

Science in preparatory and secondary schools is taught almost entirely under the headings of nature study, experimental science, physics, chemistry, and botany—the last-named branch of science being mostly confined to girls' schools. Each of these subjects includes certain facts and principles of essential value for the scientific study of geography. On the other hand, syllabuses of the chief school examinations in geography prescribe knowledge of instruments and phenomena usually dealt with in the ordinary science courses.

Among the topics which are common to school science (including nature study) and geography are the following:—

Determination of north and south points by observations of the sun and Pole Star.

Annual changes of the sun's altitude.

Phases of the moon in relation to tides.

The thermometer and its use in determining temperature; temperature scales; maximum and minimum thermometers.

Records of wind in relation to weather.

The atmosphere and barometric pressure.

Graphical records of meteorological phenomena.

Dew, fog, clouds, rain, snow, rain-gauge, ice.

Water: spring, river, and sea.

Filtration; distillation; solution.

Change of physical state of water.

Latent heat; specific heat.

Cooling of air by expansion and heating by compression.

Radiation and absorption of heat.

Conduction and convection of heat in relation to winds and ocean currents.

Factors determining climate.

It will be obvious, therefore, that a pupil who has been taught to observe and describe natural occurrences and phenomena in a nature-study course, and has afterwards followed the usual experimental course in physics and chemistry, should possess a knowledge of the scientific facts and principles required to understand physical factors of geographical significance. It is neither necessary nor desirable that teachers of geography should give instruction, as part of the geography course, in what amounts really to a general scientific vocabulary. They expect their pupils to have a working knowledge of arithmetic and the English language, and may similarly ask for acquaintance with the rudiments of science.

In actual school work difficulties arise from two causes. First, there are still teachers of geography who have not had a training in science; and next, there is often no correlation between the various stages of school courses in science and geography. The first cause will be removed only when it is understood that geography is a scientific as well as a humanistic study, and that it is desirable that those who teach it, even up to the standard of the First School Examination, shall have received a training in practical science and scientific method. It is thus specially important that geography should have a full place in the courses of the Faculties of Science in our Universities; and it can in its turn contribute to those faculties an important humanist element. The separation of faculties now in vogue has probably been carried too far, and it seems important that some students at any rate should grow up with reasonable knowledge of method on both sides. The attention of universities and of their schools of geography is invited to this point.

Assuming that the teacher possesses this knowledge, and is therefore capable of making correct use of whatever scientific facts are required to comprehend particular geographical differences, relationships, or consequences, the lack of correlation between his course and that of the science teacher results frequently in his requiring certain scientific knowledge from his pupils before they have reached the subject in their science lessons. It has been shown that almost all the topics of which an understanding is necessary to make the scientific side of geography intelligible are included in the school science courses normally followed. All that is wanted, therefore, is an adjustment of the syllabus on the one hand in the science course, and on the other in the geography course.

On account of varying conditions in schools and different interests of teachers it is difficult, and perhaps undesirable, to lay down hard-and-fast lines as to the course in which the rudiments of science required in geography should be taught. A Report lately issued by the Science Masters' Association, on 'Elementary Sciences, Nature Study, and Practical Work in the Preparatory Schools and in the Lower Forms of Secondary Schools' (Oxford University Press, 1*s.*), refers particularly to the advantage of freedom in this matter to adapt schemes of work to teaching powers or periods available. In this Report the scheme of work in nature study includes observations and experiments on subjects of astronomy, meteorology, physics, physical geography, and so on, which are also to be found in the suggested course in practical geography. The overlapping is said to be intentional, as the subjects may in some schools be taught as nature study and in others as geography or science.

Duplication can be lessened by considering nature study, science, and geography as a whole, so that each topic fits naturally into a particular section of the curriculum. There should be true co-ordination, so that no science subject need be taught as such in the geography course (though it may have special geographical aspects), and no such subject should enter into the geography course until it has been studied in the nature study or science course. Teachers of geography should make special efforts to come to an understanding with their colleagues teaching the elements of science to ensure that general observational work has been begun early, and that a pupil by the end of the first secondary school year has some knowledge of the practical uses of the thermometer and barometer, and of the recording of simple data derived from the use of these instruments. With care it is possible so to dovetail the courses in geography and in sciences that each may materially strengthen the other, *e.g.* precise consideration of thermal influences on the earth should be deferred in the geography course until after pupils have received instruction in heat in the science laboratory.

In certain types of schools, and provided that suitably qualified teachers are available, it is possible to introduce a composite scheme in geography, nature study, and physical science, in which each topic considered desirable to teach has its appropriate place, and the requirements of the geographical argument are taken as the unifying principle of the course. It is maintained that the adoption of such a plan up to the stage of the First School Examination would tend to improve the teaching both of geography and of science: for it would humanise the science by keeping prominent the relation of scientific activity and results to general human interests, and would at the same time facilitate the task of the geography teacher. It has also been suggested that where complete unification of the courses in geography and science up to the age of sixteen is not adopted, most of the simple observations of biological and physical phenomena prescribed for pupils up to the age of twelve should be related directly to their work in geography, and that the stage immediately after the age of twelve might begin with a course in the simpler parts of that branch of knowledge which Huxley called physiography—a plan suggested by Sir Joseph Thomson's Committee on the Position of Natural Science in the Educational System of Great Britain. One of the advantages of this is that it gives opportunities for out-of-door observation, to which we attach great importance not only at this stage but throughout the school course. The course in physiography should include the simpler astronomical phenomena, which in the hands of a good teacher may be made an excellent training in reasoning and observation. Geology is not often taught as a special subject in classes before the School Certificate stage, but it might well be the care of the geographer to introduce his pupils to some important principles of that subject, which is so closely related to his. An introduction of this kind will be planned so as to utilise the pupils' neighbourhood and its data as far as possible, but the excursions of the School Journeys Association and of the branches and the Touring Committee of the Geographical Association offer additional opportunities which should be utilised. In South-Eastern England the study of chalk and flint in relation to their origins as well as to their chemico-physical characters offers opportunities, as also does the study of soils in their relation to water. The study of land-forms of glaciated regions in geography may be used as a means of introducing pupils to the idea of an Ice Age in Britain and the days of early man. Senior pupils may well be introduced to the idea of fold mountains and fractured blocks, and, with some knowledge of the main periods of geological history and of contrasts between volcanic, plutonic, and sedimentary rocks, they may be prepared on the one hand to take up geology, and on the other to appreciate something of the relative ages and the phases of history of various parts of the earth's surface.

While the pupil will usually be introduced to geology through geography, the beginnings of teaching in nature study and geography will be taken at about the same time, and each may make notable contributions to help the other. The geography teacher will naturally help his classes to appreciate the different associations of plants found under different climatic influences, and he should try to use such descriptive references as those of the Old Testament, Homer, Herodotus, and so on, as well as of Marco Polo, Huc, Darwin, Wallace, Doughty, and others, in this connection.

In the Report on Science in Secondary Schools (Brit. Assoc., 1917, 2*s*. 6*d*.), the late Mr. F. W. Sanderson, Headmaster of Oundle School, made the important forecast that 'every branch of knowledge in the years to come will be influenced by the study of biology and the humane studies in history, economics, sociology will be rewritten under the same.' Since school geography, as the study of men in their various environments, is developing so fast, the geography teacher not only has a great part to play in this process of development of knowledge and thought, but also has the duty thrust upon him of trying to gain an understanding of science, including biological science, on the one hand, and of the humane studies, especially history and languages, on the other.

History.

The relationship of geography to history may be viewed from several angles. Presuming agreement with the general definition of Geography as concerned with the comparative study of distributions in space (simultaneous distributions in pure geography; sequences of such distributions in applied geography), and with the general definition of history as concerned with the interpretation of sequences of events within a given geographical region, it is obvious that economy of effort and efficiency of result must depend upon reasonable co-ordination of geographical and historical teaching. On the part of the geography teacher it is essential for his interpretation of the present that he look back into the past to find some explanation of the facts which he presents. Geology, archæology, anthropology, and history may all be drawn upon for the elucidation of the region which forms the subject of his study. It is thus obvious that the geography teacher must often rely upon himself for the historical data which he requires, and that the greater his knowledge of historical events whose influence still operates in the present, the richer and truer will be his teaching of geography.

Similarly, a further link between history and geography can and should be forged by the history teacher. Many of the events of the past find their fullest interpretation when studied in their geographical setting; thus, the greater the geographical knowledge of the teacher of history the fuller and truer is his history teaching.[3] This, however, does not mean that historical teaching must not be begun at all until a later stage than geographical. Important aspects of the relations between men in organised societies are so far purely social or political as to be intelligible either without any reference at all to the control exercised by geographical factors, or at all events without more precise knowledge of geographical environments than the pupil's own daily experience can supply. For example, in introducing a class to the elements of English political history it is not necessary to deal expressly with the climate or natural products of the British Isles. On the other hand, the systematic study of Mediterranean or Oriental history (including even the study of the Old and New Testaments so far as this is specifically historical) should be postponed until the pupil has been prepared to appreciate the differences between an English town or village on the one hand, and a Greek city-state or Palestinian village on the other, which result from their respective geographical surroundings. Indeed, from the point at which such mutual reliance begins, of the geographer and the historian on materials contributed by the other, it is essential that the periods and regions prescribed for special study should stand in intelligible relations with one another. There is obvious want of correlation if a class is confronted in the same term with the geography of India or China and with the history of France or the British oversea Dominions, or with the Mediterranean or African geography and the history of the British Isles or of Germany.

The one great difficulty, so far as the pupils are concerned, is that, in relation to the particular section of history taken, their geographical background may be inadequate for the full appreciation of the teacher's geographical references, and *vice versa* for the study of geography.

In so far as historical allusions are introduced into geographical teaching, or geographical allusions into historical, they should be such as *either* are intelligible without explanatory digression, *or* are supplementary to the subject-matter of the other course, and not a partial repetition of it. As example of this last type of correlation, the geographical position of cities or distribution of products or industries should be illustrated as far as possible from places in the region of which the political history can be presumed to be most familiar to the class, but the social and economic conditions of which have had to be treated more summarily in the history lesson.

The most satisfactory solution is that as far as possible the schemes of history and geography should be so co-ordinated as to allow the two studies to enrich each other. The local study is essentially one in which geography and history combine with each other and with the sciences. It is possible, however, to take more or less simultaneously such studies as British history and the geography of the British Isles: colonial history and the geography of the British Empire; European history and the geography of Europe; classical and biblical history and the geography of the Mediterranean lands.

The Committee has had before it one scheme at present in use in which the history of geographical discovery is the basis of the geography course. There the regional study of the world follows in its treatment the discovery, exploration, and development of the world, beginning with the lands of Egypt, Mesopotamia, and the Mediterranean, and finishing with the highly industrial lands of the North Atlantic with their world market and almost world control. The proper use of travellers' narratives is to illustrate by example the habit of mind by which experienced observers attack unfamiliar material. And examining even the barest nucleus of geographical and historical knowledge, the same attitude of mind (*mutatis mutandis*) may be induced in elementary pupils by using incidents from the history of geographical discovery as illustrations, and a short survey of this department of history may even be admitted, if time allows, as

[3] See Appendix II.

supplementary to the ordinary course at any stage. But it is probable that an intensive study of the history of geographical discovery should be limited to those students whose knowledge of history and geography is adequate to appreciate both the historical and geographical backgrounds of the subject.

There is a further course of study, possible probably for students of advanced courses and in the Universities, which is definitely a fusion of history and geography. For any region, large or small—*e.g.* England, Wales, the Mediterranean—if the requisite data are available, the geographies of bygone times may be re-created, as they were at the dawn of history and at suitable epochs from that time to the present. This application of the sequence of history to the geographical evolution of a region may best be called 'historical geography,' and shows the strongest possible link between geography and history. To all intents and purposes the 'local' study becomes one of historical geography.

Regulations Governing the Teaching of Geography in Schools.

In so far as the subject is concerned, the inclusion in the curriculum is governed to a certain degree by the Regulations of the Board of Education. The syllabus is often determined by the regulations of the examination for which the scholars are being prepared. The following extracts from the 'Regulations for Secondary Schools, England, 1922,' give the essential information relative to geography :—

CURRICULUM (p. 11).

Art. 6. 'The curriculum (with time-analysis) of the whole school must be approved by the Board, and must provide for due continuity of instruction in each of the subjects taken, and for an adequate amount of time being given to each of these subjects. The Board may require modifications in the curriculum or the time-table if a subject is taught which is not of educational value, or if the time spent on particular subjects interferes with proper instruction in other subjects, or if the time given to any subject is insufficient to allow of effective progress being made in it, or for other similar reasons.'

7. 'The curriculum must provide instruction in the English Language and Literature, at least one Language other than English, Geography, History, Mathematics, Science, and Drawing.'

PROVISION FOR ADVANCED COURSES (p. 19).

48. (*a*) 'The main subjects of study in any such course must be selected from one or other of the following groups :—

A. Science and Mathematics.

B. Classics.

C. Modern Studies.

D. The civilisation (i) of Greece or Rome and (ii) of England or another country of Western Europe.

E. Geography, combined with two other subjects approved by the Board, of which at least one must be History or a Science.'

(*c*) 'In all Advanced Courses adequate provision must be made for the study and writing of English by every pupil either in connection with the main subjects of the course or otherwise. In other respects full freedom is left in the choice and arrangement of additional subjects so long as the syllabus . . . for an E Course (provides) for some substantial work in a subject or subjects complementary to the main subjects of the Course.'

The new position thus defined in Group E above should lead to a revision of the 'Memorandum on Teaching and Organisation in Secondary Schools' (Circ. 826 (1913), Curricula of Secondary Schools) and the 'Memorandum on Advanced Courses' (Circ. 1112, 1919). The former contains the following statement :—

'It is not necessary that separate instruction in both History and Geography should be given in all forms. In schools in which the pressure on the timetable renders it necessary, a shortened course of Geography terminating at the age of fourteen or fifteen may be accepted. In this case, however, the course must be so arranged as to include the fundamental principles of Physical and Mathematical Geography.[4]

This appears to single out geography for inadequate treatment in a crowded curriculum, and the Committee is informed that heads of schools have been strongly advised to act on this instruction. Whatever justification there may have been in the past, the new position of geography in advanced courses warrants a revision of this circular.

Similarly the Memorandum on Advanced Courses appears to need revision, and the Committee expresses the hope that the Board of Education will take an early opportunity of issuing a Memorandum on the Teaching of Geography in Secondary Schools similar to those on History, English, Science, &c.

The examination of pupils under these Regulations is delegated by the Board to the following approved School Examinations Boards :—

1. Bristol University.
2. Cambridge University
3. Durham University.
4. University of London.
5. Northern Universities Joint Board.
6. Oxford and Cambridge Joint Board.
7. Oxford University.
8. Central Welsh Board.

Of recent years there has been an attempt to standardise these examinations, which has met with a fair measure of success. There is still, however, much divergence of view on the place which geography should occupy in the examinations and in the syllabuses under which the examinations should be held. All the examining bodies group the subjects for the First or School Leaving Examination (age 15-16) into the following :—

I. English group.
II. Language group.
III. Science group.
IV. Miscellaneous group.

Candidates must pass in one or more subjects within each group, as well as the examination as a whole.

Geography in Group I. only is permitted by the Boards of Bristol, London, and Oxford and Cambridge Joint Board.

Geography in Group III. only is permitted by Durham, Northern Universities Joint Board and Oxford.

Geography in Group I. or Group III. is permitted by Cambridge and the Central Welsh Board. It should be noted, however, that by the regulations of Cambridge and the Northern Universities a candidate cannot pass Group III. on geography alone.

The general tendency to include geography in Group I. along with English (compulsory) and history makes it a serious proposition to schools whether geography should not be alternative with history, which is unfortunate considering the complementary value of the two subjects in any scheme of education.

The syllabuses of the eight examining boards are substantially in agreement, and require (i) a general knowledge of the world and especially of the influence of physical conditions on plant and animal life and of the natural environment on the social life and occupations of peoples; (ii) a more detailed knowledge of the British Isles, and (iii) either a detailed knowledge of a special region or a study of several regions in varying detail.

There is, however, a marked difference in the character of the examination questions set on these syllabuses. In the majority, the questions are framed to test 'physical' geography by its application to some regional or economic problem. Others set a 'physical' paper distinct from the 'regional' paper.

The popularity of the subject in the schools may be gauged from the examination statistics for 1921, which if the figures for the Oxford and Cambridge Joint Board are omitted give 27,438 candidates (80 per cent.) taking geography out of 35,224 taking the examination. Even including the figures for the Joint Board, which examines a number of Public Schools, not all of which give geography an important place in the curriculum, the percentage is as high

[4] See, however, Appendix II.

as 73. Under the Central Welsh Board, in 1921, out of 3,319 candidates examined 2,851 offered geography as one of their subjects.

Higher School Certificate.

Great as are the differences in the position which geography occupies in the First or School Leaving Examination, it is still greater in the Higher School Examination. Indeed, the position is so varied that the Committee hopes the new Regulations of the Board of Education permitting it to be a main or principal subject will result in an immediate amendment of the regulations of some of the examining bodies. The regulations for Bristol, Cambridge, Durham, the Northern Universities Joint Board, Oxford and the Central Welsh Board allow geography to form one of the principal subjects in *either* a group of modern studies *or* a group of sciences. London has a group consisting of Geography, Economics and *either* the Economic Development of the Empire *or* Economic History. The regulations of the Oxford and Cambridge Joint Board do not permit it to be taken as a principal subject in any group. The regulation (see Prefatory Note) which states that geography may be taken as a principal subject with history or a science indicates that examination regulations should be framed to allow the subject to be taken in either the 'Science' group or the 'Modern Studies' group.

As an 'additional' or 'subsidiary' subject to any group there is the utmost freedom in almost all cases, so that there is no need for any scholar to break the continuity of his geographical study between the ordinary four-year course and the University.

The Training of Teachers of Geography.

The staffing of schools for geographical studies has in the past presented many difficulties. Formerly it was often customary to use geography for the purpose of levelling up the teaching hours of the general staff, so that the subject was liable to be taken by teachers who had little interest in and less knowledge of it. Of recent years there has been a tendency to concentrate the work into the hands of teachers who have a special interest in geography, and have in many instances made remarkable advances both in their own studies and in the standard of school work.

The Summer Schools held by the Board of Education and by various University authorities have been of special value in assisting those teachers who have taken up geography after entering on their teaching career. Many, too, have taken advantage of the Diploma in Geography of London and other Universities or of the evening schools held in London for internal degrees in geography, so that their academic qualifications have been materially improved.

The most important factor, however, both on the grounds of academic training and on account of the scale of salaries determined by the Burnham Committee, is the establishment of honours schools in geography at the Universities. At present honours schools of geography have been established in the Faculty of Arts in the following Universities: Aberdeen, Aberystwyth, Cambridge (Tripos), Leeds, Liverpool, London (internal and external), and Manchester. At Sheffield the honours school is in the Faculty of Science. The University Colleges of Nottingham, Reading, Southampton, Exeter, and Leicester prepare for the external honours degree of London.

The above Universities in the majority of cases, together with Bristol and Glasgow, make provision for geographical studies, more or less extended, for the ordinary degrees of B.A. and B.Sc. Oxford has a diploma course which may be taken either as a graduate course, or as the equivalent of two of the three subjects required in the final examination for the ordinary B.A. degree, or as part of the preparation for other examinations such as those of the history school and the honours schools of philosophy, politics, and economics. The other Universities make little or no provision at present for courses of study which may be regarded as adequate for those who desire to become teachers of geography.

The courses of study in the various honours schools differ considerably in detail, though the main requirements are the same, the differences arising through the emphasis which is given to particular aspects of the subject, or to the character of the individual study which each school demands from its students. Thus there is general agreement that students of geography should study geology, history, and political economy at least to intermediate standard; that the general principles of geography should be studied with reference to the world as a whole and to certain major regions; that map-reading and interpretation should be an integral part of the geographical course, and that some area should be studied in detail as an introduction to the methods of geographical research. In addition to these purely geographical studies, there are others of an applied character determined generally by the interests or special circumstances of the department. Such are the geography of man, including the distribution of the principal human varieties and the simpler types of human societies; the geography of trade and transport; historical geography; the history of geographical discovery; the geographical distribution of plants and animals; geodesy, surveying, and cartography.

There is among the geographers of this and other countries a consensus of opinion that the first and principal aim of advanced geographical study is an interpretation of the modern world, and to this extent the study has a regional basis. But there are upon the borders, as it were, of this study many fields of research for which a geographical knowledge is such an admirable training that some courses of honours post-graduate work have become specialised in this direction.

For those who intend to be teachers of geography, however, the Universities specified above give adequate tuition in geography and make provision for their training as teachers.

The number of graduates specifically trained in the education departments of the Universities with a view to teaching geography in secondary schools has hitherto been small—partly because, until quite recently, the heads and the governing bodies of secondary schools have, as a body, laid little stress upon professional training as a qualification for their appointments, partly because the provision of academic instruction in geography has been inadequate. In both these respects the situation is now rapidly changing. On the one hand, the Teachers' Registration Council, acting as the organ of the profession, insists upon the importance of post-graduate training for secondary school teachers, the rules of the Burnham Committee encourage it financially, and the Board of Education by permitting four-year students who graduate in honours to be transferred to the secondary training departments have done a great deal to facilitate it; on the other hand, the growth of honours schools of geography, already referred to, should before long remedy the present deficiency of graduates with the academic qualifications presupposed by any effective system of training teachers for teaching the subject in secondary schools.

Institutions which offer post-graduate training in the teaching of geography to students qualified to receive it will probably find it advisable to follow in principle, though with healthy variation in detail, the methods fairly generally pursued in regard to the better established subjects of the curriculum. The prospective teacher of geography must study side by side with the teachers of other subjects the general theory of education and the general principles which determine efficiency in all kinds of teaching; but in addition should receive definite instruction in the special craftsmanship appropriate to his subject. Under the guidance of the University expert (who may in some instances be an experienced school teacher associated for this purpose with the University department) he should be led to review and re-examine the subject-matter of geography from the point of view of its value and use as an educational instrument; should consider the natural stages in the presentation of the subject to growing minds, the character, range, and proper sequence of the topics appropriate to each stage, and the most fruitful methods of teaching them; and should inquire how boys and girls may best be taught to use the arts of map-reading and simple cartography, how observational work and practical geographical measurements may best be conducted, and, in general, how the study of the home region may most effectively be pursued under the conditions of school life and work. In addition, he should learn how instruction in geography may most usefully be correlated with the teaching in other subjects, and may for that purpose attend classes in which the methods of teaching those subjects are discussed.

It is essential that the student's studies in the theory of teaching geography should be closely associated with actual work in school, that he should have the opportunity of watching accomplished craftsmen at work goes without saying; but it is still more important that he should himself teach under expert guidance and criticism in a good secondary school, where, as he feels his feet, a definite if small area of responsibility should be assigned to him, and where he should be able to take part in geographical expeditions and learn, by experience, the practical details of all sides of the art of teaching geography.

Simultaneously therefore with the new Regulations of the Board of Education and the modifications in school examination syllabuses, there is a steadily increasing number of trained geographers leaving the Universities to take up the work. The result undoubtedly will be not only a more thorough and scientific study of the subject, but a general increase of accurate knowledge of the Empire and the rest of the world, which will affect the everyday life of the community through its economic and political relationships with other countries.

APPENDIX I.

The following syllabus has been drawn up merely to serve as a type course based upon the principles enumerated in the Report and having due regard to the requirements of schools as indicated in the many syllabuses actually in use which the Committee carefully considered. The Committee desires to emphasise the fact that this syllabus is of the nature of a suggestion from which all kinds of departures and variations are possible according to the special circumstances of schools.

SYLLABUS OF WORK FOR A SCHOOL

CONTAINING (*a*) PREPARATORY FORMS (FORMS I. AND II.); (*b*) THE NORMAL SECONDARY SCHOOL COURSE (FORMS III. TO UPPER V.); (*c*) ADVANCED COURSE (FORM VI.).

General Principles upon which the Syllabus has been drawn up.

THE *First Form* studies the Homeland from the immediate neighbourhood very carefully, the land not seen or known less intensively. The school for which the syllabus is drawn up is assumed to be situated near to a large open space, with undulating land in a natural condition, so that accurate ideas of geographical terms can be taught and a scale formed by which ideas of other areas may be built up. Theoretically, one should go slowly from the known of the home to the neighbourhood, and work through England and the lands beyond the Channel to the more remote and unknown lands of the world. As a matter of fact, something of the world at large is known very early, and what is beyond the horizon by a few miles is generally as little known as if it were thousands of miles away. Thus in the *Second Form* there is a jump to learn of *the World* as a whole, from the point of view of the homes of its peoples.

The pupils are now ready to make their first simple regional study of the British Isles.

In the *Third Form* those boys who have been through the preparatory forms meet the new entrants who come from the Elementary Schools, about the age of 11½ years, as Free Place Scholarship holders. Both sets make a new beginning at home by considering the British Isles from many points of view. In this year, however, the teacher must be prepared to vary his scheme, and, owing to the varying standards of attainment which he will find among his new pupils, may find it necessary to spend perhaps a whole term on the outlines of World Geography. An alternative course in this year might well be a simple study of the regional geography of the world, with more detailed reference to the British Isles.

The Americas are considered in the *Lower Fourth Form* because they exemplify points in physical geography which can now be appreciated, and also because in North America the European peoples, and especially British people, find scope for their surplus population, so that its study naturally follows that of the British Isles.

Asia and Australia present entirely new problems to the *Fourth Form*. The boys are now ready to make a more systematic study of climate than has hitherto been possible, and it is at this stage that geography can receive considerable help from the science lessons.

In the *Fifth Form* Africa and Europe are taken, most of the threads can be pulled together, the boys can now begin to appreciate what is meant by a natural region, and more attention can be given to the economic conditions of the modern world.

Finally, the normal Secondary School closes in *Form Upper V.*, where the regional geography of the world is revised and special attention is paid to the position of Britain and her Empire among the nations of the modern world. At the end of this year the *First Examination* is taken.

Throughout the whole of the work of the forms mentioned above no hard-and-fast line is drawn between regional geography and general, including physical, geography. There are no separate courses in physical geography, map-drawing, or the observation of weather phenomena. The attempt is made to take these things as far as possible with particular regions which supply good illustrations; to grade the subjects so that they fit into the curriculum of the school as a whole (especially nature study, mathematics, and science) and the capacity of the pupils, and to revise continually the general ideas already learned when studying fresh regions.

In the *Sixth Form* considerable individual work and modified specialisation **can** be introduced with success.

FORM I.

AVERAGE AGE, 9½ YEARS.

Two Lessons per week. No homework.

1. *The Homeland.*

(*a*) Plans (1) of the Geography Room; (2) of the Geography Room, the corridor outside the room, and the class-rooms on the other side of the corridor; (3) of the whole school; (4) of the school, playground, and roads and railway touching it. Further maps of the district are constructed to introduce (i) the routes of the railways and roads close to the school, where they go. and where they cross, (ii) the 'highlands' of the open heath and park land near the school, and the direction of stream-flow. Orientation is emphasised throughout.

(*b*) The foregoing lead on to the idea of the Thames Basin (or other river basin in which the school is situated), the towns in the basin, the hills to north and south.

(*c*) Great Britain very generally. The highlands in the North (Scotland) and West (Wales); the seas round it; a few selected towns.

2. *Other Lands: Mountains, Plains, Coastlands.*

Other Climates: Cold and Wet, Hot and Dry, Hot and Wet.

Other Vegetations: Deserts, Forests, Grasslands.

Maps are made (i) of known areas, to explain and accustom the pupils to the ideas of mapping, and (ii) of unknown areas, to teach further ideas; but there is no abrupt break: the maps merely decrease in scale. Other lands, climates, and vegetations are taught *without* maps, except the globe, and by means of lantern pictures and stereoscopic views. Typical countries are selected—Norway, Switzerland, Greece, Egypt, the Congo Basin, &c.

Observations are made of the shadows cast by the sun at midday throughout the year, for the purpose of suggesting the idea of varying altitude, and of direction.

FORM II.

AVERAGE AGE, 10½ YEARS.

Two Lessons weekly. No homework.

The World and its Peoples.

(i) A few introductory lessons on the globe.

(ii) A study of the peoples of the world following the historical sequence of the unfolding of the various regions.

During this study extensive use will be made of pictures, the electric lantern and stereoscopic views, as well as of stories of travel and discovery by sea and land. The study will follow these lines :—

(*a*) The fertile crescent of Egypt, Syria, and Mesopotamia, with their ancient civilisation, based on the flood plains and the winter rains, forms an excellent starting-point because of the wealth of ideas already learned from Biblical narratives.

(*b*) Within the crescent nomad shepherds pastured their flocks or caravans, followed the age-long beaten track between the desert and the sown, while boatmen plied their trade on the waters of the Eastern Mediterranean.

(*c*) Euro-Asia as a larger study of a similar kind—round the interior grass-lands of horsemen and herdmen of Central Asia are the fertile forest-fringe lands of the cultivators.

(*d*) The riches of the East and West passed across the continent by the combined routes of sea and land until the European seamen searched the unknown ocean for a seaway to the East.

(*e*) These new ocean routes brought the European to the homes of other peoples—the negroes of Africa, the Indians of America, the Eskimo and Samoyede of the cold North, and the poverty-stricken Blackfellow of Australia.

(*f*) Some of these discovered lands became new homes for Europeans where wheat and meat and raw materials were obtained for Europe, which, with the discovery of coal, became the home of miners and manufacturers.

(*g*) The world became a great market where Western Europe and Eastern North America sell their manufactured goods and buy food and raw materials.

The study of human activity in each case is based on a simple geographical study of the region.

Observations to be made at 9 A.M. throughout the year of the direction of the wind and of the character of the weather. The midday altitude of the sun measured in degrees (in conjunction with the geometry course to introduce the idea of degrees).

FORM III.

Average Age, 11 Years.

Two Lessons weekly. One homework (not exceeding half-hour) weekly.

The British Isles.—The descriptive geography of the regions of Britain along the following lines :—

(*a*) The British seas.
(*b*) The highlands of the North and West.
(*c*) The English plain.
(*d*) Seas, highland and plain as related features in the development of a national life.
(*e*) Rural England. Agricultural life. The villages and the market centre. The regions of the English plain.
(*f*) South-west England.
(*g*) The hills and vales of Wales.
(*h*) Moorland and Lakeland.
(*i*) The industrial regions of England.
(*j*) The Scottish Lowlands and Uplands.
(*k*) The Scottish Highlands.
(*l*) Ireland.
(*m*) Communications of Britain.
(*n*) Britain and the world.

Bartholomew's half-inch maps are used as wall-maps to introduce the idea of map-reading. Now that Highlands and Lowlands are conceived as areas, the pupils are introduced to simple studies of contour lines. Contour lines are constructed and sections are drawn. For this work visits are paid to a convenient local prominence, and each boy is provided with 1-in. and 6-in. map of the district. Many exercises in reading this map are set and worked, and in this part of the work the help of the teacher of practical mathematics is enlisted.

Daily observations are made of maximum and minimum temperatures and wet and dry bulb temperatures. These are correlated (in connection with the science lessons) with the observations made by Form II. The records are plotted in graphic form in the mathematics lesson.

FORM LOWER IV.

Average Age, 12 Years.

Two Lessons weekly. One homework (half-hour) weekly.

The Americas.—The larger area of North America is considered in detail in a similar way to that in which Britain was treated in the previous year. South America provides many sharp contrasts, but also some comparisons.

In addition the pupils are introduced to

(i) Some idea of the formation of mountains, plateaus, and plains.

(ii) The work of rivers as illustrated on a large scale by the Colorado and the Mississippi, and as seen by actual observation of the local streams. (Even small streams are often most suitable.)

(iii) Some idea of geological history as exemplified in (*a*) the Coal Period, (*b*) the Great Ice Age.

(iv) The principles of the construction of maps from statistics, as shown by the construction of population maps of different areas of the United States.

(v) The use of curves of rainfall, temperature, &c.

The daily reading (at 9 A.M.) of the rain-gauge.

FORM IV.

Average Age, 14 Years.

Three Lessons weekly. Two half-hour homeworks weekly.

1. *Studies in Climate.*—Size and shape of the earth; movements of the earth; day and night; the seasons; the annual and seasonal distribution of temperature, pressure, and winds and rainfall; ocean currents; natural vegetation.

(In actual teaching this is presented in the form of a series of problems usually consisting of the making of a map to illustrate some important distribution and the writing of a clear account of what the map shows. The work is done partly at school and partly at home.)

2. *The Regional Geography of Asia*, with special reference to the application to Asia of the principles learnt during the climatic studies. The following areas will be taken for more detailed regional studies: The N.W. Lowlands; the Land of the Five Seas; the Monsoon Lands (India, Indo-China, China, Japan); the Interior Plateaus; the East Indian Archipelago.

3. *Australasia* is rapidly taken, and is treated in such a way as to test whether the principles already learned have been mastered.

During this year the following topics of Physical Geography receive special attention: Fold and block mountains; plateaus and plains (with general geography of Asia); rift valleys (with Land of Five Seas); volcanoes (with Japan); deltas (with Ganges, &c.); river work (Chinese rivers).

The barometer is read daily (at 9 A.M.), and is corrected for height and temperature.

FORM V.

Average Age, 15 Years.

Three Lessons weekly. Two weekly homework periods (half-hour each).

1. *The detailed General and Regional Geography of Africa and Europe.*

In connection with Africa an attempt is made to teach definitely the idea of the natural region.

The general physical and climatic geography of Africa gives a good opportunity for revising the general principles of climatology, especially of those facts associated with the apparent seasonal migration of the sun. In the regional studies, the economic point of view is emphasised, and stress is laid on the relations between the natives and their European administrators.

The regional method is also pursued in Europe, but the political unit is the unit for teaching purposes. (In Africa the teaching unit is the natural region.) Whenever suitable the relations between history and geography are carefully noted, and comparisons between different countries are studied in detail.

2. In connection with the British Isles the opportunity is taken to study continental shelves and tides. The two continents also give ample opportunities for the revision of rift valleys, types of mountains and lakes, the work of ice-sheets and glaciers, the influence of rock character on surface features, &c.

3. During the study of the British Isles practical map exercises of the following types are set: the construction of January and July temperature maps from the statistics given in the Appendix to the Daily Weather Report; wind force and rainfall diagrams for periods of one year or over (using same sources); the construction of population, agricultural, industrial, and trade maps from information given in agricultural reports, trade returns, &c.

4. *Map Studies.*—A short course of study, in the Summer Term, of the area shown on one of the one-inch sheets of the Ordnance Survey. Some conveniently situated area is selected (*e.g.* the Reigate Sheet for London Schools), and during the term at least one whole-day visit is paid to study some of the special features of the area at first-hand.

FORM UPPER V.

Average Age, 16 Years.

Three Lessons weekly. Two weekly homework periods.

In this form the First Examination is taken, and its requirements must be borne in mind. The world has been covered by the end of the previous year, and the boys can normally take the examination 'in their stride' without special preparation. Some parts of the world, however, have not been taken for some time and must be re-taught; others must be revised.

1. The Regional Geography of the Americas, with special attention to the principal centres of population.
2. The study of the Daily Weather Report (including practical work in analysis of the synoptic charts), leading to a revision of the British Isles and Europe.
3. The monsoon lands of Asia.
4. A rapid revision of the outlines of world geography leading to a division of the world into its major natural regions. Special emphasis to be given to the more important parts of the British Empire not already taken above.

Throughout the revision work mapping exercises are extensively used, and memory maps are demanded to test whether the work has been mastered. Mere copying of maps is not required, but the boys are trained to map geographical facts with speed, clearness, and accuracy. In addition, essays on geographical subjects are set, and very simple research problems are given to individual boys or groups of boys.

Note.—If there were no advanced work in geography the opportunity would be taken in this year to provide a short course of lessons on (*a*) the making of maps, (*b*) map projections or network.

FORMS VI. AND UPPER VI.

Advanced Courses.

Syllabuses for three types of courses are given.

Course 1.—In this course Geography is a subsidiary subject in a Science and Mathematics Course. Three teaching periods per week. Two years' course, 'additional' paper taken at the Second Examination.

(1) *Physical Geography.*

(*a*) Elementary studies in meteorology and climatology, geomorphology.
(*b*) Map-making and map projections.

(2) *Regional Geography.*

(*a*) The outlines of the economic geography of the world.

(*b*) The detailed geography of one of the following regions: The Mediterranean Region, Western Europe, the Asiatic Monsoon Lands.

(3) *The Geographical Background of History, illustrated by one of the following*:—

(i) The world relations of history and geography; (ii) The historical geography of the British Isles or of Europe; (iii) The history of geographical discovery.

Course 2.—In this two years' course Geography is a subsidiary subject in a Modern Studies' Course. Four periods per week are allowed. At the end of the course geography is taken as a compulsory subject in the London Inter. B.Sc. Econ. or Inter. B. Com. Examination.

A. *World Geography.*

1. The distribution of the sources of power—coal, oil, water—especially in relation to the New States of Europe.
2. The distribution of foodstuffs, and raw material for the chief manufacturing industries.
3. Trade routes by land and sea, with special reference to the natural ways of Europe and their modification by tunnel and canal.
4. The distribution of the population. Regions in Europe which could support greater numbers. Regions which export people, and the lands to which they go.

B. *Regional Geography.*

1. The major natural regions of the world.
2. Detailed study of the industrial regions of the world, especially W. Europe and Eastern States of N. America.
3. Markets and localisation of industries; to what extent this is illustrated in Europe.
4. The geographical aspect of production and exchange in Europe and the New World.
5. The economic position of the Great Nations, especially the British Empire, France, U.S.A., Japan, Germany.

The teaching includes a thorough study of the physical geography necessary for an understanding of the various topics, and the opportunity is taken of comparing an area of rapid development in modern times (*e.g.* Argentina or Australia) with an area of long history (*e.g.* the Mediterranean Region or China or India).

Course 3.—In this course geography is a main subject in an advanced course. The general lines are those of Course 1, but the work is more detailed, and there is more opportunity for individual and practical work. Six hours per week are given to the subject.

[The syllabus given below is that recently adopted by the Cambridge Local Examinations Syndicate for the Higher Certificate Examination. The subject may be taken *either* in Group II. (with History) or Group IV. (with a Science). This does not differ materially from the regulations of other Examinations Boards which make provision for Geography as a principal subject.]

I. Physical Geography.

The Atmosphere.—Its composition and extent. The temperature and pressure of the atmosphere. Isotherms and isobars. Estimation of altitude by the use of the thermometer and barometer. Barometric gradients. Influence of atmospheric pressure on winds and weather. Weather charts; methods of forecasting weather. Isothermal and isobaric charts of the world. Movements of the air. The aqueous vapour in the atmosphere; evaporation; modes of condensation. Dew and its formation; dew-point. Fogs, mists, clouds, rainfall, snow. Different forms of clouds. Measurement of rainfall. Climate, and the conditions determining it. The climatic characters of different regions of the earth. The influence of climate and soil on the distribution of the chief animal and vegetation types.

The Hydrosphere.—The distribution and depths of the oceans and seas. The general contour of the ocean floor, and the methods of representing it on maps; comparison with the contour of the land. Composition of sea-water. Temperature of the oceans and enclosed seas. Movements of the sea; waves, currents, tides, and their causes. Tide charts. The courses of the main ocean currents. Marine deposits, terrigenous and pelagic; their character, distribution and origin. Coral reefs and coral islands.

The Lithosphere.—Land masses, their outline and shape. Character and origin of the principal types of islands. Mountains, valleys, plains, deserts; watersheds; springs, rivers, lakes, glaciers, ice-sheets, icebergs. The changes produced on the land by rain, rivers, and other surface agents; by underground water; and by the sea. Coast-lines. Internal drainage areas and salt-lakes. The characters and origin of the various deposits formed on land. The nature and distribution of volcanoes; the principal types of volcanoes; fissure eruptions. Earthquakes; slow movements of the land. Evidence of elevation and depression.

Map Work.—The method of construction (treated simply), and the consequent advantages for some purposes and disadvantages for other purposes, of the more important map projections. The methods of representing the relief of the land and the various topographical features on maps. The making of a map of a small area.

II. The Regional, Political and Economic Geography of the World.

The major 'Natural Regions' of the world. The geographical conditions which make it possible to divide the world into natural regions. Comparisons between regions. The distribution of the chief agricultural and mineral products and of industries as controlled by physical conditions. The influence of geographical factors upon the organisation of commerce, the development of communications and transport, the great trade routes, the growth of towns and the distribution and density of population. The interaction of physical and human conditions with economic activities. Geographical factors affecting the development, unification, frontiers, and political relationships of States.

A detailed knowledge of the whole world will not be required, but candidates will be expected to have paid particular attention to the British Isles and the more important parts of Europe and the British Empire.

III. The Detailed Geography of two Special Regions.

A. *Either* the Mediterranean Region *or* the Monsoon Lands of Asia.

In these lands of long history, in addition to the detailed regional treatment, the following points should receive special attention. The relations between geography and history. The modification of geographical values in the course of history. The geographical factors favourable and unfavourable to the early development of civilisation. Geographical conditions as favouring conquest or defence, determining routes of invasion, and affecting subsequent settlement.

B. *Either* the United States of America *or* Australia.

In these lands of comparatively recent development under modern conditions, in addition to the detailed treatment the development of the region should be compared with that of the selected region of long history, and particular attention should be given to the problems involved in its future development.

Practical Work.

It will be assumed in setting the papers that attention has been given to practical work along the following lines.

I. *Physical Geography.*—Observations of temperature of the atmosphere and the conditions affecting variations of temperature. Making isotherm maps from furnished data. Determination of dew-point. Use of the barometer. Finding heights by means of the barometer. Making isobar maps from furnished data. The prediction of weather from weather charts and observations. Observations of the direction and strength of winds. Observations of rainfall by means of the rain-gauge. The study of rainfall maps. Determination of the amount of snow-fall, and the amount of water produced by melting a given amount of snow. Observation of ground temperature. Observation of clouds and their different forms. Observation of rainbows.

Study of pilot charts and other maps showing (1) depths of the sea, (2) ocean currents. Study of tide-charts and tide-tables[5]; relation of tides to the movements of the moon. The determination of the density of sea-water.

Drawing sections from contour maps. Study of maps of the school district drawn to various scales. Making map of small area in the neighbourhood. Study of natural features of the country in the neighbourhood of the school. Observations of the flow of a stream and of the amount of matter carried in suspension and in solution. Relation of the shape of the coast-line to the nature of the rocks, direction of currents, &c. Forms of cliffs. Evidence of slow movements of the land seen near the coast.

II. *Regional and Economic Geography.*—The construction of population and economic maps, graphs, &c., from census and other returns. The correlation of simple geological, orographical, climate, population and economic maps. The study of colonial and consular reports, commercial reports, and statistics.

APPENDIX II.

Extract from recent Board of Education Pamphlet No. 37, 'The Teaching of History':—

'*Connections with Geography.*—We have not found, nor have we thought it desirable to recommend, any forced or artificial relation between the history taught and the other subjects in the curriculum. Of all these subjects geography is clearly the closest and offers the most fruitful ground for interesting matter, sometimes introductory, sometimes complementary, to the history lessons. The connection is by no means always overlooked, but we have often noticed that the history work would be much improved by a better grounding in geography. This connection has received more attention in French schools than in our own, and, among ourselves, recent attempts at promoting "Regional Surveys" are a move in the right direction. To those teachers who are specially interested in World History, the connection with geography offers special attractions, for in geography we have always aimed in our schools at some knowledge of the whole world, and if the history, as we found in one case, is more closely connected with the geography, it tends also to become the history of the world. In this case the work in the two lowest forms was introductory to a systematic treatment both of general World History and World Geography. In the Middle Forms the history was dealt with in chronological periods, English and general history receiving parallel treatment, and a two years' course on the history of exploration was given to the third and fourth forms with a fortnightly lesson. This aspect of history offers a valuable link between the two subjects, and in the school referred to the work was completed in the Upper Forms by essays of considerable scope on topics of present interest.

'The influence of geography is, of course, a matter of profound and constantly recurring importance, and should receive more attention than it often does. Trade routes and naval and military history are obvious examples. The fact that geography too often disappears from the curriculum of our secondary schools before the later years of the historical course is from this point of view a disadvantage.'

[5] As given in Whitaker's and other almanacks.

On Certain of the More Complex Stress Distributions in Engineering Materials.—*Report of Committee* (Prof. E. G. COKER, *Chairman*; Profs. L. N. G. FILON *and* A. ROBERTSON, *Secretaries*; Profs. A. BARR, GILBERT COOK, *and* W. E. DALBY, Sir J. A. EWING, Mr. A. R. FULTON, Dr. A. A. GRIFFITHS, Prof. J. J. GUEST, Dr. B. P. HAIGH, Profs. Sir J. B. HENDERSON, C. E. INGLIS, F. C. LEA, A. E. H. LOVE, *and* W. MASON, Sir J. E. PETAVEL, Dr. F. ROGERS, Dr. W. A. SCOBLE, Mr. R. V. SOUTHWELL, Dr. T. E. STANTON, Mr. C. E. STROMEYER, Mr. G. I. TAYLOR, *and* Mr. J. S. WILSON).

Introduction.

THE Committee submit as their Report the following contributions embodying: (1) A report on Stresses in Bridges; (2) accounts of recent researches on alternating stress; (3) further investigations on the Thermodynamic theory of fatigue and rupture; (4) an account of a new graphical method of obtaining the stress system in a plate from photo-elastic observations; (5) a discussion of the stresses in reinforced pipes.

I. The Stresses in Pipes reinforced by Steel Rings. By Prof. Gilbert Cook, D.Sc.

II. The Graphical Determination of Stress from Photo-Elastic Observations. By Prof. L. N. G. Filon, F.R.S.

III. Thermodynamic Theory of Mechanical Fatigue and Hysteresis in Metals. By Prof. B. P. Haigh, D.Sc., M.B.E.

IV. Stresses in Bridges. By J. S. Wilson and Prof. B. P. Haigh, D.Sc., M.B.E.

V. The Distribution of Stress in Round Bars under Alternating Torsion or Bending. By Prof. W. Mason, D.Sc.

VI. The Repeated Bending of Steel Wire. By Dr. W. A. Scoble.

The Committee ask for reappointment, with a grant of 50*l*.

I.

The Stresses in Pipes reinforced by Steel Rings.

By Prof. GILBERT COOK, *D.Sc., King's College, London.*

IN a contribution to the Report of this Committee for 1921 the author has given the results of a theoretical and experimental investigation of the influence of a flange on the stress distribution in a pipe under internal pressure. The close agreement between the calculated and observed stresses proved the method of analysis to be adequate for the purpose, and may justify its application to the analogous problem of the reinforced steel pipe.

In large hydro-electric installations working under high heads the design of the pipe line presents considerable difficulties. For a given discharge and head at the power station, considerable economy in material is effected by increasing the size and reducing the number of the pipes, but in a plain welded pipe a limit is imposed to the size by the maximum thickness which can be satisfactorily welded, which may be taken to be about 1½ inches. A type of construction recently introduced whereby large diameters may be used for high heads without an excessive pipe thickness consists in reinforcing the pipe by means of steel rings shrunk on at intervals along the pipe. The author has not been able to discover any published account of the method by which the strength of such pipes may be estimated. The investigation which follows has several points of interest, amongst these being the question as to the conditions under which a reinforced pipe may be made lighter than a plain pipe even when no difficulties of welding would be encountered. It also leads to some unexpected conclusions regarding the relation between the spacing of the rings and their effectiveness.

It was shown in the previous paper that the radial displacement at any point of the pipe wall is given by the equation

$$\frac{E \cdot m^2}{m^2 - 1} \cdot \frac{t^3}{12} \cdot \frac{d^4 z}{dx^4} + \frac{Etz}{R^2} = P,$$

where R is the mean radius of pipe, t the thickness, P the internal pressure, E Young's Modulus, $\frac{1}{m}$ Poisson's Ratio, and z the radial displacement at any point x measured along the axis from some fixed origin, the longitudinal stress being assumed zero. The solution of the equation is

$$z = \cos nx\,(A \cosh nx + B \sinh nx) + \sin nx\,(C \cosh nx + D \sinh nx) + \frac{PR^2}{Et} \quad . \quad (1)$$

where $n = \sqrt[4]{\frac{3}{t^2R^2} \cdot \frac{m^2 - 1}{m^2}} = \frac{1 \cdot 285}{\sqrt{tR}}$ if $\frac{1}{m}$ for steel be taken as $0 \cdot 3$. If l be the

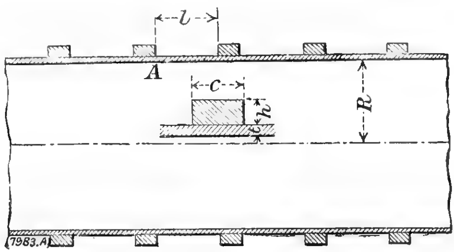

FIG. 1

length of the pipe between successive rings (fig. 1) and x be measured from A as origin, then, assuming that the pipe wall remains cylindrical under each ring,

$$\frac{dz}{dx} = 0 \text{ for } x = 0 \text{ and } x = l$$

and

$$z = z_0 \text{ for } x = 0 \text{ and } x = l,$$

where z_0 is the radial displacement at the ring.

Evaluating the constants A, B, C, D, equation (1) becomes

$$z = \frac{PR^2}{Et} - \left(\frac{PR^2}{Et} - z_0\right)(\cosh nx \cos nx - H \sinh nx \cos nx + H \cosh nx \sin nx - L \sinh nx \sin nx) \quad . \quad . \quad . \quad . \quad (2)$$

where

$$H = \frac{\cosh nl - \cos nl}{\sinh nl + \sin nl}, \quad L = \frac{\sinh nl - \sin nl}{\sinh nl + \sin nl}$$

In determining the radial displacement at the ring it will simplify the work if, as will always be the case in practice, the radial thickness h of the ring is small compared with R, and the small error involved in taking R to be the radius of the ring be neglected.

Considering the portion of the pipe in contact with the ring, the forces acting upon it in the radial direction will be (1) the internal pressure, (2) the external pressure produced by the ring, and (3) the shearing force across the pipe wall at each side of the ring. Denoting by P the pressure per unit area exerted by the ring on the pipe, and by F the shearing force per unit length of the circumference, the equivalent pressure tending to increase the radius will be

$$P - p + \frac{2F}{c}$$

being the width of the ring, and therefore

$$z_0 = \frac{R^2}{Et}\left(P - p + \frac{2F}{c}\right) \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The value of P depends on the amount of 'shrinkage' allowed in fitting the rings, and on the radial displacement z_0. Let s be the shrinkage, *i.e.* the amount by which the radius of the ring is less than that of the pipe when both are in the unstressed state. Then the actual stress in the ring is

$$\frac{E(s + z_0)}{R}$$

and

$$p = \frac{E(s + z_0)h}{R^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Again, applying the method described in the previous paper to the determination of the shearing force F, we have

$$F = -\frac{Em^2}{m^2 - 1} \cdot \frac{t^3}{12} \cdot \frac{d^3z}{dx^3}$$

which from equation (2) leads to

$$F = \frac{Em^2}{m^2 - 1} \cdot \frac{t^3}{3} \cdot \left(\frac{PR^2}{Et} - z_0\right) Hn^3 \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Substituting the values of p and F given by equations (4) and (5) in equation (3), we obtain

$$z_0 = \frac{PR^2 - Esh + \frac{2R^2}{c} \cdot \frac{m^2}{m^2 - 1} \cdot \frac{t^3}{3} \cdot PR^2 \cdot Hn^3}{E(t + h) + \frac{2R^2}{c} \cdot \frac{Em^2}{m^2 - 1} \cdot \frac{t^3}{3} \cdot Hn^3}$$

$$= \frac{cPR^2 - cEsh + 1{\cdot}55\, PR^2\sqrt{tR}\,.H}{cE(t + h) + 1{\cdot}55\, Et\sqrt{tR}\,.H}$$

The radial displacement z at any point is then obtained by substitution in equation (2), and the circumferential stress

$$q = \frac{Ez}{R}$$

In all cases of any practical importance q will be greatest at the point midway between consecutive rings, and an expression for its value at this point may be more conveniently obtained by determining the constants A, B, C, D in equation (1), taking the middle point as origin, so that the boundary conditions are

$$z = z_0 \text{ and } \frac{dz}{dx} = 0 \text{ for } x = \pm\frac{l}{2}$$

We then obtain, for the radial displacement at the centre, where $x = 0$,

$$z^1 = \frac{PR^2}{Et} - M\left(\frac{PR^2}{Et} - z_0\right) \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where

$$M = \frac{\sinh\frac{nl}{2}\cos\frac{nl}{2} + \cosh\frac{nl}{2}\sin\frac{nl}{2}}{\cosh\frac{nl}{2}\sinh\frac{nl}{2} + \cos\frac{nl}{2}\sin\frac{nl}{2}}$$

and the stress q^1 at the centre is given by

$$q^1 = \frac{Ez^1}{R}$$

$$= \frac{PR}{t} - M\left\{\frac{PR}{t} - \frac{1}{R} \cdot \frac{cPR^2 - cEsh + 1\cdot55\,PR^2H\sqrt{tR}}{c(t+h) + 1\cdot55\,tH\sqrt{tR}}\right\}$$

$$= \frac{PR}{t} - \frac{Mch}{c(t+h) + 1\cdot55\,Ht\sqrt{tR}}\left(\frac{PR}{t} + \frac{Es}{R}\right) \quad . \quad . \quad . \quad (7)$$

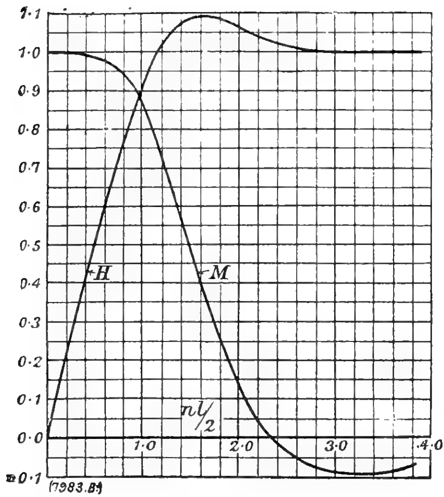

FIG. 2

The values of M and H are plotted in fig. 2 on a base of $\frac{nl}{2}$. Given the radius R and thickness t of the pipe, and the distance apart l of the rings,

$$\frac{nl}{2} = 0\cdot642\,\frac{l}{\sqrt{tR}}$$

the values of M and H may be read off from fig. 2, and the maximum stress q^1 readily obtained from equation (7).

The stress that would be produced in a pipe of the same dimensions without reinforcing rings is equal to $\frac{PR}{t}$, and it would appear, therefore, in order that the rings should have any strengthening effect, that M must have a positive value greater than zero. It will be seen from fig. 2 that this is only the case when $\frac{nl}{2}$ is less than 2·36,

or $$l < 3\cdot66\sqrt{tR}.$$

This limiting length is independent of the amount of shrinkage given to the rings. When l is greater than $3\cdot66\sqrt{tR}$ and less than $8\cdot5\sqrt{tR}$, M has a negative value, and the tensile circumferential stress is greater than would occur in a plain tube of the same thickness. It will further be seen from equation (7) that under these conditions an increase in the shrinkage allowance results in an increase in the tensile stress between the rings. Evidence of a similar effect was clearly shown by the experiments described in the previous paper, the stresses being increased by a constraint which would, at first sight, be expected to reduce them.

Through the courtesy of the Chief Electrical Engineer to the Department of Public Service, City of Los Angeles, the author has been supplied with details of the dimensions of a reinforced pipe which forms part of the pipe line to the power station of that city, and it will be instructive to investigate the stresses which may occur in it under certain assumed conditions.

The internal diameter of the pipe is 80 in., and the thickness 0·63 in. The reinforcing rings are 4·45 in. wide by 1·575 in. thick, and are spaced 11·05 in. centre to centre, leaving an unsupported length of pipe equal to 6·60 in. The working pressure is stated to be 642 ft. of water, or 278 lb. sq. in. For this case we have

$$n = \frac{1\cdot285}{\sqrt{t\mathrm{R}}} = 0\cdot255,\ \frac{nl}{2} = 0\cdot841,\ \mathrm{H} = 0\cdot800,\ \mathrm{M} = 0\cdot925.$$

The circumferential stress which would be produced in a similar pipe without reinforcing rings would be

$$\frac{\mathrm{PR}}{t} = 17{,}900 \text{ lb. sq. in.}$$

The actual maximum stress in the pipe, from equation (7), is

$$q^1 = 0\cdot528\frac{\mathrm{PR}}{t} - 0\cdot472\frac{\mathrm{E}s}{\mathrm{R}}$$

The stress q_0 in the ring is most readily obtained from equation (6); thus

$$z_0 = \frac{\mathrm{PR}^2}{\mathrm{E}t} + \frac{1}{\mathrm{M}}\left(z^1 - \frac{\mathrm{PR}^2}{\mathrm{E}t}\right)$$

and

$$q_0 = \frac{\mathrm{E}(s + z_0)}{\mathrm{R}} = 0\cdot490\left(\frac{\mathrm{PR}}{t} + \frac{\mathrm{E}s}{\mathrm{R}}\right)$$

The author has no information regarding the amount of shrinkage allowed for the rings. The manner in which, according to this theory, the stress in the rings and the maximum stress in the pipe vary with the initial shrinkage is shown in Table I.

TABLE I.

Initial Shrinkage s (in.).	Stress in Rings q_0 (lb. sq. in.).	Max. Stress in Pipe q^1 (lb. sq. in.).
0·000	8,780	9,450
0·002	9,500	8,750
0·004	10,230	8,060
0·006	10,950	7,360
0·008	11,680	6,670
0·010	12,400	5,970
0·013	13,490	4,930
0·016	14,570	3,880
0·020	16,020	2,490

Assuming a maximum working stress of 6 tons per sq. in. in the rings, the shrinkage would require to be 0·013 in., but under these conditions the maximum stress in the pipe, viz. 4930 lb. sq. in., would appear to be unnecessarily small. The weight per foot of the reinforced pipe is 1090 lb. The thickness of a plain pipe designed to carry the same pressure with a stress of 6 tons per sq. in. would be 0·842 in., and its weight 722 lb. per foot.

If a working stress of 6 tons per sq. in. be assumed for both the pipe and the rings, the working pressure may be 408 lb. sq. in., and the shrinkage necessary 0·0014 in. To sustain this pressure a plain pipe would weigh 1059 lb. per foot, which is still lighter than the reinforced pipe. It is, of course, evident that for a given maximum stress and pressure a plain pipe must have the advantage in weight owing to the fact that the stress is uniformly distributed through the material.

The possibility of allowing a higher working stress in the rings than would be safe for the pipe does, however, enable a reinforced pipe to be made lighter than a plain pipe, provided that the rings are sufficiently close together. This is shown by Table II., which gives the results of a calculation based on the dimensions of the Los Angeles pipe, assuming a stress of 10 tons per sq. in. for the rings and 6 tons per sq. in. for the pipe. In this table the pressure and the initial shrinkage required to produce these stresses are given for various distances apart of the rings, and the weights per foot of the reinforced pipe and a plain pipe to carry the same pressure with a stress of 6 tons sq. in. It will be seen that the spacing of the rings must be less than 12 in. in order to obtain a lighter pipe.

TABLE II.

Distance between Rings (clear) l (in.)	Initial Shrinkage required s (in.)	Working Pressure P (lb. sq. in.)	Weight per foot.	
			Reinforced Pipe (lb.)	Plain Pipe (lb.)
3·0	0·0122	720	1350	1890
5·0	0·0131	628	1180	1645
6·6	0·0145	541	1085	1410
9·0	0·0187	448	988	1170
12·0	0·0258	345	905	896
18·5	0·0394	209	800	536
25·1	0·0425	175	740	450
43·0	0·0395	209	595	536

II.

On the Graphical Determination of Stress from Photo-Elastic Observations.

By Prof. L. N. G. FILON, *M.A., D.Sc., F.R.S., University College, London.*

1. In the 1914 Report of this Committee various methods were given by Prof. Coker and the author for obtaining the stresses in a plate of transparent material strained in its own plane from the 'isochromatic' and 'isoclinic' lines (*B.A. Report*, 1914, pp. 201–210). It was there shown that the isoclinic lines, together with the conditions at the boundary, theoretically determine the stress-system completely. Before, however, this determination can be carried out, it is necessary to fit exact functional relations to these isoclinic lines, and this is a very difficult matter in practice.

In the same report a method was given whereby the stresses $\widehat{xx}$, $\widehat{yy}$, $\widehat{xy}$ could be derived from a knowledge of both the isoclinic and the isochromatic lines. If P, Q are the principal stresses at any point, and the stress P makes an angle ϕ with the x-axis, then

$$\widehat{xy} = (P - Q) \sin \phi \cos \phi \qquad (1)$$

and is thus known everywhere.

Step-by-step integration of the stress-equations

$$\frac{\partial \widehat{xx}}{\partial x} + \frac{\partial \widehat{xy}}{\partial y} = 0, \quad \frac{\partial \widehat{xy}}{\partial x} + \frac{\partial \widehat{yy}}{\partial y} = 0 \qquad . \quad . \quad . \quad . \quad . \quad (2)$$

along straight lines parallel to the axes then gives $\widehat{xx}$ and $\widehat{yy}$ at every point if their values (as is usually the case) are known at the boundary.

The weakness, however, of this last method in practice is that the observations are never really accurate enough for the differential coefficients $\frac{\partial \widehat{xy}}{\partial x}, \frac{\partial \widehat{xy}}{\partial y}$ to be determined with sufficient exactness from the values of $\widehat{xy}$ given by (1), using the observed values of ϕ and $P - Q$.

For these reasons neither of the methods given in the report referred to has been employed in practice to obtain the stress-system.

The method at present generally used is one which has been described fully by Prof. Coker in various places, in particular in his Presidential Address to Section G of the British Association in 1914 (*Report*, p. 495), and which was originally suggested by Mesnager. It consists in obtaining the sum $P + Q$ of the average principal stresses in the plane of the plate by measuring the lateral contraction of the plate at the point in question.

This method has given good results, but it is not, from the theoretical standpoint, entirely unexceptionable, for in the calculation it is assumed that the material is perfectly elastic, with a definite Poisson's ratio, which has to be measured by a separate experiment. But, as a matter of fact, the experiments of Filon and Jessop (*Phil. Trans.*, A., vol. 223, pp. 89–125) have shown that celluloid exhibits considerable strain creep for limits of stress well below those which occur in the large majority of photo-elastic experiments, and this introduces an undesirable element of uncertainty into the results, unless, as in Coker's investigations, the material employed is selected with the greatest care.

Moreover, it should theoretically be possible to deduce the stresses completely from observation of the isoclinic and isochromatic lines alone, and the introduction of a strain measurement really brings in superfluous data, with a possibility of inconsistencies which it may be difficult to trace to their source.

Finally, the measurement of such minute lateral contractions is one of extreme delicacy, and very few investigators have at their disposal the necessary apparatus for carrying it out.

For the above reasons it appears of importance to describe in some detail a practical method of deriving the stresses in a transparent plate directly from the isoclinic and isochromatic lines, and to give an actual example of its application.

It is believed that this method is free from the defects inherent in the other method of step-by-step integration, described in the 1914 *B.A. Report*, p. 206, and referred to previously.

2. The method is based upon equations given by A. Mesnager (*Annales des Ponts et Chaussées* (partie technique); Sér. 9, tome 16, vol. 4, pp. 135–186) for the space-rates of change of the principal stresses, taken along the lines of principal stress.

If we denote by s_1, s_2, arcs taken along the lines of principal stress corresponding to stresses P, Q respectively (fig. 3), ds_2 being obtained from ds_1 by a counter-clockwise rotation of 90°; and if ρ_1, ρ_2 are the radii of curvature of the two lines of principal stress, being measured positive when the tangents to the curves rotate counter-clockwise as the arcs s_1, s_2 increase, we have the equations

$$\frac{\partial P}{\partial s_1} + \frac{P - Q}{\rho_2} = 0 \qquad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\frac{\partial Q}{\partial s_2} + \frac{P - Q}{\rho_1} = 0 \qquad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

These equations are very readily obtained by considering the equilibrium of a 'curved elementary rectangle' bounded by four near lines of principal stress, and expressing the conditions that the total force resolutes parallel to the tangents to the lines of principal stress at one corner A are zero, it being assumed that the plate is under no 'body-force.'

These equations, it will be noted, are quite independent of stress-strain relations, and hold equally in a plastic and in an elastic solid.

If we start from a point O, where the P-stress is P_0, and proceed along the corresponding line of principal stress to any point A, we have, integrating (3),

$$P = P_0 - \int_0^A (P - Q)\, ds_1/\rho_2 \quad . \quad . \quad . \quad . \quad (5)$$

And, similarly, if we proceed from O along a line of Q-stress to a point B, we have

$$Q = Q_0 - \int_0^B (P - Q)\, ds_2/\rho_1 \quad . \quad . \quad . \quad . \quad (6)$$

Now there are two ways in which we may conveniently compute the integrals on the right-hand sides of (5) and (6). Call ϕ as before the angle which ds_1 makes with the positive direction of the axis of x.

Then $$1/\rho_2 = \frac{\partial \phi}{\partial s_2}.$$

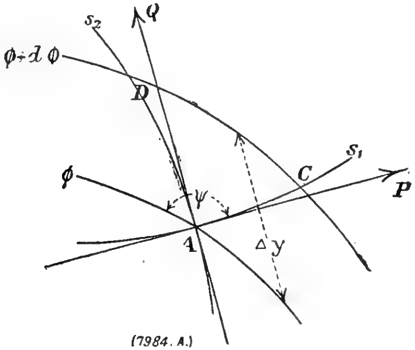

Fig. 3

Now consider a point A (fig. 3) through which passes the isoclinic of parameter ϕ, and let CD be a near isoclinic of parameter $\phi + d\phi$, which meets the line of P-stress through A at C and the line of Q-stress through A at D. Then

$$1/\rho_2 = d\phi/\text{AD},$$

and $$ds_1 = \text{AC}. \quad \therefore ds_1/\rho_2 = d\phi \times (\text{AC}/\text{AD}).$$

Let ψ be the angle through which the line of P-stress has to be rotated (counter-clockwise) in order to bring it upon the isoclinic.

Then from fig. 3, AD/AC $= -\tan \psi$, and thus

$$P = P_0 + \int_{\phi_0}^{\phi} (P - Q) \cot \psi d\phi \quad . \quad . \quad . \quad . \quad (7)$$

Equation (6) will then take the symmetrical form

$$Q = Q_0 + \int_{\phi_0}^{\phi} (Q - P) \cot \psi^1 d\phi, \quad . \quad . \quad . \quad . \quad (8)$$

where ψ^1 is the angle through which the line of Q-stress has to be rotated to bring it upon the isoclinic.

Now the value of P — Q can be read off at any point from observation of the isochromatic lines or by direct measurement with a compensator.

The values of ψ are obtained from the isoclinics by subtracting, from the inclination to the x-axis of the tangent to the isoclinic, the parameter of the isoclinic itself.

The isoclinics are usually well-defined brushes, of which the *direction*, at any point, can be observed with considerable accuracy. Accordingly ψ should be read off with an error of only 1° or 2° in most cases.

It is necessary, of course, to *draw* the lines of principal stress, since these are the paths of integration. But, given the isoclinic lines, this usually presents no difficulty; and, as a rule, this is the most accurate and immediate deduction from the optical data.

Once the lines of principal stress have been drawn, P — Q and ψ should be noted for the various points at which a given line of stress meets the successive isoclinics. The values of (P — Q) cot ψ can then be calculated and plotted to ϕ, and the area of the curve so found obtained by any of the usual methods.

3. In this way P and Q can be obtained for any point on the line of stress, provided P_0 (or Q_0) is known.

Now, at the boundary, both principal stresses can be obtained if the applied traction is entirely known. If the P-stress line makes an angle χ with the normal n to the boundary, s denoting the direction of the boundary itself,

$$\widehat{ss} - \widehat{nn} = (Q - P) \cos^2\chi,$$

and $\widehat{nn}$, $\widehat{ns}$ being supposed known, $\widehat{ss}$ is given by this equation.

The simplest and most important case occurs when we are dealing with a part of the boundary entirely free from traction. In this case $\widehat{nn} = \widehat{ns} = 0$, the boundary itself is a line of principal stress (say Q-stress) and

$$\widehat{ss} = Q - P$$

as given optically: P, of course, being here zero.

We may thus follow any one line of principal stress which starts from a free portion of the boundary, and the stresses P, Q are completely known along this line.

It may be that this will allow us to reach directly all the region of the plate which we wish to explore, in which case the problem is solved.

If, however, this is not the case, we may now take any point already reached as starting-point and proceed from it along the orthogonal line of principal stress. In this way the whole of the plate will ultimately be reached.

4. The formula (7) becomes highly inaccurate if ψ be small, in which case a slight error in ψ makes a large error in cot ψ; and also, the isoclinics being then nearly parallel to the line of principal stress considered, the intervals along the path of integration are too large for the method of quadratures to give accurate results.

In this case we have to treat equation (5) by a different method.

Let Δy (fig. 3) be the intercept, measured perpendicular to the path of integration between two near isoclinics in the neighbourhood of the point considered, whose parameters differ by $\Delta\phi$. Then $1/\rho_2 = \Delta\phi/\Delta y$ approximately. And if we take the interval $\Delta\phi$ constant throughout, which will usually be the case since the isoclinics should be drawn for constant differences of ϕ, we have equation (5) leading to

$$P = P_0 - \Delta\phi \int_0^A \frac{P - Q}{\Delta y}\, ds_1 \quad . \quad . \quad . \quad . \quad . \quad (9)$$

and the integration can be proceeded with graphically as before.

This method is specially useful when, as not infrequently happens in cases of symmetry, there exists a line of principal stress which is *straight*, and therefore is also an isoclinic. Δy is then the intercept between this line and the nearest (curved) isoclinic, measured perpendicular to the (straight) path of integration.

5. As an example of the method, a small disc of a transparent insulator called *bakelite* was placed in a straining-frame and compressed along a diameter. The disc carried a network of reference lines and the appearances were projected on a screen, upon which the isoclinics and isochromatics were traced with a pencil.

Bakelite was selected because its stress-optical coefficient (recently determined as 50 brewsters by Mr. I. Arakawa in a M.Sc. dissertation of the University of London) is at least five times that of celluloid, and therefore, for a given thickness, a far larger number of isochromatic lines is brought into the field. The difficulty with this material is usually that it shows considerable optical effect in the unstrained state, but it was found possible, by a method due to Mr. H. T. Jessop, to obtain almost perfect annealing of this particular specimen.

The disc compressed along a diameter was selected as a type of stress because its mathematical solution is simple and well known (*See* Love, *Theory of Elasticity*, 3rd edition, Art. 155) and would afford a basis for comparison. It was found, however, in practice, that the compressing pieces flattened the disc and the pressure was spread out over a quite considerable arc.

The straining-frame used did not allow of the total pressure being found directly. The ratio of this to the stresses has been deduced from the observations themselves.

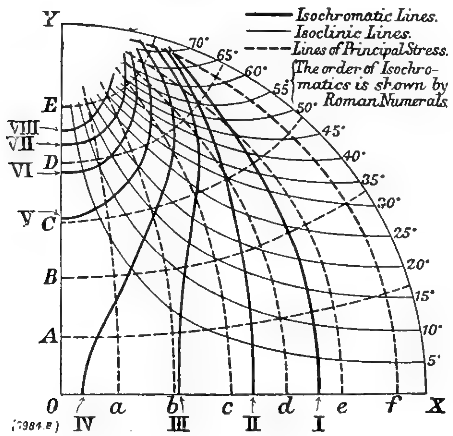

FIG. 4

In like manner it will appear that neither the stress-optical coefficients of the bakelite, nor its elastic constants, needed to be determined; and these points are of some importance, as they show how, in many cases, the method is largely independent of subsidiary determinations.

6. The isoclinics (drawn for every 5° of ϕ) and the isochromatics, of orders 1 to 8, are shown in fig. 4, for one quadrant of the disc only, the others being deducible from symmetry. The isoclinics are shown in fig 4 by thin lines and the isochromatics by thick ones, the isochromatic of order zero being the boundary itself. The lines of principal stress, drawn from the data supplied by the isoclinics, are shown by the dotted lines, which should be coaxial circles according to theory. Those surrounding the point Y show a certain amount of ellipticity which agrees with what one would expect if the pressure is spread out on either side of Y.

The first step was to use the method of §4 to obtain P and Q along OX, P being here horizontal. The radius r of the circular image was $3\frac{1}{4}$ in., and measurements were taken in inches. The results, however, are not affected by the scale of the diagram.

Unit stress was taken to be that which produced the retardation corresponding to the 'tint of passage.'

A preliminary curve was drawn giving P − Q to x, as obtained from the intersections of the isochromatics with Ox. From this curve the values of P − Q corresponding to $x/r = 0 \cdot 1, 0 \cdot 2, 0 \cdot 3$, etc., were read off, and Δy was the vertical intercept for those values of x between the isoclinics $\phi = +5°$ and $\phi = -5°$, so that $\Delta\phi = \text{arc } 10°$. The results are shown in Table I.

TABLE I.

CALCULATION OF P ALONG OX.

x/r	P − Q	Δy (inches)	$\frac{(P-Q) \text{ arc } 10°}{\Delta y}$	P Graphical	P Theory	Q Graphical	Q Theory
0	4·08	∞	0	0·84	1·06	−3·24	−3·18
0·1	3·94	3·05	0·226	0·81	1·02	−3·13	−3·10
0·2	3·53	2·03	0·304	0·72	0·90	−2·81	−2·86
0·3	3·04	1·45	0·366	0·61	0·74	−2·43	−2·51
0·4	2·53	1·08	0·409	0·48	0·56	−2·05	−2·03
0·5	2·03	0·88	0·403	0·35	0·38	−1·68	−1·66
0·6	1·50	0·74	0·354	0·23	0·24	−1·27	−1·23
0·7	1·00	0·65	0·269	0·13	0·12	−0·87	−0·85
0·8	0·60	0·59	0·178	0·06	0·05	−0·54	−0·52
0·9	0·28	0·59	0·083	0·01	0·01	−0·27	−0·23
1·0	0	0·60	0	0	0	0	0

The integration for P (graphical) was carried out by simple addition of mid-ordinates. The columns marked P (Theory) and Q (Theory) were computed as follows: The values of Q obtained graphically were taken from the seventh column and $\int_{-r}^{+r} Q dx$ computed. This was found to be 10·84, and this value was taken as the total applied force F; and the theoretical stresses for a disc under forces F diametrically applied were computed. The Q values are seen to agree quite well. The P values shown by the graphical analysis are somewhat lower (but not really by large absolute amounts) than the theoretical values; but the spread of the applied pressure already mentioned would act in this sense.

7. The next step was to compute P along the lines of stress marked A, B, C, D in fig. 4 (E was omitted as the observed lines were too crowded for the drawing to have been sufficiently accurate).

Formula (7) was now used, bearing in mind that at the boundary P_0 is zero; and the observed values are tabulated for the intersections of the stress line with the successive isoclinics.

TABLE II.

CALCULATION OF P ALONG LINES A, B, C, D OF PRINCIPAL STRESS.

	ϕ (obs.)	ψ (obs.)	P − Q (obs.)	(Q−P) cot ψ	P (Graphical)	Q (Graphical)
A	17°	—	0	0	0	0
	15°	161·5°	0·40	1·20	0·02	−0·38
	10°	157·5°	1·50	3·62	0·18	−1·32
	5°	151·5°	2·72	5·00	0·56	−2·16
	0°	90°	4·20	0	0·93	−3·27
B	32° 30′	—	0	0	0	0
	30°	144·5°	0·28	0·39	0·01	−0·27
	25°	144°	0·89	1·23	0·06	−0·82
	20°	143°	1·60	2·13	0·21	−1·39
	15°	137·5°	2·50	2·72	0·42	−2·08
	10°	131°	3·27	2·84	0·67	−2·60
	5°	124°	3·91	2·62	0·92	−2·99
	0°	90°	4·35	0	1·06	−3·29
C	48°	—	0	0	0	0
	45°	134°	0·43	0·42	0·01	−0·42
	40°	131°	0·83	0·72	0·06	−0·77
	35°	129°	1·44	1·17	0·14	−1·30
	30°	129·5°	2·00	1·64	0·27	−1·74
	25°	124°	2·90	1·94	0·42	−2·48
	20°	121°	3·60	2·16	0·60	−3·00
	15°	122°	4·15	2·57	0·80	−3·35
	10°	115·5°	4·55	2·18	1·02	−3·53
	5°	108°	4·82	1·54	1·18	−3·64
	0°	90°	4·85	0	1·25	−3·60
D	63°	—	0	0	0	0
	60°	128°	0·75	0·58	0·01	−0·74
	55°	118°	1·90	1·01	0·08	−1·82
	50°	114°	2·85	1·27	0·17	−2·68
	45°	113°	3·40	1·44	0·29	−3·11
	40°	113°	3·90	1·65	0·42	−3·48
	35°	113°	4·25	1·80	0·57	−3·68
	30°	115°	4·70	2·19	0·74	−3·96
	25°	114°	5·15	2·29	0·93	−4·22
	20°	108°	5·55	1·80	1·12	−4·43
	15°	105°	5·90	1·58	1·27	−4·63
	10°	101·5°	6·15	1·25	1·39	−4·76
	5°	97°	6·30	0·77	1·48	−4·82
	0°	90°	6·40	0	1·50	−4·90

In computing the above table the values of (Q − P) cot ψ were plotted to ϕ on squared paper and the areas read off by counting squares.

It will be noticed that we have now a system of values of P and Q which practically cover the whole of the disc, excluding the immediate neighbourhood of the points of application of the load. Our problem is therefore practically solved.

8. Comparison with the theory along the diameter $x = 0$ shows divergences, *e.g.* the progressive rise, as we move away from O, in the value of P, which in the

theoretical example should be constant; but these discrepancies might be plausibly accounted for by the fact that the theoretical distribution of load is not accurately realised.

The real test of the validity of the method lies in the agreement between the values of P and Q obtained at the same point by integration along lines of principal stress belonging to different (*i.e.* orthogonal) systems.

In order to apply such a check, the value of Q at $x = 1\cdot5''$, $y = 0$, where the line of principal stress marked c in fig. 4 begins, was interpolated from Table II. and found to be $-1\cdot845$ in our units. Q and P were then computed for various values of ϕ along the line c from the data given in Table III., each successive entry in the fifth column being obtained by adding to the preceding the arithmetic mean of the two corresponding entries in the fourth column.

TABLE III.

CALCULATION OF P AND Q ALONG THE LINE "c" OF PRINCIPAL STRESS.

ϕ	ψ	P − Q	(P − Q) cot ψ × arc 5°	Q	P
0°	90°	2·25	0	−1·85	0·40
5°	67°	2·33	0·086	−1·89	0·44
10°	57°	2·38	0·135	−2·00	0·38
15°	47°	2·53	0·206	−2·17	0·36
20°	41°	2·70	0·271	−2·41	0·29
25°	37·5°	3·30	0·471	−2·78	0·52
30°	29°	4·00	0·630	−3·33	0·67
35°	24·5°	4·70	0·900	−4·09	0·61
40°	18°	5·50	1·477	−5·28	0·22

Finally, if we estimate the values of ϕ at the four intersections Ac, Bc, Cc, Dc, and compare the values of P and Q obtained from Tables II. and III. by interpolation, we obtain Table IV. below.

TABLE IV.

CROSS-CHECK OF STRESSES.

ϕ	Point	P (II)	P (III)	Q (II)	Q (III)
6·5°	Ac	0·45	0·43	−1·91	−1·92
15°	Bc	0·42	0·36	−2·08	−2·17
23·5°	Cc	0·47	0·45	−2·64	−2·66
33°	Dc	0·64	0·63	−3·79	−3·79

The slight difference shown in the values of P − Q in the above is due to the fact that the values of P and of Q were interpolated for separately.

Looking at these values, however, the agreement is singularly good, and may be looked upon as a remarkable confirmation of the accuracy of the method.

It appears, therefore, that it is practically feasible to obtain the complete stress system in a transparent model from purely optical observations and without reference to the elastic properties of the material.

The best thanks of the author are due to Mr. H. T. Jessop, M.Sc., of University College, London, who actually annealed the specimen of bakelite used in these observations and who obtained the tracings of the isoclinic and isochromatic lines.

III.

Thermodynamic Theory of Mechanical Fatigue and Hysteresis in Metals.

By B. PARKER HAIGH, *D.Sc., M.B.E., M.Inst.C.E., Royal Naval College, Greenwich.*

Introduction.

In contributions to the reports of this Committee, in 1919 and 1921, the author outlined a thermodynamic theory of ductile strain, and showed how that theory could be applied to deduce an approximate relation between the different elastic limits exhibited by a given metal when subjected to stresses of different kinds, tensile, shear or complex combinations of different principal stresses. The theory was summarised in a convenient quadratic equation giving the elastic limit combination (x, y, z) for a complex stress in terms of the ordinary tensile elastic limit (f) and Poisson's ratio ($\sigma = 0 \cdot 25$ to $0 \cdot 30$)—

$$(x^2+y^2+z^2) - 2\sigma\,(y.z+z.x+x.y) = f^2$$

It was shown that this theoretical relation is well supported by experimental evidence published by many different investigators; thus, for example, fig. 5, reproduced from the report for 1919, shows how closely the calculated strength of a thick-walled tube agrees with experimental determinations carried out with the greatest care for accuracy.

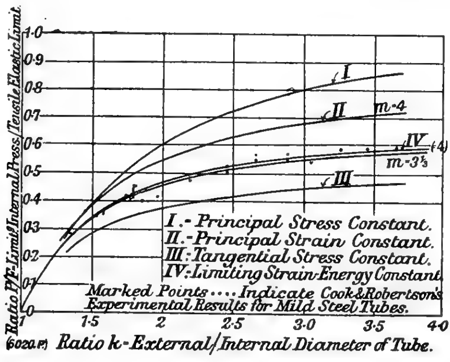

FIG. 5

It is proposed, in the present paper, to extend the application of thermodynamic principles to investigate the problem of mechanical fatigue and the relation between the phenomena of fatigue and hysteresis. It will be shown that fractures produced by steady tensile stress, or by alternating or pulsating stresses, have certain features in common; and that these indicate an action distinctly different from that 'gliding' action which affords a sufficient explanation of ductile or plastic strain. In the view of the author, fatigue and hysteresis are associated with, and directly due to, a dual process of decrystallisation and recrystallisation, substantially equivalent to the dual process of solution and recrystallisation that was shown, in 1861, by the late Professor James Thomson, to occur when a crystal immersed in its saturated solution is subjected to stresses tending to change its shape. Such a process is associated with thermal actions; evolution, absorption and conduction of heat, and with the conversion of mechanical work to heat; and is subject to the established thermodynamic laws that govern also the actions of working substances in heat engines.

An introduction to these thermodynamic relations will be found in two papers published by Thomson in 1861. In discussing the apparently plastic flow of ice, in an *extension* of the theory by which, in 1849, he had already calculated the depression of the freezing point by pressure, Thomson states: ' Stresses (of any kind) tending to change the form of any crystals in the saturated solutions from which they have crystallised must give them a tendency to dissolve away, and to generate, in substitution for themselves, other crystals free from the applied stresses.' It does not appear that Thomson applied this principle for metals; nor was the subject then ripe for such an application. Thomson states: 'I have not . . . any clear conception of continuous crystalline structure admitting of what may be called ductile or malleable bending. . . . What may be the nature of the molecular arrangement induced by bending them I cannot say; but I suppose that . . . their crystalline structure is materially altered, and rendered discontinuous where, before, it was continuous.'

Beilby's memorable work identified the change in question as the physical change from the crystalline to the vitreous state. Ewing, Rosenhain, and Humphrey demonstrated microscopically that the change occurs on gliding surfaces within the grains; and showed that ductile strain is due to numerous small displacements on surfaces spaced at finite distances that vary in different circumstances. It is understood that the ' vitreous ' theory of plastic strain is now widely accepted, although, since it asserts that the phenomena of strain depend upon a change of physical state, its acceptance involves a variety of thermodynamic consequences which hitherto have not been fully investigated or verified.

While the vitreous theory of non-elastic strain affords an explanation of plastic flow, on the assumption that the changed metal behaves as a viscous liquid, and offers an incomplete explanation of the hardening action of cold-work, on the assumption that the same changed metal behaves as a rigid vitreous substance, it remains to be shown that the two requirements are not mutually incompatible. As a deduction from the first law of thermodynamics, the author will show that the changed metal must be formed at high temperature, such that it may well be viscous during the short period of time that elapses before it cools to the temperature of the surrounding metal.

It will further be shown that the phenomena of hysteresis are attributable to the action of a dual process of decrystallisation and recrystallisation occurring in a cyclic manner that is always irreversible in the thermodynamic sense, but may be mechanically reversible or irreversible according as the range of applied stress lies within or beyond the fatigue limit of the metal; and that the incidence of fatigue may be explained by the formation of small cavities in the metal, in consequence of the imperfect mechanical reversibility of the action when it occurs with undue energy and on too large a scale.

Thermodynamic Elasticity.

In the usual definition of elasticity, reliance is placed on a phrase ' no permanent strain *after removal* of stress '; and attention is focussed on the comparison of measurements taken before and after loading. Since the behaviour of the material *during* loading and unloading is not usually specified, the phenomena of ' elastic hysteresis ' often escape attention, or are regarded as of minor importance and to be ascribed to 'molecular friction.' For theoretical purposes it is desirable to define a more ideal type of elasticity, as exhibited by cold vitreous substances such as glass, free from hysteresis.

Thermodynamic elasticity may be defined—without reference to Hooke's approximate law of proportionality—by regarding as an ideally elastic change an action that is thermodynamically reversible: the work done on the metal, in straining it, shall be completely recovered when the stress is released. On this basis, a definition may be given as follows:—A test-piece is thermodynamically elastic if, in an experiment in which the applied stress is varied within limits and under specified control of temperature and other external conditions, the strain observed at any stage of loading or unloading is found to depend solely on the stress applied at that stage, being independent of whether that stress is rising or falling.

Thermodynamic elasticity does not necessarily entail fulfilment of Hooke's law: thus the compression of water is thermodynamically elastic although the bulk modulus varies with the applied pressure. In the absence of hysteresis, however, metals would doubtless fulfil Hooke's law even more approximately than they do in actual experiment.

On the assumption that Hooke's law is fulfilled, the work done by external forces in straining unit volume of an isotropic substance under a combination of three principal stresses, x, y, and z, may be expressed in terms of Young's modulus, E, and Poisson's ratio, σ, thus :

$$\text{Work per unit volume} = \frac{1}{2E}[(x^2 + y^2 + z^2) - 2\sigma\,(y.z + z.x + x.y)]$$

Under a single tensile stress, f, this reduces to $f^2/2E$; or under a single shear stress, q, the work is $q^2/2C$, where C is the modulus of rigidity. It is conceived that these quantities of work are stored in the metal in virtue of changes in the relative positions of the molecules or atoms, or in their orbital or oscillatory movements. In a metal that is thermodynamically elastic, the resilience and, doubtless, also the internal arrangement and motions of the molecules or atoms depend wholly on the state of stress and temperature.

Again, on the assumption that Hooke's law is fulfilled, the quantity of heat absorbed from surrounding bodies by unit volume of an isotropic substance, strained without change of temperature, may be expressed :

$$\text{Heat per unit volume} = \theta . \alpha . f$$

where α is the coefficient of linear thermal expansion and f is the tensile stress applied ; θ is the absolute temperature.

The above expressions were used by Lord Kelvin to calculate the slight fall of temperature that occurs when a test-piece is extended adiabatically ; and, also, the ratio in which the adiabatic modulus slightly exceeds the ordinary isothermal value. It appeared to the author, at one time, that hysteresis might be due to conduction effects associated with the transferrence of such small quantities of heat into or out of the test-piece as a whole ; but simple calculations show that the influence is of too small an order, and usually quite negligible. Moreover, the slight conduction effect varies, with stress and frequency, in a manner quite different from the action of mechanical hysteresis. In metals of highly complex microstructure, comprising intermingled constituents with widely different expansibilities, the conduction effect may be the cause of a perceptible part of the total observed hysteresis ; but in general it appears that a more important cause of hysteresis must be sought in another action.

First Law of Thermodynamics in relation to 'Gliding' Strain.

Any heat given out by a test-piece, during a cyclic process of strain in which the piece is restored to its original dimensions, must be derived from one or other of two sources ; viz., work done by the forces applied in straining the test-piece, or change of internal energy associated with change of physical state. In the case of ductile strain, the heat given out is almost exactly equivalent to the work done on the test-piece : the quantity of metal that suffers change of state and energy, in the slip-bands, is but a very small fraction of the total mass.

Since the whole of this large quantity of energy is converted to heat within the relatively small masses that suffer the change of state and the subsequent gliding movements that result in plastic strain, it follows that the changed metal must attain, temporarily at least, a temperature much higher than that reached by the test-piece as a whole. Unless the specific heats differ more widely than is currently believed, the temperature ratio must be nearly the inverse of the mass ratio ; and the changed metal must attain a temperature of the order of a bright red heat sufficiently high to account for a variety of phenomena which, otherwise, might appear inexplicable.

So long as the changed metal is maintained at this high temperature, we may expect that it will behave as a highly viscous liquid and act as a lubricant between adjacent crystalline masses, allowing of gliding movements such as result in plastic strain. But films as thin as slip-bands may be expected to cool rapidly, in contact with cold unchanged metal, and when the vitreous metal cools it becomes hard and rigid, acting as a cement between the crystalline masses. Thus the dual nature of the vitreous-liquid, required for the explanation of ductile strain, is completely in accord with the idea that the energy available on formation is rapidly dissipated by conduction. It is interesting and significant to note that the more ductile metals are commonly good conductors of heat.

A large part of the total quantity of heat evolved during ductile strain is produced, doubtless, *during* the gliding movement and therefore *after* the occurrence of the change of physical state which, according to the Beilby theory, must occur before gliding is possible within a crystal. This part of the energy is drawn from the strain-energy of crystalline layers on either side of the slip-band, which layers are thereby relieved of further tendency to glide until restrained by change in the applied forces. The period of duration of any one glide is probably limited to the short period of time during which energy is transmitted, with the speed of detonation, across short distances proportional to the pitches between adjacent slip-bands, pitches which depend on the configurations and elasticities of the grains and their boundaries. There is little evidence to suggest that fatigue is directly due to repeated to-and-fro slipping on one and the same series of slip-bands; and it seems highly improbable that this is the real nature of the action that leads to fracture. The slip-band is stronger than the original crystal, and less liable to fail under a second application of the load.

The complex action of gliding may be likened to the release of a spring resisted by a dashpot containing a very viscous liquid that congeals when the exhausted spring is no longer able to supply the energy required to keep the liquid warm. The incompleteness of this analogy is one of its more interesting and valuable features: It is apparent that energy would have to be supplied to melt the dashpot initially, before the release of the spring could supply further energy to compensate the loss of heat by conduction and thereby maintain motion.

This initial quantity of energy is discussed in the next section. The author conceives that the energy with which the first few molecules are endowed, as they leave the crystalline lattice and enter the vitreous assemblage, is supplied by the strain energy between these molecules and their immediate neighbours in the lattice, and is intimately related to the limiting value of the strain-energy required to bring the metal to its elastic-limit.

Second Law of Thermodynamics in relation to Change of State.

When one and the same change can be produced in matter at a given temperature, by the agency of different forces acting in manners that are thermodynamically reversible, the work done by these forces in producing the change is always the same. Applications of this principle in the theory of heat engines are well known, and other applications are established in physics and chemistry.

The application of the principle is fraught with difficulty on account of the incidence of the phrase 'thermodynamically reversible.' If the quantity of work in question is measured experimentally, the observed values will be more or less accurate according as the experimental processes approach, more or less closely, to the ideal of reversibility; or if the quantity is calculated theoretically, the process of change considered must be ideally reversible although not necessarily such as can be carried out in any actual experiment.

In contributions to the reports for 1919 and 1921 the author showed how this principle might be applied to deduce an approximate relation between the elastic limits of a ductile metal for different simple and complex stresses; and showed that that relation was approximately fulfilled in the wide range of experiments covered by published data. The principle will now be applied to deduce the thermal consequences of the dual process of decrystallisation and recrystallisation which has already been described as being conceived to be the cause of mechanical hysteresis and of fatigue in metals.

The change from the crystalline to the vitreous state, in the process of ductile strain, is followed by consequences that are far from reversible. In the presence of any shear-stress, gliding ensues, and the action of the shearing forces is resisted by viscous friction, so that large quantities of strain energy are converted to heat. On account of these complications the total quantities of work actually absorbed are usually much greater than the invariant quantity required to effect change in a reversible manner. In the author's earlier papers, the resilient strain-energy alone was taken as a close first approximation to the invariant quantity.

In attempting to calculate the ideal invariant quantity in terms of the applied stresses and the elastic constants of the metal, we are confronted with two fundamental difficulties as follows: (1) On account of the non-isotropic properties of crystalline matter, work done on an ordinary test-piece, containing large numbers of grains, is not uniformly distributed among those grains. (2) It is difficult although not impossible to visualise a probable nature for the ideal reversible stages which, in any real process of change, must precede the irreversible gliding motion which can occur only in the changed metal. The same two difficulties are met with when we attempt to study the change in relation to hysteresis and fatigue.

The reversible process of change is conceived to occur in two distinct stages. In the first stage the metal is gradually strained—elastically—to the stress at which the change will occur; and in the second stage the first few molecules or atoms are projected out of the continuous lattice into the discontinuous assemblage. Even without a detailed mental image of this latter stage, it may still be regarded as inherently reversible, for if the first projected molecule struck an imaginary rigid body normally, immediately after its projection and before it had suffered loss of energy by viscous resistance or conduction, it could only rebound into the lattice and re-establish its position ready to make a second sortie. A number of considerations lead the author to the view that the work done in the second stage, per unit volume of metal suffering the change, must be nearly independent of the applied stresses, or small in comparison with the strain-energy imparted to the metal in the first stage. In such circumstances the equation of constant resilience may be used, as described in the introduction, as a relation between the elastic limits under simple and complex stresses. Thus, for example, the elastic limit in shear should be approximately 62 per cent. of the tensile elastic limit (instead of only 50 per cent., as is often assumed).

On the assumption or hypothesis that fatigue also is due to consequences that *follow* from the change of physical state in the metal, and no matter exactly what may be the processes that connect the change of state with the opening of the crack, we may infer that the same quadratic equation will afford an approximate relation between the fatigue limits of a ductile metal under different combinations of complex stresses. Since the fatigue limits under complex stresses are difficult of determination, and are still uncertain, it cannot be said that this relation has yet been verified. But a considerable bulk of rough evidence is available to show that the fatigue limits in shear and direct stress approximately fulfil the rule; and it is understood that recent more accurate experiments support the validity of the 62 per cent. ratio, at least as a close approximation.

Tensile and Fatigue Fractures: Comparison and Cause.

Although the tensile and fatigue fractures of a ductile metal commonly differ widely in appearance, the two have features in common; and the differences are of degree rather than fundamental. In both types of fracture, it is considered, rupture is associated with and directly due to an action other than that gliding which is regarded as a sufficient explanation of plastic shear strain.

The tensile fracture of a ductile metal exhibits two characteristically different zones. The outer annulus, of ‘ cup and cone ’ form, is admittedly due to shearing: the surfaces coincide with the planes of maximum tangential stress, as in the typical plane fractures observed in torsion tests. Within the annulus is observed a second zone of characteristically different appearance, nearly flat in many metals, granular or even toothed in others. Since this second zone lies on the plane of symmetry of elongation, precisely on the cross-section of minimum area, while the surfaces of the cup and cone run outwards to edges of greater diameter, it is inferred that the cracking of the inner zone is the determining cause of fracture, and *interrupts* the continuous gliding movement of shear which, in other circumstances, might continue further without necessarily resulting in fracture. The relative size of the two zones differs in different metals that exhibit different local elongations and reductions of area; and varies also with the character of the applied stress, whether steady, pulsating, or alternating. The cup-and-cone annulus is to be regarded as characteristic of ductility, and the inner zone of inherent or induced brittleness.

In a ductile metal, brittleness may be induced by the action of the complex stresses associated with local elongation, which sets in at a particular stage of elongation, when the capacity of the metal for hardening—by the cold-work of elongation—falls below a certain limit that is unable to compensate the reduction of area. In this physical sense, the ultimate strength of a ductile metal is not directly related to its resistance to rupture, but is related to its cold-working capacity only. As there appears to be much misconception of this point, it may be well to put the matter in

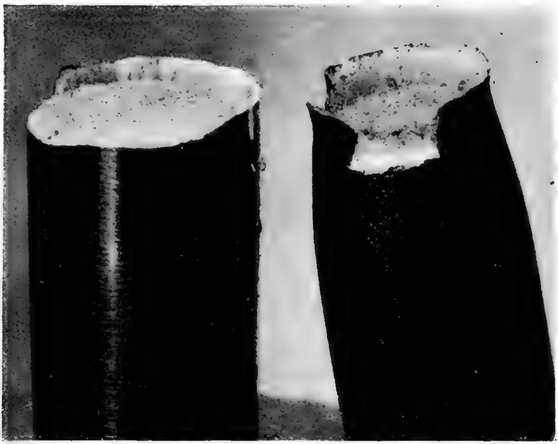

FIG. 6.—Comparison of fractures of one and the same steel: under tensile stress, right; and under pulsating tension, left.

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mathematical terms. The ultimate tensile strength is the maximum value of the nominal stress given by the term $(f \cdot a/A)$, where A is the original cross-section of the test-piece, and f is the stress on the reduced cross-section a. It follows that the ultimate strength occurs when the differential of $(f \cdot a)$ is zero; *i.e.* when

$$(f \cdot da) + (a \cdot df) = 0;$$

$$i.e.\ \text{when}\ \frac{df}{f} = -\frac{da}{a} = 2\frac{dl}{l};$$

where df is the increase of yield stress produced by a further elongation, dl, on the already extended length l. The ultimate tensile strength is therefore the particular 'nominal' stress that corresponds to a definite stage of elongation at which

$$\frac{df}{dl} = 2\frac{f}{l};$$

that is, at which 2 per cent. increase of yield stress (reckoned on the reduced area, as in wire-drawing) is produced by a further 1 per cent. elongation (reckoned on the already extended length).

The necking that occurs in a ductile metal strained beyond this stage produces lateral pull stresses in the core of the bar: the exterior layers, subject to tension, are held in their curved positions by these lateral tensions. When the curvature is considerable, it may happen that the core is subject to an almost symmetrical 'triple-tensile' stress. It is of interest to consider, therefore, the probable action of this unusual type of stress, regarding which we have but little direct experimental evidence. According to the 'strain-energy' theory, symmetrical triple-tensile stress of sufficient intensity promotes change of state, from crystalline to vitreous, but causes no tendency to glide. The metal becomes 'pseudo-rigid,' ceasing to glide although suffering the change of state. If such an action occurs in the core of a tensile test-piece, we may expect that that core will take up an undue share of the applied load, will suffer increasingly rapid change without the relief that might be derived from gliding, and will rupture in the manner characteristic of a brittle metal that breaks without plastic strain.

The above description of the action of triple-tensile stress, in promoting fracture in a ductile metal, is supported by evidence from wire-drawing operations. In the process of wire-drawing, the occurrence of triple-tensile stress is prevented by the lateral pressure exerted by the dies; and, as a consequence, more shear strain can be imposed without fracture, so that the metal can be hardened much further than by simple tensile elongation. The profile and lubrication of the dies are of importance, not only on account of their dragging action but also because they affect the magnitude and location of the lateral pressure that neutralises the destructive triple-tension which, in the absence of the dies, would promote rupture. In 'cupped' wire, internal cracks occur in a manner suggestive of a deficiency of this action.

The view that rupture can be caused by change of physical state resulting in the formation of cavities, with or without gliding motion, is supported by several considerations. When the densities of crystalline and vitreous metals are compared, using dilatometer methods at temperatures such that the change occurs without stress, the vitreous metal is found to occupy the smaller volume; and, on account of the different thermal contractions, it is probable that the difference of volume is still greater at ordinary temperatures. Moreover, the slight but definite expansions that accompany distortion by tension, shear, and even compression, are regarded as evidence that the change of state results in the formation of cavities, even when it is followed by gliding movements which tend to seal together the gliding faces. The author holds the view that gliding is to be regarded not as the cause of rupture, but rather as an imperfect protection against rupture caused by the opening of cavities and the spreading of a crack, much in the same manner as occurs evidently in a 'notched-bar' test for brittleness.

When fatigue occurs under a pulsating pull that attains only a moderate crest value, not necessarily exceeding the yield-point and much lower than the ultimate tensile stress, the fatigue fracture assumes a characteristic form intermediate between the typical tensile fracture and the typical fatigue fracture under alternating stress. Fig. 16 illustrates the comparison, and shows how the pulsating stress fracture might be taken, at first sight, to be that of a more brittle quality of steel. The pulsating stress fracture shows the cup and cone, but less markedly than the tensile fracture.

Through all the variations of form of the fatigue fractures produced by different combinations of steady and alternating stresses, the flat face of the fatigue crack may be identified as corresponding, in some measure, to the flat inner zone of the tensile fracture; while the final distorted tear of the fatigue fracture corresponds to the regular cup and cone of the tensile. It is inferred that the determining cause of fracture is the same in the two cases: that fatigue is associated with the formation of small cavities within the metal, without the protective action of gliding. Whereas, in the tensile test, these cavities form only when the metal becomes brittle—through the agency of triple-tensile stress in metals that are normally ductile—their formation occurs under alternating stress even while the metal retains its full ductility. General observation shows that fatigue is associated with little if any of that hardening effect which, otherwise, is invariably associated with such gliding movements as produce ductile strain. It is inferred that fatigue is due to the formation of cavities under conditions such that the openings cannot be healed by gliding movements; that the action originates from numerous zones of exceedingly small dimensions, zones at which undue stress concentrations are present, and are so small that the numbers of molecules involved in simultaneous motion do not suffice to allow of gliding—probably because their movements are too rapidly quelled by loss of thermal energy by conduction. It is, of course, to be understood that gliding motion may occur under alternating stresses as well as in simple tension—for example, when the fatigue limit lies near to or above the tensile yield-point, or when a certain amount of slipping occurs in the initial stages of a fatigue test; but this slipping or gliding movement is not regarded as the cause of that fatigue which, after the repetition of many millions of cycles of stress, breaks the metal in such a characteristic manner.

The development of a fatigue crack is attributed, therefore, to the formation of cavities in the metal, these cavities being produced initially by the contraction of volume that accompanies change of state, and extended gradually at each application of stress. The detailed action may be pictured as follows: In a test-piece composed of crystalline grains and intermingled vitreous matter (or other constituents) present before the start of the test or produced during the test by gliding movements that may have converted crystalline to vitreous, certain molecules are nearly unstable. Some are nearly ready to spring out of the crystalline mass into the vitreous, while others are nearly ready to fall into the lattice from the vitreous assemblage. Both actions may be precipitated by a change of energy, due to change of stress or temperature; but both are very local, involving only small numbers of molecules. When the temperature of the metal is raised slightly, as by boiling, in Dr. Muir's well-known experiments, these molecules fall into positions of greater stability; and, in subsequent mechanical tests, only still smaller numbers are influenced by any change of stress that may be imposed upon the metal. Thus the metal is rendered more nearly elastic, in respect that hysteresis is reduced.

It is conceived that this dual action may occur indefinitely without necessarily causing fatigue, provided that the effects of crystallisation completely neutralise those of decrystallisation: that is, if the action is mechanically reversible—the molecules that are displaced at one extreme of the stress cycle falling back into their original places at the opposite extreme, or at the mid-stroke. But it is clear that such a dual action, occurring with sufficient violence, would speedily open a crack if the two parts of the action did not exactly compensate. The nature of the action is such that it must either die away gradually, leaving the metal unbroken, or increase gradually, leading to fracture; but its increase or decrease may be so gradual that, in tests continued only for moderate periods, it may appear constant in magnitude.

We may next ask what evidence, if any, may be expected of such an action as has been described above—a dual change in which the two parts nearly neutralise one another. If the change involves no gliding motion, we can expect no changes of shape or volume such as would afford a basis of measurement. But since the two parts of the change involve the giving out and absorption of quantities of heat, and occur at different stages of the stress cycle, we may expect that the action will be irreversible in the thermodynamic sense; and accompanied, therefore, by a conversion of mechanical work to heat, on an overall balance. The irreversible action must be accompanied by an increase of entropy. Evidence of such an action is at hand in the phenomena of hysteresis, described in the following section.

If the action occurred in a metal endowed with zero thermal conductivity, we might expect that the action would be ideally reversible, the heat given out during one stage of the dual change remaining ready to be absorbed in the second stage of the action. But in actual metals, of good conductivity, the heat produced in the one stage is dissipated by conduction, and in the second stage must be received back from the surrounding metal by conduction in the opposite direction. The action as a whole must be similar to that of a reversed heat-engine (refrigerator) taking in a quantity of heat at one temperature and giving out a greater quantity at a somewhat higher temperature, the balance being made good by mechanical work supplied by an external source. A still closer analogy would be that of a refrigerating engine working under conditions such that thermal leakage was an important effect. The operation of such an engine, thermodynamically irreversible, might still be mechanically reversible; thus the action does not necessarily involve fatigue.

Hysteretic heating is not, therefore, to be regarded as evidence that the metal will necessarily fail from fatigue if the test be continued long enough; but merely as evidence of an action that may result in fatigue if the quantities of energy involved exceed certain limits. The evolution of a given quantity of heat from a large number of small zones, each containing only a few molecules, may cause no perceptible growth of cavities; but the same evolution of heat from a smaller number of large zones may involve so many adjacent molecules in simultaneous movement that orderly replacement is impossible, so that change of submicrostructure proceeds apace, forming internal cavities that eventually develop into cracks.

Experimental Evidence of Hysteresis.

The term 'mechanical hysteresis' has long been used to describe a group of actions that occur in metals subjected to cyclic variations of stress, within determined limits less than the yield-point. These actions are revealed by phenomena of two kinds, viz. (1) the absorption of a quantity of work, represented by the net area of the stress-strain loop for the cycle; and (2) the giving out, during each cycle, of a quantity of heat that produces a slight or moderate rise or gradient of temperature in the test-piece. Hysteresis may be measured mechanically or calorimetrically; and experiments have shown that the quantities of work and heat are very approximately equivalent.

When hysteresis is measured mechanically, by means of an extensometer or torsion meter used in conjunction with a suitable testing machine, the results are readily expressed in absolute units, but the degree of accuracy is unsatisfactory, because the hysteretic strains can be determined only by a process of subtraction involving the much greater elastic strains. Nevertheless, reliable measurements are obtained with moderate stresses, and sensitive instruments reveal definite hysteresis under very low stresses. The hysteretic work may be measured also by observing the decrements of amplitude of a test-piece oscillating *in vacuo*; and this method, many years ago, was used by Lord Kelvin in torsional experiments.

Calorimetric measurements offer the advantage that the hysteretic energy may be measured directly—without reference to elastic effects—in terms of the rise or gradient of temperature in the test-piece, which is considerable when a large test-piece is stressed at a high frequency. This method was first applied successfully with high frequencies in Prof. Hopkinson's laboratory at Cambridge; and to the Cambridge group of investigators we are indebted for many interesting results regarding hysteresis. It was shown that the heat generated is very approximately equivalent to the work absorbed, and that this work is practically independent of the time occupied in making the cycle of stress, at least within wide limits from 0·01 second upward; also that the actions in shear and in direct pull and push are very similar, and that the work per cycle varies as a function of the range of stress and is measurable down to very low stresses. It was further observed that hysteresis is much greater in annealed than in cold-worked metal; but this last conclusion requires important qualification.

In these early investigations, however, attention was directed solely to the hysteresis exhibited in the earliest stage of fatigue tests, or to that observed in static tests; and no attempt appears to have been made to follow its characteristic changes during the course of a complete fatigue test resulting in fracture after many million repetitions. In pursuance of the view that fatigue is closely associated with hysteresis, the author has carried out special experiments to measure hysteresis sensitively during the continuance of tests that led to fracture or, alternatively, left the test-piece still unbroken after many million cycles of stress.

The electro-magnetic fatigue-testing machine designed by the author and used in these tests has been described elsewhere (*Journal of the Institute of Metals*, 1917; also in *The Engineer*, 1920), and it will suffice here to mention that this type of machine offers great advantages for measurements of hysteresis, because a considerable body of metal is subjected to the full range of stress—not merely a thin film as in rotating cantilever tests—and because the range can be measured with accuracy, and the frequency of reversal is rapid (2000 cycles per minute).

The test-piece used was fitted with a special form of sensitive thermocouple arranged in such a manner that errors due to the conduction of heat from extraneous sources were almost wholly eliminated, so that the gradient of temperature in the test-piece was measured with accuracy. The galvanometer used, therefore, gave a direct measure of the rate at which heat was being given out by the metal at any moment, under any desired range of stress. The thermocouple was attached to the test-piece before the commencement of the test, and the readings of the galvanometer were observed at intervals during the continuance of the fatigue run.

The changes of hysteresis during such fatigue tests differ widely in different metals and with the range of stress. The more important conclusions indicated by a study of many records, for test-pieces that did or did not break under the applied loads, are summarised below:

(1) In many metals, particularly those which have been annealed, the great hysteresis commonly observed in static tests *dies away* rapidly and gradually during the first few minutes or hours of a continued fatigue test. Such hysteresis may be termed 'transient' or 'primary,' and is ascribed to gliding motion in the crystals resulting in hardening action akin to that of cold-work of any other kind. This primary hysteresis disappears long before fracture in a test under moderate stress, and is not regarded as the cause of fracture, but rather as a protective action that allows of beneficial redistributions of stress within the metal, particularly in parts of complex shape, such as the plates of riveted joints studied by Wilson and Haigh (British Association: 1922).

(2) In test-pieces that are not going to break under the applied range of stress, hysteresis *decreases* continuously during a very long period, but does not completely disappear. Moreover, the definite decrease may not show itself, in some cases, until several millions of repetitions of stress have been imposed. This 'continuous' or 'secondary' hysteresis is regarded as evidence of the irreversible thermodynamic action that has been described.

(3) In test-pieces that are going to break under the range of stress applied in the test, hysteresis continues to *increase* gradually, after the disappearance of the initial transient effect, sometimes for many millions of cycles before fracture. This phenomenon is regarded as evidence of the gradual unstable extension of the zones at which 'secondary' hysteresis is occurring.

(4) Immediately before fracture hysteresis increases rapidly, and often to very high values, such that the heating effect is obvious and occasionally painful to the sense of touch. This final stage may be described as 'tertiary' hysteresis, and is ascribed to the rapid extension of cavities, probably with gliding motion, associated with the formation of open cracks in the metal.

(5) In many metals, particularly cold-worked or otherwise hardened, hysteresis that is initially slight or almost imperceptible increases slowly but greatly (*e.g.* in ratio 20 : 1) during the first few million cycles of stress, and thereafter remains more or less constant, or fluctuates, until the rapid rise sets in after many more millions have been imposed.

(6) If, at any stage in a long fatigue test under constant range of stress, the hysteresis is measured for a series of different ranges—and plotted against these different ranges—the result is a smooth graph with no distinct indication of the fatigue limit. Cursory inspection may give the impression that fatigue increases rapidly near the known fatigue limit; but the impression is illusory, being dependent on the scales employed for plotting.

(7) The hysteresis observed under a given range of stress, and the form of the 'hysteresis-range of stress' graph, vary widely in any given metal according to the treatment given to the metal immediately before the tests. Thus static elongation, or a short fatigue test under a high stress, greatly increases the hysteresis; and conversely, boiling a steel test-piece, or applying a moderate range of stress for a fairly long period, tends to reduce the hysteresis observed under this and other ranges.

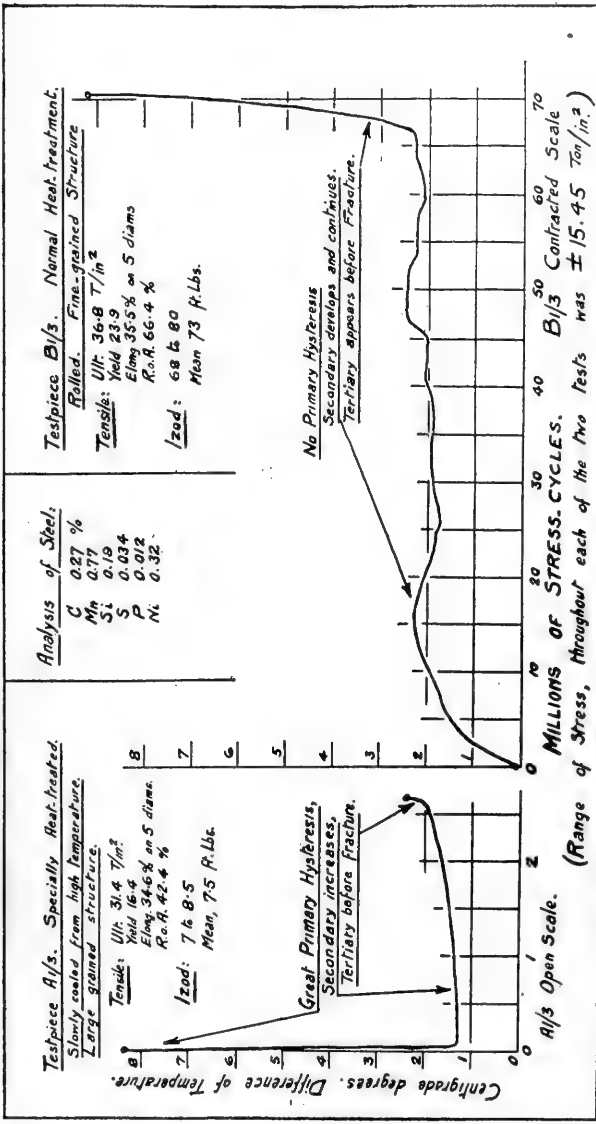

Testpiece B1/3. Normal Heat-treatment.
Rolled. Fine-grained Structure
Tensile: Ult. 36·8 T/in²
Yield 23·9
Elong. 35·5% on 5 diams
R.o.A. 66·4 %
Izod: 68 to 80
Mean 73 ft.Lbs.
Analysis of Steel:
C 0.27 %
Mn 0.77
Si 0.19
S 0.034
P 0.012
Ni 0.32
Testpiece A1/3. Specially Heat-treated.
Slowly cooled from high temperature.
Large grained structure.
Tensile: Ult. 31.4 T/in²
Yield 16.4
Elong. 34.6% on 5 diams
R.o.A. 42.4 %
Izod: 7 to 8·5
Mean, 7·5 ft.Lbs.
Great Primary Hysteresis,
Secondary increases,
Tertiary before fracture.
No Primary Hysteresis
Secondary develops and continues.
Tertiary appears before Fracture.
Centigrade degrees. Difference of Temperature.
0 1 2 3 4 5 6 7 8
A1/3 Open Scale.
0 1 2
MILLIONS OF STRESS. CYCLES.
0 10 20 30 40 50 60 70
B1/3 Contracted Scale
(Range of Stress, throughout each of the two tests was ±15.45 Ton/in.²)

FIG. 7

Many other conclusions might be added for particular metals, but it is believed that the foregoing summary gives a general survey, and affords a suitable basis for criticism of the theory that has been set forth.

The diagram fig. 7 represents two fatigue tests on samples of the same steel with different heat treatments, and serves to illustrate generally two typical forms taken by the hysteresis-time diagram. The total hysteresis measured may be regarded as comprising three parts: transient, or primary; continuous, or secondary; final, or tertiary.

Transient hysteresis has been ascribed above to gliding action, and is associated with all the phenomena of cold-work. It preponderates in static measurements of hysteresis, and in the earlier stages of fatigue tests on an annealed metal. Being usually completed long before the appearance of the rapid rise that signals the approach of fracture, and absent in many metals that are none the less liable to fatigue, it is not regarded as the direct cause of fatigue, but rather as an imperfect protection against fatigue.

Continuous hysteresis maintains a variable activity throughout the whole duration of a fatigue test, and, in a test-piece that is going to break, increases in magnitude for a long period before the appearance of the final rise. This continuous hysteresis is conceived to be due to the dual process, of decrystallisation and recrystallisation, that has been described as comparable with the process of solution and recrystallisation that occurs in a mixture of strained crystals immersed in their saturated solution. Continuous hysteresis is regarded as evidence of an action that is thermodynamically irreversible and mechanically irreversible, or reversible according as the metal will or will not eventually fail by fatigue.

Final hysteresis occurs immediately before fracture, and is regarded as evidence of the gradual extension of small cavities to form cracks. The action may be only a development of the preceding continuous hysteresis, but may differ in respect that it is often associated with gliding movements and ductile strain.

As regards the bearing of this theory, and of the foregoing experimental work, on the practical testing of fatigue in metals, it appears that the observation of hysteresis should be a useful weapon of research, adding greatly to the information derived from any fatigue test in which a considerable body of metal is subject to uniform range of stress.

IV.

Stresses in Bridges.

By J. S. Wilson, *A.C.G.I., Assoc.M.Inst.C.E., and* Professor B. P. Haigh, *D.Sc., M.Inst.C.E.*

In recent years the stresses in iron and steel bridge members have been investigated in detail, and have been demonstrated by experiment and mathematical analysis to be of a complex nature. The investigations have an important bearing on the choice of maximum or nominal stresses adopted in bridge design. The question of allowable stress and its complement, loading, in relation to railway bridges, has during recent years received a great deal of attention in America, India, and this country. Here and in India elaborate experimental researches are still in progress. These investigations were rendered necessary by the gradual increase in locomotive weights and the necessity of deciding on the renewal of some of the older bridges.

In this country we have the oldest railway bridges in existence, many of which have successfully carried all locomotives and trains without restriction for upwards of sixty years, and, as the stresses in these bridges have an important bearing on the subject, the system followed in their design is of interest.

Method of Design by Coefficient.

It is important to note that the strength of these early bridges and girders was not estimated in relation to the stresses in them till 1859. Before that time the working strength was always referred to the breaking strength of the girder, which was calculated from the dimensions with the help of a coefficient determined experimentally for the different types of girder section. Thus at about the date mentioned, Sir William Fairbairn wrote:

'After the completion of the Conway and Britannia tubular bridges, and during the early stages of wrought-iron bridge constructions, the engineers of this country, and the Board of Trade, had adhered to the principle that every bridge composed of wrought iron, whether designed upon the plate, lattice, or tubular principle, should have a resistance, tending to break the bridge, (*sic*) of six times the rolling load, exclusive of its own weight.[1]

'Owing to the success of these undertakings (the Britannia and Conway tubular bridges) there was a general demand for wrought-iron bridges in every direction, and numbers were made without any regard to first principles . . . so clearly and satisfactorily shown in the early experiments. The result of this was a number of weak bridges, many of them so disproportioned in the distribution of material as to be almost at the point of rupture with little more than double the permanent load.

'The defects and breakdowns which followed the first successful application of wrought iron to bridge-building led to doubts and fears on the part of engineers; and many of them contended for eight and even ten times the heaviest load as the safe margin of strength. Others, and amongst them the late Mr. Brunel, fixed a lower standard; and, I believe, that gentleman was prepared in practice to work up to one-third or two-fifths of the ultimate strength of the weight that would break the bridge. Ultimately it was decided by the authorities of the Board of Trade, but from what data I am not informed, that no wrought-iron bridge should with the heaviest load exceed a strain of 5 tons per sq. in.'[2]

The coefficient to give the breaking strength was used in the simple formula:

$$W = \frac{adc}{l}$$

W = breaking load in tons applied at centre of girder;
a = sectional area of flange in tension;
d = overall depth in inches;
l = length in inches between supports;
c = coefficient.

Applied to cast-iron girders, for instance, in which the tension flange had an area six times as great as the compression flange, the coefficient was 26. For wrought-iron tubular or box girders it was 80, for plate-web girders 74, and lattice girders 67.

These coefficients were based on experiments made on large-scale models, in which the most satisfactory distribution of sectional area for tension and compression was determined, and coefficients were applied to full-size girders with the metal in the flanges similarly distributed. This system, not being based on stress, did not assume a straight-line distribution of stress; but with a coefficient based on a breaking strength, when parts would be stressed beyond the yield-point, it must of necessity indirectly assume other than a straight-line distribution. Among the many famous iron bridges built on this coefficient principle are the Britannia and Conway tubular bridges ($c = 80$), and the Tay bridge (Highland Railway) ($c = 74$).

The introduction of the stress method revolutionised the system of design, and the distribution of stress had to be considered. The fixing of a stress of 5 tons per sq. in. as the maximum, without any details as to its application to different parts, led to great uncertainty, but also to further most important investigations. In applying the coefficient method the reduction of area by rivets in the tension flange had been disregarded, as it was also disregarded when determining the coefficients experimentally. The unexpected necessity of measuring the strength of a girder in a new unit with which engineers were not familiar naturally led to inquiries as to how the new standard compared with what had been proved by actual practice to be satisfactory. Fairbairn having at that date (1859) just completed the Spey bridge, and the Board of Trade taking exception to it on account of the stress being above 5 tons per sq. in., it was decided to make a test on a riveted girder roughly of the proportions of the Spey bridge. To quote Fairbairn: '. . . the Board of Trade threatened to stop the traffic which had been at work some months over the bridge. To make everything smooth, it was ultimately arranged that the bridge should be

[1] *Researches on the Application of Iron to Buildings*. W. Fairbairn.

[2] *Philosophical Transactions*, 1864, p. 316. 'Experiments to Determine the Effect of Impact, Vibratory Action and long-continued Changes of Load on Wrought-iron Girders,' by W. Fairbairn, LL.D., F.R.S.

strengthened up to the standard adopted by the Board of Trade, on condition that the Treasury should grant £150 to defray the expense of experiments to ascertain the durability, and the measure of strength to be allowed, of wrought-iron bridges, subjected to changes, shocks, and vibrations of a continued and variable load.'[1]

This fatigue test carried out on a riveted girder 20 ft. long is unique. Dr. W. C. Unwin, F.R.S., who assisted Fairbairn in making this remarkable experiment, which continued for two years, remembers the circumstances well and has kindly helped to supply information. The load was applied at the centre of the girder at the rate of about eight changes per minute and the shock was sufficient to make the girder vibrate vertically for some seconds at every application.

The details of the experiment are rather scattered among Fairbairn's books and Reports. Some particulars with additional figures are given in the appendix hereto.

The experiment proved that the metal of the girder would withstand over three million repetitions of a stress, accompanied by shock, of 6·25 tons per sq. in. on the net area, and we know now that if three million repetitions fail to rupture, the stress can be little if any greater than that which may be applied an unlimited number of times.

Notwithstanding the result of the experiment, the 5-ton limit remained unaltered, and this preliminary reference to the introduction of the stress system of design and the fixing of the 5-ton limit is given in order to emphasise the fact that the limiting stress fixed was not based on any very thorough investigation of the stresses in the successful or unsuccessful iron bridges built before the introduction of the new limit. Among the bridges still in daily use, therefore, we have, as stated in the extract from Fairbairn above, bridges designed intentionally with various factors of safety. The stress limit having been fixed, however, any disregard of it led to delay in the opening of new railway extensions,[2] consequently all new railway bridges *had* to be built to that limit. Although stipulated as the maximum, stresses in those days were only calculated approximately, and the 5 tons per sq. in. can only be regarded as a nominal stress.

Stresses Considered in Design.

Changes of stress in bridge members can be determined with considerable accuracy by strain meters, as has been done in the recent investigations. An increase of stress measured in this way[3] while an engine or train passes over at speed would generally be greater than that measured with the engine standing. Both these measured stresses would be different from the figure arrived at by calculation in the usual way even for the exact axle-loads of the engine and train. Denoting the several stresses by symbols, we have:

f_v = stress increase measured under travelling load;
f_s = ,, ,, ,, ,, standing load;
f_c = ,, ,, calculated for ,, ,,
f_d = stress due to dead load of structure.

The difference between f_v and f_s may be due to speed combined with its concomitant vibrations of bridge and load; that between f_s and f_c to the method of calculation not being sufficiently exact as to stress distribution or inclusion of secondary stresses.

The difference between f_v and f_s, though not actually measured in the early days, was nevertheless realised from the beginning, and some system was required for the graduation of the nominal stresses so as to enable bridge members to withstand the expected increase without damage. The next development was the preparation by several engineers and various railway authorities of designing specifications which, in addition to fixing the stresses, gave instructions regarding details of design and formulæ for compression members. Two distinct methods have been followed in drawing up these specifications.

[1] *Researches on the Application of Iron to Buildings.* W. Fairbairn.

[2] *See* reference to Torksey Bridge at Hull Meeting, *Engineering*, Sept. 15, 1922, p. 350.

[3] A stress deduced thus from strain must of necessity be the increase due to the live load. The dead-load stress cannot be measured, as the girder cannot be relieved of the dead load.

Graduated Stress Specifications.

In one is given a series of stresses, carefully graduated according to the length and character of the bridge member having regard to the relation of $f_d + f_e$ to f_d, and the expected effect of fatigue combined with the relative values of f_v and f_x.

The late Sir Benjamin Baker's well-known specification for steel main-line bridges is of this type and has been extensively used in the design of a very large number of bridges and other structures in this country and abroad. This specification was prepared in 1892 and published later.[1]

In another form of graduated stress specification, the graduation is done according to the range of stress. The following are examples of formulæ which have been used by two British Railways:

Maximum permissible stress in member or part,

$$= 4\cdot 66 \left(1 \pm \frac{\text{Minimum load or B.M.}}{2 \times \text{Maximum load or B.M.}}\right) \text{ tons per sq. in.}$$

$$= 4\cdot 0 \div \left(1 \pm \frac{\text{Minimum load or B.M.}}{2 \times \text{Maximum load or B.M.}}\right) \text{ tons per sq. in.}$$

These graduated stresses are obviously extensions of the simple stress limiting rule originally made by the Board of Trade. The type of specification may be called the graduated stress specification. It is perfectly definite and easy to apply and has many advantages over the alternative form.

Standard Stress and Impact Specifications.

The second type may be called the single or standard stress specification. In it the load or moment to be borne by any particular member is increased by a factor so that that larger load represents the increased or more damaging effect of the actual load travelling at speed and of any other influence. The particular member is then designed to carry this increased load on the basis of a standard maximum stress. This type of specification is of American origin, and there are many variations of it. One of the first formulæ for getting this increase of load to be added appeared

[1] The graduated stresses are as follows:

TENSILE STRESSES.

	Tons per sq. in.
For Main Girders, Cross Girders and Rail Bearers of plate construction:	
Under 20 feet span	$4\frac{1}{2}$
20 feet and under 25 feet	$4\frac{3}{4}$
25 „ „ 30 „	5
30 „ „ 50 „	$5\frac{1}{4}$
50 feet and above	$5\frac{1}{2}$
For Truss or Lattice Girders:	
80 feet and under 160 feet span—	
Bottom chords	$5\frac{1}{2}$
Diagonals	$4\frac{1}{2}$ to $5\frac{1}{2}$
160 feet and under 200 feet span—	
Bottom chords	$5\frac{3}{4}$
Diagonals	$4\frac{1}{2}$ to $5\frac{3}{4}$
200 feet to 400 feet—	
Bottom chords	6 to 7
Diagonals	$4\frac{1}{2}$ to 7
For wind bracing, all spans	$8\frac{1}{2}$
For floor suspenders „	$2\frac{1}{2}$

NOTE.—The $4\frac{1}{2}$ tons stress on the diagonals will apply to those at the central portion of the span, and to the counterbracing at the same point. The higher stresses will apply to those at the end portions of the span where the variations of stress are not so great. Intermediate diagonals will be subject to stresses lying between the two limits. The object in all cases of the varying working stresses is to guard against the relatively destructive action of suddenly applied loads on lightly loaded girders or members of girders, having reference both to the effects of impact and to the inferior ultimate resistance of material subject to considerable and frequent variations in stress. Special regard must be had to these conditions in the general design of the bridgework, and in the form and proportion of gussets and other minor details.

in a specification prepared by Mr. Schneider for the Pencoyd Co., and is now well known as the Pencoyd formula.[1]

The additional allowance termed 'impact' is based on the loaded length of the girder when the greatest load or bending moment is brought to bear on the member considered. The addition to the load thus made, taken in conjunction with the standard stress allowed, covers the necessary provision for fatigue and vibration, etc.

This formula and slight modifications of it have been very extensively adopted.[2]

Recent Investigations.

The question of bridge renewal in America led to the elaborate investigations made by the American Railway Engineering Association, from 1907 to 1909, described in their Bulletins of 1910. In addition to the question of loading, the important subject of impact was investigated and a modified coefficient $\frac{30,000}{30,000 + L^2}$ was adopted, as preferable to that in the Pencoyd formula.

The investigations of the Indian Railway Bridge Committee, carried out for the Government of India, were started in 1917 and are still in progress.[3]

The work has been directed principally to the consideration of the 'impact' question, and the possible substitution of a new formula for the Pencoyd one which was adopted for Indian Railway bridges in 1903.

The experimental work in this country has been done by the Ministry of Transport, and investigations made in 1920 are given in the Report of 1921.[4]

In that report the impact coefficient suggested is $\frac{120}{90 + L}$.

In connection with each of these investigations, a large number of experiments have been made in which strains taken on various lengths, and deflections of girders, have been measured with the object of getting values of $\frac{f_v - f_s}{f_s}$.

In some cases only the maximum strain during the passage of the load is measured, as with the La Touche gauge, and in others a complete photographic record of the

[1] Extract from the section book of the Pencoyd Co.:

'*Effect of impact.*—In proportioning the members of the structures, the effects of impact and vibration shall be considered and added to the maximum strains resulting from the above-mentioned engine and train loads. The effect of impact is to be determined by the following formula:

$$I = S \left(\frac{300}{L + 300}\right)$$

where I = impact to be added to the live-load strain,
S = calculated maximum live-load strain,
L = length of loaded distance in feet which produces the maximum strain in member.

'*Permissible Tensile Strains.*—All parts of the structure shall be so proportioned that the sum of the maximum loads, together with the impact, shall not cause the tensile strain to exceed:

On soft steel, 15,000 pounds per sq. in.

On medium steel, 17,000 pounds per sq. in.

The same limiting unit strains shall also be used for members strained by wind pressure, centrifugal force, or momentum of train.'

[2] An interesting comparative table giving the flange areas of rail bearers, cross girders, and main girders required to satisfy five representative specifications applied to a particular bridge has been prepared by Mr. Conrad Gribble, *Proc. Inst. C.E.*, vol. cc., p. 238.

[3] Indian Railway Bridge Committee:

1st	Report	1917,	Technical paper	187.
2nd	,,	1918	,,	198.
3rd	,,	1919	,,	211.
4th	,,	1920 Vol. I.	,,	224.
4th	,,	1920 Vol. II.	,,	225.
5th	,,	1921	,,	228.

See also Technical papers 194 and 199.

[4] Ministry of Transport, 'Tests on Railway Bridges in respect of Impact Effect,' 1921.

strains against a time base is made, as with the Fereday-Palmer instrument. The value of the ratio obviously depends on a large number of factors relating to the locomotive and train as well as the bridge itself, such as :

The moving load and its distribution among the axles.
Speed.
The unbalanced revolving and reciprocating parts.
Stiffness of springs.
Longitudinal and lateral oscillations of the loads.
Weight and various characteristics of stiffness, period of vibration, etc., of the whole bridge as well as of any particular part under investigation.

The analysis of the experimental records is difficult, owing to the large number of variable factors which affect the results. In some cases, to assist in the analysis of the strain-time records, the positions along the girders at which the effects of unbalanced weights would take effect have been recorded. These positions can be controlled within limits, but equally powerful influences, such as those of the pitching and rolling and side-lurching of a locomotive travelling at speed are so far uncontrollable.[1]

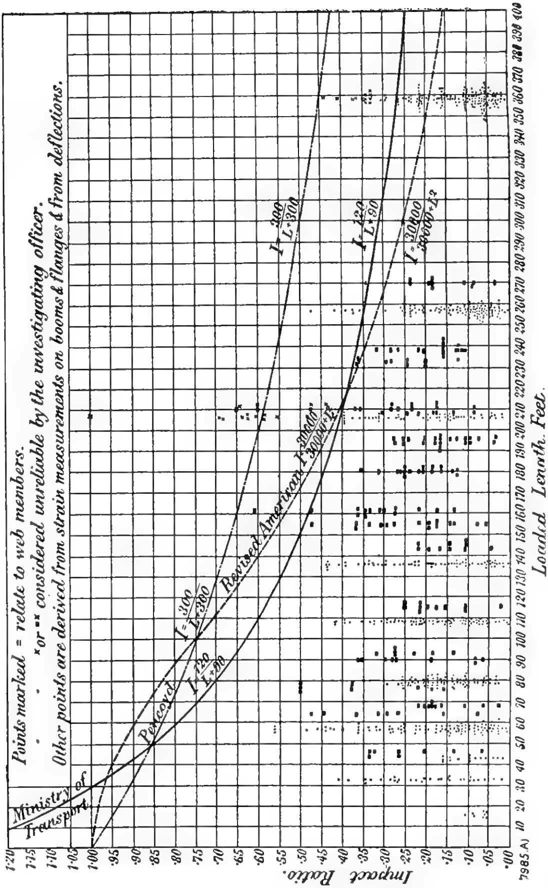
A very large number of measurements are available, 362 made by the Ministry of Transport, and about 3000 by the Indian Railway Bridge Committee, in addition to a large number of American records. Deflections and strains can be measured accurately enough under stationary and slowly moving loads; but when the movement is rapid, vibrations of the bridge and its parts combined with the inertia of the instrument have resulted in many of the records being considered of doubtful accuracy. The measurements made by the Ministry of Transport, and 1500 of those made by the Indian Bridge Committee, were taken with the Fereday-Palmer photo-recording instrument, a carefully designed and accurately made apparatus, the records of which are considered accurate. All the most accurately measured ratios of the Indian experiments are plotted in fig. 8,[2] in which the graphs of the various impact formulæ are also drawn. The points marked * are considered unreliable by the investigating officer because the 'measured static stress on which they are based are extremely low.' It will be seen that for each particular loaded length up to 200 feet the numerous ratios are distributed comparatively evenly over a range of from 0 to 45 per cent. The same ratios plotted against speed fall into no recognisable order, as the following figures show. For instance, the ratio for 18 miles per hour is higher than that for 45·4 miles per hour, and all that can be deduced is that generally they rise with increase of speed.

Speed. M.p.h.	Impact Ratio. Per cent.	Speed. M.p.h.	Impact Ratio. Per cent.	Speed. M.p.h.	Impact Ratio. Per cent.
7·8	7·5	30·2	36·0	39·7	28·0
12·0	3·5	31·7	22·5	40·8	36·5
16·5	10·2	32·3	32·0	43·8	20·0
18·0	36·0	34·3	25·0	44·3	56·0
18·5	32·0	36·7	22·0	45·4	33·5
24·7	43·5	37·0	45·0	46·3	46·0
25·7	17·5	37·8	20·0	49·6	56·5
27·2	16·0	39·0	31·0	55·6	46·0

[1] An instance is given by Baker in *Long Span Bridges* of the destructive effect of these influences. The platform and shallow cross girders of a bridge were completely destroyed in four years by locomotives of short wheel-base and long overhang, although the calculated stresses in the ironwork did not exceed 4 tons per sq. in.

Also the single very high impact ratio of 159 per cent. obtained by the Ministry of Transport in their experiments was measured on one side of a shallow-trough rail-bearer, a case where lateral movement and the exact lateral position of the application of the load would have a marked effect on the stress.

[2] From the Fifth Report, Indian Railway Bridge Committee.



Points marked ▪ relate to web members.
" " ×or ▪× considered unreliable by the investigating officer.
Other points are derived from strain measurements on booms & flanges & from deflections.
Ministry of Transport
Pencoyd
I = 300/(L+300)
I = 120/(L+90)
Revised American I = 30000/(30000+L²)
Impact Ratio.
Loaded Length Feet.

FIG. 8

The widely varying nature of these ratio measurements is obviously due to vibrations set up by the uncontrolled causes; indeed, ratios that would plot along a defined graph could hardly be expected. Exhaustive and very skilful attempts to analyse various strain-time records have been made by Messrs. C. W. Lloyd-Jones and H. S. Sales, of the Indian Bridge Committee, but even with the assistance of freely made assumptions the results are disappointing. The dominating causes in producing vibration are the kinetic characteristics of the moving load combined with the vibration periods of the bridge and its various parts, together with the degree to which one synchronises with the other. This leads to the unavoidable conclusion, suggested by Mr. Lloyd-Jones, that to interpret records requires both the locomotive and bridge to be 'calibrated' experimentally with respect to the above characteristics. With a calibrated bridge and calibrated locomotive a strain-time record taken with all variables under control could probably be analysed so as to determine the maximum ratio producible in members of that bridge by that locomotive.

In view of the above it seems obvious that, in making attempts to arrive at the impact ratio by measuring strains, the same load might be run over a bridge, under identical conditions so far as could be controlled, very many times before the maximum value on a member might be registered.

The solving of the impact ratio problem will therefore necessitate a large amount of research, for, with the variety of bridges and numerous types of more or less well-balanced locomotives, many combinations will have to be investigated.

Having attained exact maximum ratios, however, the likelihood of their taking effect except at long intervals would have to be considered in fixing the standard stress to be adopted with them.

An alternative course to that suggested above would be to treat a number of the older bridges as full-size experiments which have been under test for the last fifty or sixty years. Strain measurements under simple definite static loads would give the relation of actual stresses to those calculated in the usual manner, and similar measurements under stationary loads equal to those which the bridges have carried successfully at speed would provide nominal or basic stresses for guidance in design.

Choice of Standard or Graduated Designing Stresses.

Except in cases where design is considerably at fault, damage to a bridge is the result of the repeated loading and stressing of its members, and in nearly all cases the first signs are loose rivets and cracks which develop at rivet-holes and extend from them.[1]

It has been established that the resistance of steel and iron to fatigue by simple tensile and compressive stresses is dependent on the ratio of its yield strength to its ultimate strength and to the relation of the maximum and minimum stresses impressed on it. The maximum and minimum stresses are most conveniently expressed in terms of a steady stress with a push-and-pull pulsating stress added; thus:

Calling S = steady stress and A = pulsating stress,

then the maximum stress would be $S + A$;
and the minimum ,, ,, ,, $S - A$.

Fig. 9 represents to scale the general fatigue properties of a mild steel of about 22 tons per sq. in. ultimate strength. This was the quality used for some fatigue tests on thin perforated plates described at the Hull[2] meeting, and some details of them are given below.

The base line represents different 'steady component stresses,' S; Y represents the yield-point, and U the ultimate tensile strength. The ordinates represent the 'alternating component stresses,' A, applied in the fatigue tests. Any point in the diagram, with co-ordinates S and A, represents the combination of stresses applied in a particular experiment. The line YY′, whose equation is $S + A = Y$, may be described as the 'yield line'; thus the steel yields when the maximum stress, equal to $(S + A)$, exceeds the yield-point Y. In any fatigue experiment the stress-point

[1] Numerous instances are given in *The Anatomy of Bridge Work*, by W. H. Thorpe.
[2] *Engineering*, Sept. 8, 1922.

must be kept below this yield-line, since otherwise the metal will yield before fatigue can develop. In the thin plates used in the experiment buckling would occur if the minimum stress (S − A) became compression. Hence, as a second limitation in this instance, the stress-point must be kept below the line OZ, whose equation is A = S. Combining these two theoretical limitations based on the yield stress and non-reversal, we see that the stress-point must keep within the 45° isosceles triangle OTY, of which the apex T is the intersection of the loci OZ and YY′ which run at right angles to one another.

For a low tensile steel such as that used in the experiments, the ‘basic’ fatigue limit is about 45 per cent. of the ultimate strength, say 10 tons per sq. in. = A_0. That is, when S = zero, fatigue can occur only if A exceeds this value A_0. This point, marked

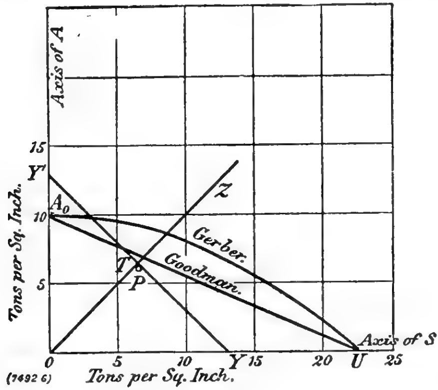


FIG. 9

on the axis of the diagram, is joined to the ultimate strength point U by two graphs: the one a parabola (A_0, Gerber, U) and the other a straight line (A_0, Goodman, U). According to Gerber and to Goodman respectively, fatigue can occur under different combinations of S and A only when the stress-point lies above the one or other locus respectively. Thus the metal is liable to fatigue when, and only when,

$$A > A_0(1 - (s/u)^x),$$

where the index x is to be taken as 2 according to Gerber, or 1 according to Goodman.

It will be observed that, in the scale diagram fig. 9, even the Goodman locus lies wholly above the triangle OTY, indicating that fatigue should not occur under the limiting conditions explained above. The Gerber locus lies still farther above this limiting triangle; and accumulated evidence[1] indicates, at least for mild steel as used in practice and in this investigation, that the Gerber locus is the more correct of the two. It appears, therefore, improbable that fatigue can occur under stresses within the yield range, unless these stresses reverse in direction—acting as pull and push alternately. This conclusion has been verified in an experiment (A) described below, using metal with a low value of the ‘yield ultimate’ ratio; and a further experiment (B) on steel with a high value of this ratio serves to limit the sphere of application of the conclusion.

In experiment **A**, the test-plate was $1\frac{1}{2}$ in. in width, narrowed to $\frac{3}{4}$ in. for a length of 1 in. in the middle, and joined to the ends by smooth transition curves such as would cause no appreciable concentration of stress. A fatigue test was made with S = $6\frac{1}{2}$ and A = 6 tons per sq. in., as represented by the point P (fig. 9) just below the apex of the limiting triangle. After 2·852 millions of cycles of stress the test-piece was still unbroken. The steady component was then increased to $7\frac{1}{2}$ tons per

[1] Haigh, *Brit. Assoc. Report of Stress Committee*, 1914.

sq. in., giving a maximum of 13½, and it was found that the test-piece yielded slowly but steadily.

Referring to fig. 9, it will be seen that the increase in S from 6½ to 7½ puts the stress-point just above the yield-line TY. Thus the non-occurrence of fatigue in the first test and the occurrence of yield without fatigue in the second are both in agreement with the theory given above.

To show that in steel having a high 'yield ultimate' ratio fatigue may occur under unidirectional stresses that do not suffice to cause elongation by yielding :

In experiment B, a test, similar to the above, was carried out on a sample of cold-rolled steel with Y = 45·5, U = 46·1 tons per sq. in., corresponding to a ratio Y/U of nearly 99 per cent. In this case the apex-point T is given by $S = A = Y/2 =$ 22·7 tons per sq. in. A fatigue test was made with S = 20 and A = 16, well within the

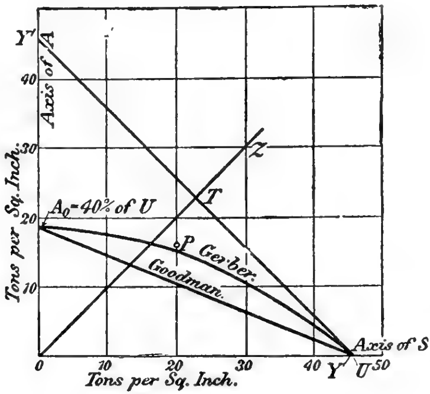


FIG. 10

triangle corresponding to OTY (fig. 10), and it was found that the test-piece grew quite warm and fractured after only 60,000 cycles of stress. The contrast between figs. 9 and 10 and the different behaviour of the two steels may be explained, in the first place, by the fact that the triangle OTY for the harder steel is relatively larger than for the soft one on account of the high ratio Y/U; and, in the second place, by the Goodman and Gerber lines being relatively lower for the hard steel because the ratio A_0/U is usually lower than the 45 per cent. value assumed for the mild steel.

These experiments were made with the Haigh alternating-stress testing machine,[1] on test-pieces shaped to secure uniform stress conditions and avoid concentrations at shoulders. In this machine the pulsations have a frequency of 2,000 per minute, and experiments have shown that the frequency of pulsation does not within wide limits appreciably influence the results of fatigue tests.

The perforations for rivets in bridge members introduce stress concentrations of great magnitude in the metal. In certain simple cases the local concentration of stress round an opening may be investigated mathematically; and the conclusions hold rigorously when the stresses lie wholly within the elastic range. Thus Dr. Suyehiro [2] has shown that for a circular hole in a plate of unlimited width the greatest stress occurs on a transverse diameter and is three times the mean intensity, and Professor Inglis [3] has extended the mathematical analysis to a variety of other openings.

The most common form of perforation in steel structures is of course the circular hole, which is more or less perfectly filled by the rivet. The exactitude of fit and the proximity of adjacent holes unquestionably affect the distribution of stress and present conditions too complex for mathematical treatment.

[1] *The Engineer*, July 29, 1921.
[2] *Engineering*, September 1, 1911.
[3] *Transactions Inst. Naval Architects*, vol. 55, p. 219.

Local concentrations of stress may be deduced also from experiments on elastic materials, and one of the authors [1] helped to measure these stresses in an exact representation of the filled rivet-hole of practice. A number of holes were made in a slab of rubber (9 in. wide, ⅜ in. thick) and accurately plugged with the same material.

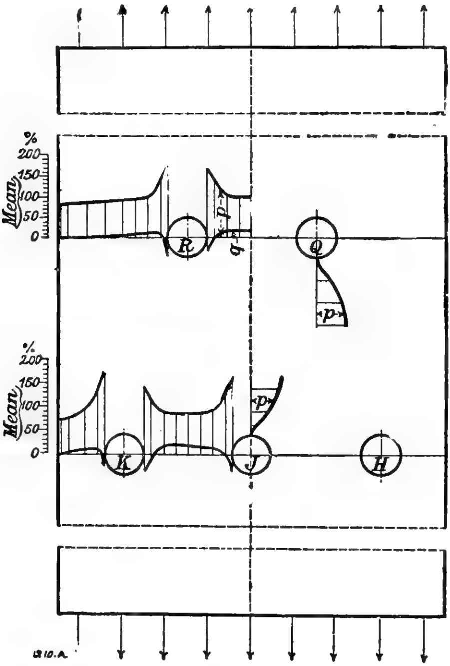


FIG. 11

The results are represented in fig. 11, and show that the maximum longitudinal stress at the sides of the holes is nearly double the mean stress. It will be noticed that, owing to the hole being filled, this longitudinal stress is accompanied by a transverse compressive stress.

Many other cases, including plates with circular perforations, have been investigated by Prof. Coker,[2] using perforated strips of celluloid and polarised light for determining the stresses.[3]

In cases that can be compared, the results obtained experimentally agree with the conclusions drawn from mathematical investigation, and the experiments on groups of holes show that when a number are pitched on a transverse section the maximum stress concentration is less than the three-times mean value applicable to a single hole in a wide plate, and depends on the ratio of the diameter to the pitch.

[1] Institution of Naval Architects, April 1911: experiments by Wilson and Gore described in discussion on Prof. Coker's paper. Also see *Engineering*, April 21, 1911.

[2] See Edinburgh Report of this Stress Committee; also Cantor Lectures, Royal Society of Arts, 1913.

[3] That stresses measured in celluloid and other materials truly represent the stresses sought within a negligible margin of error has been completely proved by Prof. L. N. G. Filon, F.R.S., Edinburgh Report of this Committee.

If these stress concentrations due to perforations seriously increased the liability to fatigue, only very moderate stresses could be used in practice. For instance, assuming that the steel used in a perforated member were of 30 tons per sq. in. ultimate tensile strength, and that its fatigue limit for pulsating unidirectional stress were 40 per cent. of this, say 12 tons per sq. in., then if the stress-concentration ratio were as great as 3 : 1, fatigue would be inevitable if the mean stress pulsated from zero to 4 tons per sq. in. This supposition is not supported by the results of the experiments.

The experiments were carried out by the authors on model plates 1½ in. wide and $\frac{1}{16}$ in. thickness, 6 in. in length. These dimensions were adopted to suit the testing facilities available, and to reproduce the proportions found in a typical full-size plate in a bridge member, 9 in. × $\frac{3}{8}$ in., with $\frac{15}{16}$-in. holes to suit $\frac{7}{8}$-in. rivets. To simplify the preparation of the test-pieces the holes were not plugged.

To test the stress-concentration effect under conditions more comparable with theory, a test-piece shaped as in experiment A and $\frac{3}{4}$ in. wide at mid-length was drilled with a very small hole in its centre line. The test-piece thus approximately fulfilled the conditions for giving a 3 to 1 magnification of stress at the margin of the hole on a transverse section.

The results of all these experiments are in agreement with what would be expected from practical experience with steel structures, for the stress concentrations appear to have little effect. The results are given in the following table. Test-pieces E had five holes side by side transversely, and the others had rows of three and two holes at various pitches giving a staggered arrangement. The stresses are calculated on the gross sections, for with staggered holes the net sectional areas cannot be given definitely; but if the net area ratios given in the table be assumed correct, it will be seen that these test-pieces withstood maximum stresses approximating to the yield stress, applied for from 0·45 to 1·2 million times before fracture. These numbers are high enough to indicate that a slight reduction of stress would enable the tests to stand an indefinite number of repetitions.

Experiment	E	E	G	F	F
Holes in rows	5	5	2 and 3	2 and 3	2 and 3
Pitch between rows	—	—	$\frac{1}{8}$ in.	$\frac{1}{4}$ in.	$\frac{3}{8}$ in.
Endurance millions	·908	1·224	0·538	0·534	0·456
S tons per sq. in.	4·01	3·24	4·18	4·89	5·13
A tons per sq. in.	2·76	2·78	2·87	3·50	3·67
(S+A) tons per sq. in.	6·77	6·02	7·05	8·39	8·80
(Net section) / (Gross section)	0·48	0·47	(?)	0·69	0·69
Holes deducted	5	5	(?)	3	3

Experiment D on the specimen drilled with the fine hole gave the following record:

Maximum stress 9·5, minimum 0·5 tons per sq. in. (S = 5, A = 4·5). Unbroken after 5·69 million.

Maximum stress 10·5, minimum 0·5 tons per sq. in. (S = 5·5, A = 5·0). Unbroken after 2·976 million additional repetitions.

Maximum stress 11·5, minimum 0·5 tons per sq. in. (S = 6·0, A = 5·5). Unbroken after 2·768 million additional repetitions.

Maximum stress 12·5, minimum 0·5 tons per sq. in. (S = 6·5, A = 6·0). Fractured after a further 0·998 million repetitions.

These stresses are calculated on the gross sectional area.

The test proves that, in spite of stress concentration, a stress closely approaching the yield stress (about 13 tons per sq. in. for the material) was necessary to fracture by fatigue.

In each of the tests failure occurred by cracks starting at the holes. They always developed at the ends of the transverse diameters of holes and extended along the transverse section. Adjacent holes, placed comparatively closely but not on the same transverse centre line, do not appear to affect the development of the crack or cause it to deviate from the transverse path.

From the general point of view, therefore, with material having a low yield-ultimate ratio as in mild steel, in the case of simple direct stresses the concentrations caused by rivet-holes do not greatly affect the endurance of the metal, so that under these conditions, if the real maximum stress could be accurately anticipated, then a standard stress a little below the yield-point could be adopted.[1]

Nevertheless, as is shown by the above experiments, fatigue can occur in perforated mild-steel pieces subject to unidirectional stresses; and it is desirable and important to avoid arrangements of rivets that produce undue concentrations of stress. This is particularly true for metals having comparatively high yield-points, for if higher stresses were allowed in such metals, fatigue would become imminent as indicated in Fig. 10. But even in very mild steel it is desirable that the range of alternating stress (A) should not exceed some definite fraction of the basis fatigue range (A_0) no matter what value the steady stress may have. The values of this fraction, it is hoped, may be determined—for different perforations and joints—in the course of further experiments.

If a high stress approaching the elastic limit be fixed as the standard for design, the stresses must be exactly calculated, allowing for secondary stresses in order to arrive at the actual stresses in the members, and the impact allowance must also be known with certainty, for the margin of strength, or, more exactly, margin of endurance, will be in the difference between the yield stress and the standard stress and in the impact allowance.

The conception of 'factor of safety' has to be considerably modified when strength is related to endurance. The record of the test D shows that a maximum stress of 11½ tons per sq. in. could be endured millions of times, but that anything above 12½ would have produced fracture in a few thousand repetitions. Assuming the load and impact damaging effects to be at their maximum and repeated uniformly, a member designed on a standard stress of, say, 11½ tons per sq. in., to use the above figures, would do its work for an indefinite period, whereas, if designed on, say, 12¾ tons per sq. in., it would not immediately fail, but would deteriorate rapidly. The factor of safety cannot be related to these two stresses or to the number of repetitions necessary to produce failure in each case.

Considering two such comparative designs with respect to normal traffic conditions, the occurrence of the maximum impact effect, depending on the worst engine and train combination travelling at a critical speed, might be so infrequent that the 12¾ stress design would show no more signs of deterioration than the other, and both would have a substantial margin.

Evidence of the magnitude of impact factors and the frequency with which maximum impact effects occur is afforded by the bridges which have withstood such effects for many years. For instance, if in a girder the measured maximum stress under a stationary locomotive or train were 9 tons per sq. in., it is certain that the impact factor cannot have been 100 per cent.; it is equally certain that the margin in the strength of the girder has been sufficient to withstand all the impact effects. It is for reasons similar to that suggested above that the measurement of actual static stresses in proved bridges promises a solution of the impact question. Measured stresses could be related to stresses as calculated in the usual way, and nominal working stresses adapted to different conditions could be fixed.

The Relation of Measured Strains to Actual Stresses.

By means of extensometers and recording strain-meters, strains in bridge members caused by stationary or slowly moving loads can be accurately measured. With rapidly moving loads the vibration of the bridge member, combined with that of the moving parts of the instrument, render the strain measurements less reliable, although the strain records obtained with Fereday-Palmer photographic instruments are considered very satisfactory. The conversion of the measured strains to the actual stresses introduces some difficulties. The rivet-holes in bridge members introduce

[1] It is interesting to note that where the permissible stress has to be raised to its highest limit to avoid rebuilding old bridges, in one instance the elastic limit has been fixed as the standard stress by one of the American Railways.—Indian Railway Bridge Committee, Fourth Report, vol. ii.

stress concentrations and alter the elastic properties, and the modulus of elasticity applicable to an unperforated plate cannot be used to get the stresses accurately; a corrected modulus is necessary.

The writers have found no records of experiments on the effect of the perforation on the modulus, and made the experiments of which details are given in fig. 12. The two test-pieces measured $1\frac{1}{2}$ in. wide by about $\frac{1}{16}$ in. thick and 12 in. long; one was plain and one had holes drilled along its length, so that it formed the model of a plate 15 in. wide, $\frac{7}{8}$ in. thick, with holes $\frac{7}{8}$ in. diameter at 3 in. pitch. Both were of the same mild steel. The strains measured with a Ewing extensometer are plotted in fig. 12 as parts in 10,000. The full lines represent the first measurements on an increasing

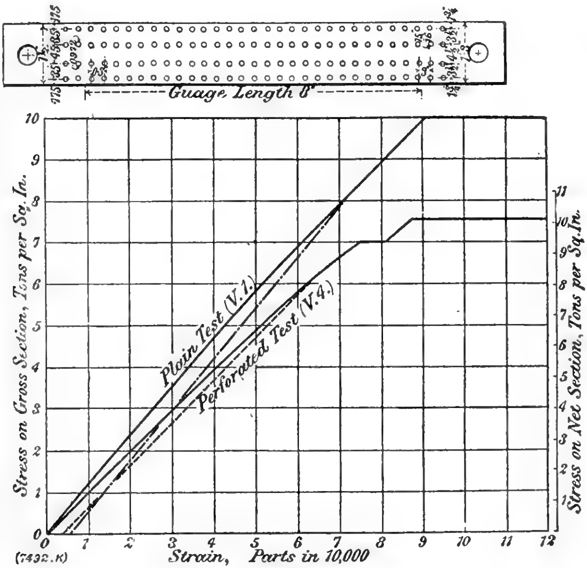


FIG. 12

stress, and the dotted ones represent the elastic lines up and down which the strains lay after the stress had been carried up to about 8 tons on the net area in each case. The modulus corresponding to the dotted line of the plain test is 12,150 tons per sq. in., and to that of the perforated plate 10,150 tons per sq. in.[1]

In applying the corrected modulus it saves confusion to apply it to the gross area. Thus in the experiment, assuming the area to be 1 sq. in., the change in load to produce a strain of 4 in 10,000 was 4·86 tons, and on the perforated plate the change in load for the same strain was 4·06 tons total. This load converted into stress on the net area (0·741 of gross) would equal 5·48 tons.

[1] The ratio of the two moduli $\frac{10{,}150}{12{,}150} = 0{\cdot}835$.

In comparison

the ratio $$\left(\frac{\text{volume of perforated plate}}{\text{volume of plain plate}}\right)^2 = 0{\cdot}870,$$

and $$\sqrt{\frac{\text{net length along perforations}}{\text{gross length of plate}}} = 0{\cdot}822.$$

The error introduced by not applying the corrected modulus in this example would be as follows:

Correct mean stress on gross area	$0 \cdot 0004 \times 10{,}150 = 4 \cdot 06$ tons per sq. in.	
Approx. ,, ,, ,,	$0 \cdot 0004 \times 12{,}150 = 4 \cdot 86$,, ,, ,,	error 20%.
Correct mean stress on net area	$0 \cdot 0004 \times 10{,}150 \div 0 \cdot 741 = 5 \cdot 48$ tons per sq. in.	
Approx. ,, ,, ,, ,,	$0 \cdot 0004 \times 12{,}150 \div 0 \cdot 741 = 6 \cdot 56$, ,, ,, ,,	error 20%.

The discrepancies often found between calculated stresses and those deduced from measured strains are no doubt partly due to inaccuracy in the modulus, as well as to stiffness of end connections, etc.

Conclusion.

The intricacies of the problem suggest that useful progress can best be made by experiment and measurement undertaken in a systematic manner.

The course by which the required knowledge can be most readily acquired would appear to be by treating existing bridges as full-size experiments. What can be done in this direction was demonstrated in the extremely valuable paper by Messrs. A. C. Cookson and J. S. Nicholas [1] read at the Hull Meeting.

A bridge's history and the traffic it has carried is on record, and the strengths and stresses can be determined as accurately as required; also the loads they have carried can be related to the stresses calculated in the usual simple manner.

With this information, by the use of similar calculations and similar nominal stresses, girders with the desired endurance could be designed. This course avoids the numerous difficulties of secondary and indeterminate stresses to which reference was made at the Hull Meeting by Mr. Conrad Gribble [2] in a paper full of valuable suggestions.

The investigations outlined above, together with some experiments to determine the relative damaging effects of want of balance in old locomotives compared with new ones, would permit of allowances being made for changes of that nature. As suggested by Mr. Gribble, the testing to destruction of old bridges on their removal from service would provide valuable additional data, especially if fatigue tests were applied.

The other course, which necessitates the establishment of accurate allowances for impact and a standard stress, has, in addition to the impact difficulties, to overcome that of fixing the stress and details of the method of its application.

Some of the difficulties are reflected in the following resolution [3] passed by the Indian Railway Bridge Committee after four years' work:

'After carefully studying the Fereday-Palmer extensometer records of 1500 tests on bridges of spans varying from 15 feet to 358 feet on the North-Western Railway, the Committee are of opinion that, although these tests do not afford sufficient information to warrant their recommending any modification of the Pencoyd formula for impact at present, the records indicate that a single load concentrated at the main driving-axle of each engine passing over a bridge more accurately represents the true allowance for impact than a uniformly distributed load. The Committee are also of opinion that many more tests are required before a scientific formula covering all sources of impact can be evolved.'

APPENDIX.

Fatigue Test of a Riveted Girder 20 Feet Long, made by Sir William Fairbairn.

Particulars of the experiments are given in the Report published by the Board of Trade [4] in 1864, and additional information will be found in various papers and in Fairbairn's books.

[1] *Engineering*, September 8, 1922.
[2] *Engineering*, September 8, 1922.
[3] Indian Railway Bridge Committee, Fifth Report.
[4] Report of Mr. Fairbairn to the Board of Trade, Command Paper 1864.

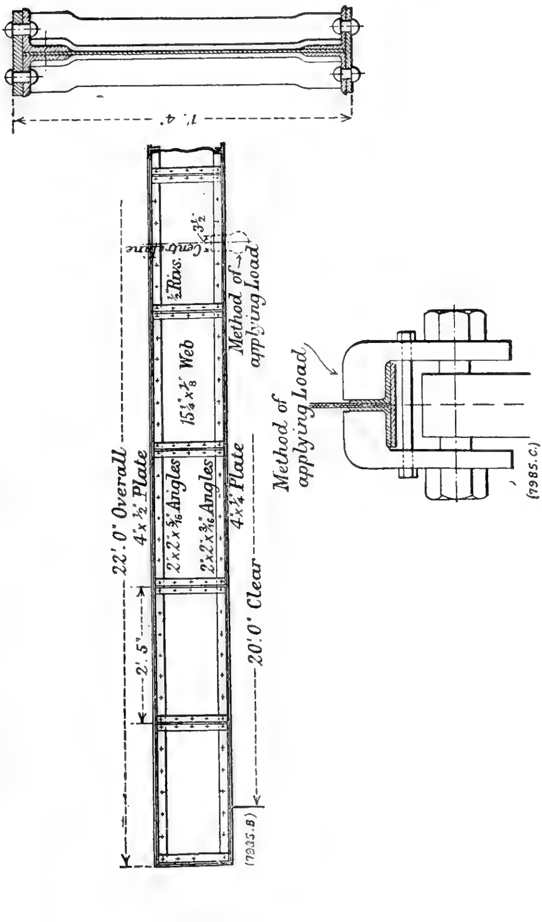

1' 4"
22' 0" Overall
4"x½" Plate
2"x2"x5/16" Angles
2"x2"x3/16" Angles
4"x¼" Plate
15¼"x⅛" Web
½" Rivs.
Centre Line
3½"
Method of applying Load
Method of applying Load
2' 5"
20' 0" Clear
(7985.B)
(7985.C)

Fig. 13

The results of the tests and calculated stresses are given in the table opposite.

It is unfortunate that exact details and observations of this very remarkable fatigue test are not on record. Full details of the girder are not available. The plates attached to the Board of Trade Report have been assumed correct in preparing fig. 13. The total weight is given by Fairbairn as 7 cwt. 2 qrs., but the weight of the girder shown (assuming the stiffeners to be double 3″ × 1½″ × ¼″ tees joggled on to the main angles) is below that figure.

The rivets were ½ in. diameter and arranged as shown in elevation; the pitch would be about 4½ inches. The arrangement of riveting in the flanges is not shown. In estimating the net area of the bottom flange it has been assumed that there were two rivets in line breaking pitch with the rivets in the vertical legs of the angles. It is important to note, however, that in Fairbairn's calculations of the stresses in the net area he has deducted 0·625 sq. in., which is the area of the three rivet holes.

The stresses given in the table have been calculated in the following ways:

Fairbairn's, by the formula

$$\text{stress} = \frac{w}{4\,ad}$$

l = span in inches, taken as 240, the clear span;
w = the weight at the centre in tons;
d = overall depth (16 in.);
a = area of the flange, the total sectional area of the plate and two angles (2·4 sq. in. gross, 1·775 sq. in. net).

Method I. (*a*), by moment of inertia, ignoring the rivet holes and then increasing the stress in the ratio of the gross to net areas. Two rivets allowed for. The span of girder taken as 21 feet.

Method II. (*a*), by moment of inertia calculated with the two rivet holes out. Span, 21 feet.

The testing arrangements were intentionally made so that the load should be applied with a jarring effect, and under (*b*) of Methods I. and II. an increase of from 7 to 10 per cent. is made for the velocity with which the load was probably applied.

Illustrations of the testing arrangements indicate that the load was applied to the bottom flange, as shown in fig. 13. Severe secondary stresses must have been set up in the flange with every loading, and although the calculated stresses required to cause failure were comparatively high, they would probably have been much higher had the load been applied to the top flange. The distance from the centre of the point where the flange failed is not recorded.

The endurance of some of the rivets is remarkable. In referring to the first test, Fairbairn writes: 'It is satisfactory here to observe that during the whole of the 1,005,175 changes none of the rivets were loosened or broke.' At the centre of the beam the rivets holding the lower angles to the web must have been very severely loaded. The 4-ton load, if taken by the three nearest rivets, would give a bearing pressure of 21·3 tons per sq. in., but a shearing stress of only 3·4 tons per sq. in.

A second experiment was made on the same beam. It was 'repaired by replacing the broken angle-irons on each side, and putting a patch over the broken plate equal in area to the plate itself.' The results of the second test are given in the table.

Dates	Weight on Middle of Beam	Deflection	Number of Changes	Stresses given by Fairbairn on Bottom Flange		Stresses on Bottom Flange calculated by Moment of Inertia Tons per sq. in.					Remarks
				On Gross Area	On Net Area	On Gross Area	On Net Area				
							Method I		Method II		
							(a)	(b)	(a)	(b)	
	Tons	Inch		Tons per sq. in.	Tons per sq. in.						
March 21 to May 14, 1860	2·96	0·17	596,790	4·62	6·25	4·66	6·21	6·85	5·36	6·86	
May 14 to June 26 .	3·50	0·22	403,201	5·46	7·39	5·51	7·35	7·96	6·34	6·86	
July 25 to July 28 .	4·68	0·30 Total :	5,175 1,005,175	7·31	9·88	7·37	9·83	10·51	8·47	9·06	'Broke by tension a short distance from the middle of the beam.'
Beam repaired											'The apparatus was accidentally set in motion.'
August 9, 1860	4·68	—	158	7·31	9·88	7·37	9·83	10·51	8·47	9·06	'With this weight the beam took a large but unmeasured set.'
Aug. 11 and 12	3·58	0·22	25,742	5·59	7·56	5·64	7·52	8·17	6·48	7·04	
Aug. 13 to Oct. 16, 1861	2·96	0·17	3,124,100	4·62	6·25	4·66	6·21	6·85	5·36	5·90	
Oct. 18, 1861, to Jan. 9, 1862	4·00	0·20 Total :	313,000 3,463,000	6·25	8·45	6·30	8·40	9·23	7·24	7·96	'Broke by tension as before, close to the plate riveted over the previous fracture.'

V.

The Distribution of Stress in Round Mild Steel Bars under Alternating Torsion or Bending.

By Professor W. Mason, *D.Sc*

Abstract.

The distribution of stress in round bars overstrained in alternating torsion or bending is studied with the object of finding a relation between stresses in hollow and solid specimens.

The probability of linearity of strain distribution is discussed.

Alternating torsion or bending of round bars leads to a condition in which the range of strain, at a given range of torque or bending, increases to a stationary value, provided that such given range is less than the fatigue range and greater than the primitive elastic limit range.

For mild steel in this stationary condition of strain the following assumptions are made concerning the distribution of strain and stress throughout the body of the specimen at instants of maximum strain of the cycle :

(1) A distribution of strain linear from axis to skin.

(2) (*a*) A distribution of stress conforming to Hooke's law (*i.e.* of perfect elasticity) from the axis for a portion of the radius. (*b*) For the remainder of the radius, a relation between stress and strain similar to the linear relation found experimentally between the ranges of strain and stress in thin-walled tubular specimens in alternating torsion.

Applying these assumptions, it is found that the results of certain alternating tests of solid specimens in torsion become practically identical with those of hollow specimens, and that the results of the author's alternating tests of hollow and solid specimens in bending (bending always about the same axis) are in fair agreement.

The author concludes that the difference between (*a*) fatigue stresses calculated from the range of torque or bending moment on the usual assumption of linearity of stress, and (*b*) the actual fatigue stresses, must be greater than is commonly supposed for solid specimens, and also for hollow specimens in alternating bending.

Aim of the Work.

When the elastic limit of a round bar has been exceeded in bending or torsion, the stress in it is unknown, except in the case of a hollow bar with thin walls under torque. If the stresses are cyclic, as in a torsion or bending fatigue test, the range of stress throughout the body of the specimen follows a straight line distribution only so long as the elasticity is unimpaired. If the ranges of stress at the skin of the specimen are calculated, as is usual, by a formula which is founded upon linearity of stress, considerable error results, even when the ranges of stress are of the magnitude that produce fracture by fatigue. One object of this paper is to form an estimate of the amount of this error in accordance with certain experimental data.

Linearity of Strain Distribution.

Imagine a wedge bounded by a pair of planes passing through the axis of a round bar and by a pair of planes perpendicular to the axis of the bar. Suppose that the bar is overstrained in torsion. Linearity of strain entails that the latter pair of planes

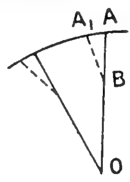


Fig. 14

remain plane after the overstraining, and that the radial lines of intersection of the two pairs of planes remain straight lines. Suppose these radial lines do not remain straight, but take any deviation from the radial direction such as shown by the dotted lines in fig. 14. Now at each section normal to the axis the relative position of lines

A_1B and BO must be identical, and any distortion producing an angle such as A_1BO must be common to every section, except perhaps near the ends of the twisted specimen. A displacement of A to A_1 at each section would be due to a sliding or distortion common to each portion along the length of the specimen, and a distortion of this kind would not be produced by equal and opposite torsional couples except perhaps near the gripped ends. Thus any deviation of these radial lines AO from straightness is difficult to imagine for torsional strain of the amount met with in fatigue tests.

Consider a uniform bar under a bending moment uniform over its length—the conditions the author is herein concerned with. It is clear that the strained shapes of equal slices A and B (fig. 15) must be exactly alike, and that such slices must fit

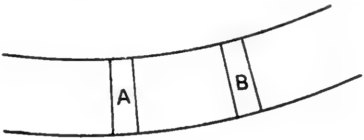


FIG. 15

together to make the strained whole. It seems impossible that these conditions can be fulfilled unless the sectional surfaces of the slices remain plane. It appears to the writer—possibly, however, by defect of imagination—that any other than linear distribution of strain is not conceivable.

In the following work linearity of strain distribution will be assumed. In the tests to be cited, the strains at the skins of the specimen were measured; with linearity of strain distribution from the axis, the strains at any radius are, of course ascertainable.

Stress-Strain Curves for Alternating Stress Tests.

If a test-specimen is subjected to increasing stress of equal + and − maxima a series of hysteresis loops is obtained such as shown in fig. 16. At any one constant range of stress the width of the loop increases, and if the range of stress is not too great, this width increases to a maximum value and remains constant at that value. The increase of width to a maximum is illustrated by curves in a former paper by the writer.[1] We will suppose that the loops of fig. 16 represent a series of these constant maximum loops for a corresponding series of increments of stress. We may suppose that the loops are obtained for increments of either torsion or bending. The loops then represent the cyclic stress-strain condition at the skin of the specimen when constancy of cyclic strain has been reached. The writer has found that points such as B_1 C_1 D_1 lie on a straight line when the ordinates parallel to OY are the semi-ranges of the torque (or bending moment); or when (what amounts to the same thing) the ordinates are semi-ranges of stress at the skin calculated from the torque or bending moment by the formula founded on the assumption of perfect elasticity. In the writer's experiments the ranges of strain at the skin—not the whole loop—were observed; and the stress-strain curves (an example of which is the curve ORDF of fig. 20) from which he begins his argument are of values of these ranges (or rather semi-ranges), when constancy of range has been reached, plotted to the semi-ranges of stress calculated on the assumption of perfect elasticity.

Considering an abscissa ON of any point C_1 on B_1 C_1 D_1 (fig. 16) with linearity of strain from the axis outwards, the strain at any radius r in the body of a specimen of outside radius r_0 will be $\text{ON} \times \frac{r}{r_0}$ at the epoch when the constant value of the skin-strain ON has been reached at a range of 'calculated' stress NC_1. That is, distances from O along the x-axis represent, to the scale on which ON represents the semi-range of strain at the skin, the semi-ranges of strain at corresponding radii; in other words, at any one such epoch, abscissæ represent both radii and semi-ranges of strain at those radii.

[1] *Proc. Inst. Mech. Eng.*, Feb. 1917. See fig. 8, p. 129; fig. 12, p. 134.

Though the strains are known at any epoch of constant strain-range, the real stresses are not known, even at the skin. Consider the epoch at which the semi-range of skin-strain is ON_1, and suppose the stress calculated from the torque by the usual formula on the assumption of perfect elasticity (*i.e.* on assumption of linear stress distribution) is represented by N_1D_1. If the strain and stress each vary as the distance from axis, then the strain and stress must be proportional to each other, which is obviously wrong, except for regions of the bar near the axis. This point may be illustrated (fig. 16) by joining the points O and D_1; the straight line OD_1 represents proportionality between stress and strain from axis to skin. It is clear that both stress and strain cannot have a linear distribution. If the stress did vary as distance from axis, then the distribution of strain, in the case of torsion of a solid round bar, would be represented by some line, not straight, such as A_1BO in fig. 14. As mentioned previously, such a distribution of strain is scarcely conceivable. It

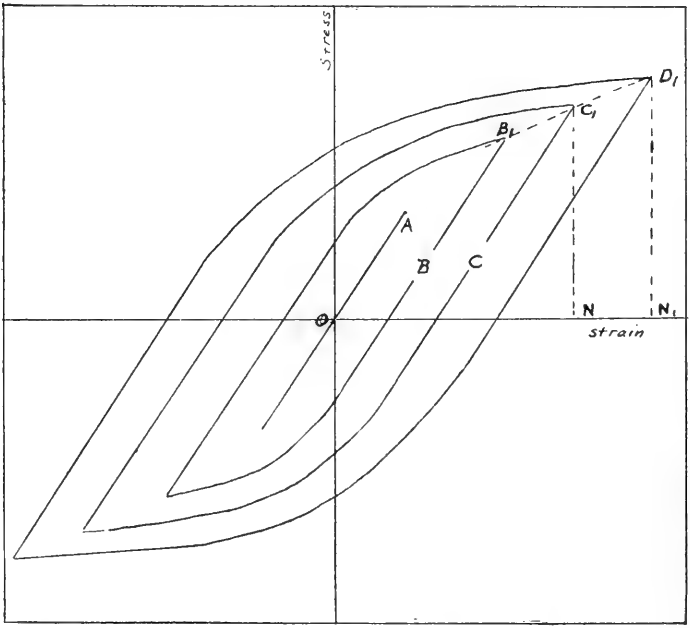


FIG. 16

seems clear, then, that the stress cannot have a linear distribution, except near the axis, where the elasticity will not be impaired. Part of the real stress-strain graph through the body of the bar will evidently be the line OA for all epochs such as mentioned above. In order to ascertain, if possible, the parts of the true stress-strain curve, other than OA, for any epoch of the test (an epoch immediately subsequent to a number of cycles sufficient to establish constancy of ranges of stress and of strain throughout the specimen is considered only), it is necessary to examine the true stress-strain curve for a thin-walled tube under alternating torsion.

Hollow Tubular Specimens under Alternating Torsion.

If the thickness of wall is less than about 20 per cent. of the radius of the tube, the actual stress at the middle of the wall can be calculated with very little error. Whatever may be the variation of stress through the wall, it is obvious that the stress at the mean radius of the tube will be very little different from the stress calculated on the assumption of uniform distribution of stress throughout the tube-wall.

Let q_u = shear stress on assumption of uniformity of stress,
r_0 = outside radius of tube;
r_1 = internal radius of tube;

then the resisting moment of the section

$$= \frac{2\pi q_u}{3}(r_0^3 - r_1^3).$$

Let q_m = real stress at middle of tube-wall, then q_m cannot differ appreciably from q_u.

And resisting moment $= \frac{2\pi q_m}{3}(r_0^3 - r_1^3)$.

Now, since it has been convenient to express the resisting moment in terms of the stress at the skin ($= q_c$, say) calculated on the assumption of linearity of stress,

$$\text{Resisting moment} = \frac{q_c}{r_0} \cdot \frac{\pi}{2}(r_0^4 - r_1^4).$$

Hence

$$\frac{2\pi . q_m}{3} \cdot (r_0^3 - r_1^3) = \frac{q_c}{r_0} \cdot \frac{\pi}{2} \cdot (r_0^4 - r_1^4),$$

and

$$\frac{q_m}{q_c} = \frac{3}{4} \cdot \frac{1 - r_1^4/r_0^4}{1 - r_1^3/r_0^3}$$

This formula has been used to calculate the values of q_m for four mild-steel tubular specimens—viz. B22, B27, A10, and A2. Full data concerning these will be found in the former paper referred to by the author.[1] Table I. gives certain data taken from that paper, as well as other items of which use is now to be made. These specimens were not made to the same dimensions, though all were of the same general form.[2] It has been convenient to reduce the observed scale readings—in cms. (which are proportional to the angle of twist)—to values of the shear strain. This has been done by assuming that the elastic modulus of rigidity was the same for each specimen. All the four specimens were from the same batch of steel; B22 and B27 were cut from one long bar, and A10 and A2 from another bar. The value of the elastic modulus has been assumed to be $12 \cdot 1 \times 10^6$ lb. per sq. in., a value which is consistent with other measurements made while each specimen was below the elastic limit. Thus, for specimen B22, a range of 5·86 cm. of scale was observed under a range of stress of $\pm 5 \cdot 00$ tons per sq. in. If F is a factor for converting cm. on scale to strains at the skin, then—

$$\frac{5 \cdot 00 \times 2240}{5 \cdot 86 \times F} = 12 \cdot 1 \times 10^6,$$

and

$$F = \frac{5 \cdot 00 \times 2240}{5 \cdot 86 \times 12 \cdot 1 \times 10^6} = 1 \cdot 58 \times 10^{-4}.$$

Factors F, given in Table I., have been calculated for each of the four specimens using the same value of modulus, $12 \cdot 1 \times 10^6$. In this table, strains at the skin for each specimen are given for a number of epochs when the range of strain had become constant. The number of cycles is not in all cases sufficient to make the range of strain quite constant; but constancy of range had been approximately attained, at least, in each case. The curves of fig. 17A have been plotted from the values of the strain and stress (at middle of tube-wall) given in Table I.

These curves have, by reason of the method of plotting just described, a common elastic line, whose inclination is $12 \cdot 1 \times 10^6$ lb. per sq. in. The curves then turn away

[1] *Proc. Inst. Mech. Eng.*, Feb. 1917.
[2] *Ibid.* See fig. 1, p. 122.

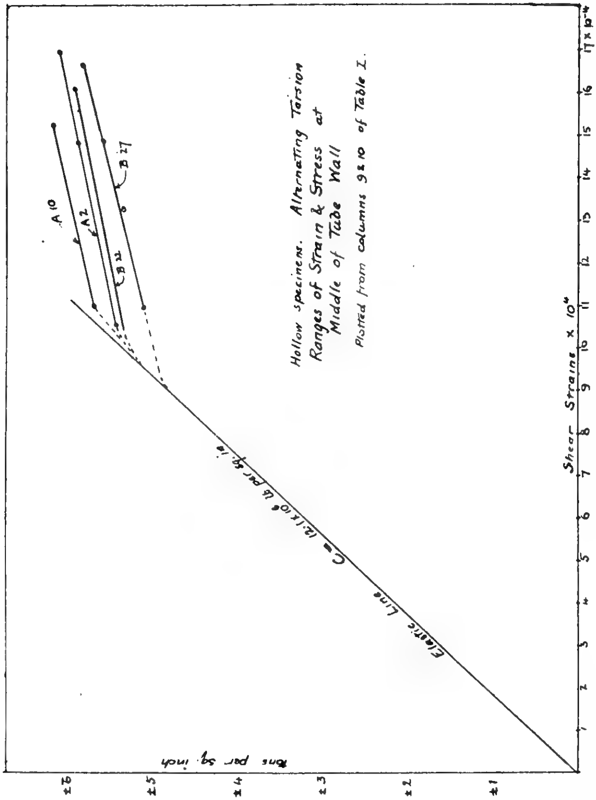

Hollow specimens. Alternating Torsion
Ranges of Strain & Stress at
Middle of Tube Wall
Plotted from columns 9 & 10 of Table I.
A 10
A 2
B 22
B 27
Elastic Line
Tons per sq. inch
Shear Strains × 10⁴
±1
±2
±3
±4
±5
±6
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17 × 10⁻⁴

FIG. 17A

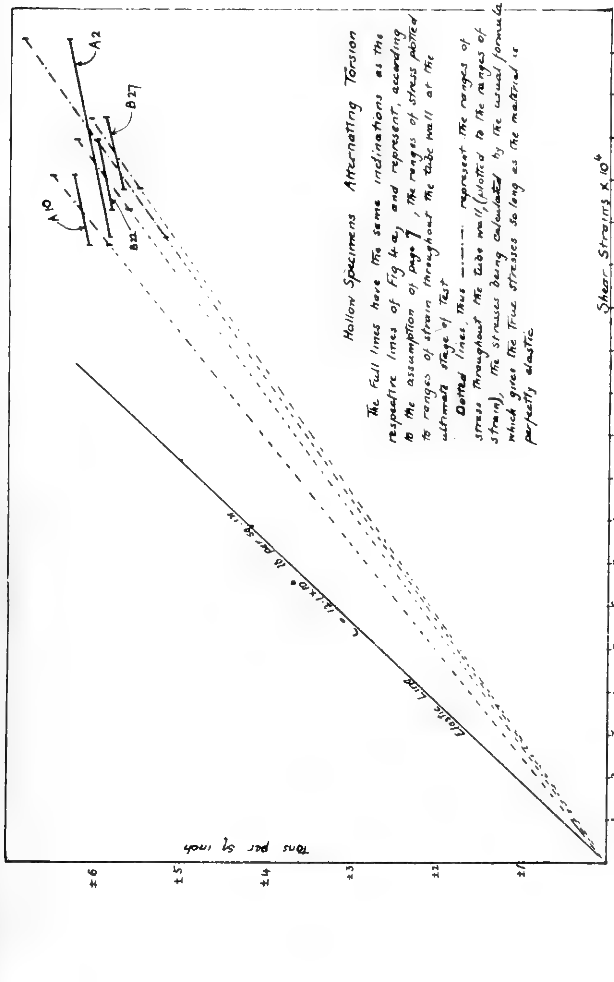

Hollow Specimens Alternating Torsion
The Full lines have the same inclinations as the respective lines of Fig 4a, and represent, according to the assumption of page 7, the ranges of stress plotted to ranges of strain throughout the tube wall at the ultimate stage of test.
Dotted lines, thus ——·—· represent the ranges of stress throughout the tube wall (plotted to the ranges of strain), the stresses being calculated by the usual formula which gives the true stresses so long as the material is perfectly elastic
A2
B27
A10
B22
Elastic Line
Tons per sq inch
Shear Strains × 10⁴
±1
±2
±3
±4
±5
±6

FIG. 17B

at their respective elastic limits (under torsional cycles), and afterwards proceed in sensibly straight lines, whose inclination is nearly the same. The average inclination of these lines corresponds to a value of $\frac{\Delta\,(\text{stress})}{\Delta\,(\text{strain})} = 2\cdot 50 \times 10^6$ lb. per sq. in. This stress is not a 'modulus of elasticity,' but it will be convenient to denote it by the symbol C′, while the elastic modulus $12\cdot 1 \times 10^6$ is denoted by C. The ratio $\frac{C'}{C}$ for these four specimens is thus approximately $0\cdot 225$. The feature of these curves, then, is that for increments of range of stress beyond the elastic limit—the cycles at a range of stress being continued until the strain attains a constant value—the increment of range of strain is proportional to the increment of range of actual stress. This proportionality, it will be observed, is for the middle of the tube-wall.

Distribution of Stress throughout Wall of a Tube subjected to Alternating Torsion.

The distribution of stress throughout the tube-wall has not entered into the preceding calculation, the stress at the middle of the wall only having been calculated and plotted in fig. 17A.

Let RS (fig. 18) represent a curve like those of fig. 17A. At an epoch 1, after cycles of an actual range of stress $\pm B_1S_1$ (at the middle of tube-wall), numerous enough to attain constancy of strain at this range of stress, let the constant semi-range of strain attained be OB_1 at the middle of wall.

Set off a length B_1B_2 such that $\frac{B_1B_2}{OB_2} = \frac{r_m - r_1}{r_m}$, where r_1 is the internal radius and r_m the mean radius;

or, what amounts to the same thing, lay off OB_2 so that $\frac{OB_2}{OB_1} = \frac{r_m}{r_1}$. Now, suppose OB_2 and B_2S_2 to be the strain and corresponding stress respectively, at the middle of wall, after a sufficient number of cycles at the larger range of stress B_2S_2. Then, by the previous section, S_2 will lie on RS. Now with linearity of strain, OB_1 must be equal to the strain at the internal radius r_1 at epoch 2. The assumption will now be made provisionally that the stress at the inner skin at epoch 2 will be equal to B_1S_1. This is a large assumption to make, and it can only be considered to have validity if the deductions from it have experimental confirmation. Stated in general terms, and including in its scope solid as well as hollow specimens, this assumption amounts to the following: At any epoch after a number of cycles sufficient to produce constant range of strain, the relation between the ranges of stress and strain at any point of the specimen is expressed thus:

$$q = Ce_e + C'(e - e_e),$$

C being the elastic modules;

C′ ,, ,, value of $\frac{\Delta\,(\text{stress})}{\Delta\,(\text{strain})}$ corresponding to the line RS (fig. 18);

e_e ,, ,, semi-range of strain corresponding to the intersection of OP and RS (fig. 18);

e ,, ,, semi-range of strain corresponding to the range of stress $\pm q$.

Illustrating this assumption a little further by the aid of fig. 18, lay off B_2B_3 such that

$$\frac{B_2B_3}{OB_3} = \frac{r_m - r_1}{r_m}$$

Let OB_3 and B_3S_3 be the semi-ranges of strain and stress at middle of wall at an epoch 3. Then linearity of strain makes the range of strain at inner skin at epoch 3 equal to OB_2, and the above assumption makes the range of stress at inner skin equal to B_2S_2. Thus the stresses and strains at the inner skin of the tube at various epochs will be represented by the same graph as the stresses and strains at the middle of the wall.

In the same way, following the above assumptions, the graph RS represents the relation between the ranges of strain and stress not merely at the middle of the tube-

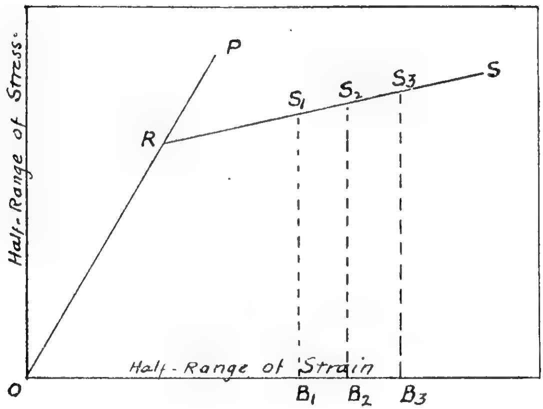

Half-Range of Stress.
P
R
S
S1
S2
S3
Half-Range of Strain
O
B1
B2
B3

FIG. 18

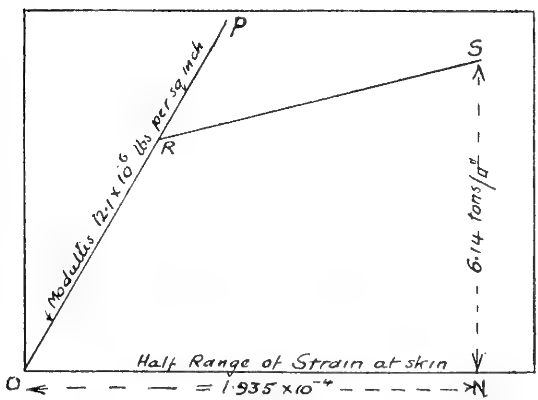

P
S
R
Modulus 12·1 × 10^6 lbs per sq inch
6·14 tons/□"
Half Range of Strain at skin
O
= 1·935 × 10^-4
N

FIG. 19

wall, but it also represents the relation between the ranges of strain and stress at any point of the tube-wall, provided that constancy of range of strain has been reached.

The validity of this provisional assumption will be tested with reference to solid specimens.

Alternating Torsion of Solid Specimens.

Specimen A7 was cut from the same batch of steel as the foregoing hollow specimens. It was tested at the various ranges of torque shown in Table II., and at each range the strain was allowed to reach a constant value before the next higher range was imposed. Since this was also the method of testing the hollow specimens (Table I.), the author proceeded as follows. The average value of the shear stress at fracture of these hollow specimens was found to be 6·14 tons per sq. in. (see Table IV.). The shear stress at fracture of A7 ought presumably to have approximately the same value; hence, as a first trial of the foregoing assumption, the real ultimate range of stress at the skin was also taken to be 6·14 tons per sq. in. The distribution of stress through the body of the specimen was, following the above assumption, taken to be represented by lines such as OP, RS, fig. 19 (see also fig. 18). The inclination of the line OP corresponds to the modulus $C = 12\cdot1 \times 10^6$ lb. per sq. in.; the point S is fixed by the ultimate range of strain $= 1\cdot935 \times 10^{-3}$, and by NS, the ultimate (fracture) range of stress, which is taken to be 6·14 tons per sq. in. If the strain throughout the specimen is represented by a line such as RS, then the inclination of RS will be fixed by equating the torque imposed to the resisting torque. That is,

$$\text{Torque imposed} = \int^{N} 2\pi . r^2 . dr . q.$$

This calculation (see Appendix I.) makes the inclination of the line RS to correspond to a ' modulus ' C′ of $2\cdot18 \times 10^6$ lb. per sq. in., and $\frac{C'}{C} = 0\cdot18$. The ratio $\frac{C'}{C}$ for the hollow specimens was, as mentioned previously (p. 392), 0·225. The line RS, with this inclination, is plotted in fig. 20. In fig 20 ORDF represents to scale the ranges of strain and stresses (as usually calculated) for the skin of specimen A7. The ranges of strain had reached constant values at the ranges of stress plotted.

It will be observed (fig. 20) that the inclination of the line RS makes the point of elastic breakdown in the body of the specimen to be at R for the ultimate range of constant strain $1\cdot935 \times 10^{-3}$. Scaling from the figure gives ER = 5·15 tons per sq. in., as against 5·30 tons per sq. in. (see Table I., col. 1), which is the average of the four hollow specimens before cited.

It is, of course, more than probable that, if the true distribution of stress throughout A7 at the ultimate range of stress and strain is represented by the lines OR, RS, the change of modulus at R is not a sharp one as shown on fig. 20. The stress near R would be represented by the dotted line, and the calculation of the resisting torque will be affected somewhat. The error of assuming a sharp change at R will, however, be small, especially for the larger ranges of stress and strain. Ordinates to a straight line OD represent the stress throughout the specimen on the basis of linearity of stress, at the epoch when the range of strain at the skin had settled down to OB_2; the strain and stress at a radius $r = \frac{OB}{OB_2} \times$ (radius of specimen) at this epoch appearing respectively as OB_1 and B_1D_1. This linear distribution of stress throughout the specimen is, of course, an absurd supposition, inasmuch as the material near the core cannot have suffered a change of modulus. On the basis of the provisional assumption, at an epoch when the semi-range of strain at the skin had settled down to OB_2, the semi-range of stress would be B_2S_2; and the strain and stress at the same radius 'r' (above) would be OB_1 and B_1S_1 respectively.

The result of applying to A7 the provisional assumption regarding distribution of stress seemed to the author to bring that test so nearly into line with the tests of the hollow specimens that he made the torsional tests now to be described.

Confirmation of the Assumption concerning Distribution of Stress.—In order to obtain further evidence concerning the validity of the assumption of p. 392, tests were made of four specimens of another steel—the 0·35 per cent. carbon steel provided by the Aeronautical Research Committee. Two of these were hollow and two solid, and all were tested under alternating torsion. The stress was not applied in steps as in the former tests cited. The elastic limits of two of them (see Table III.) were

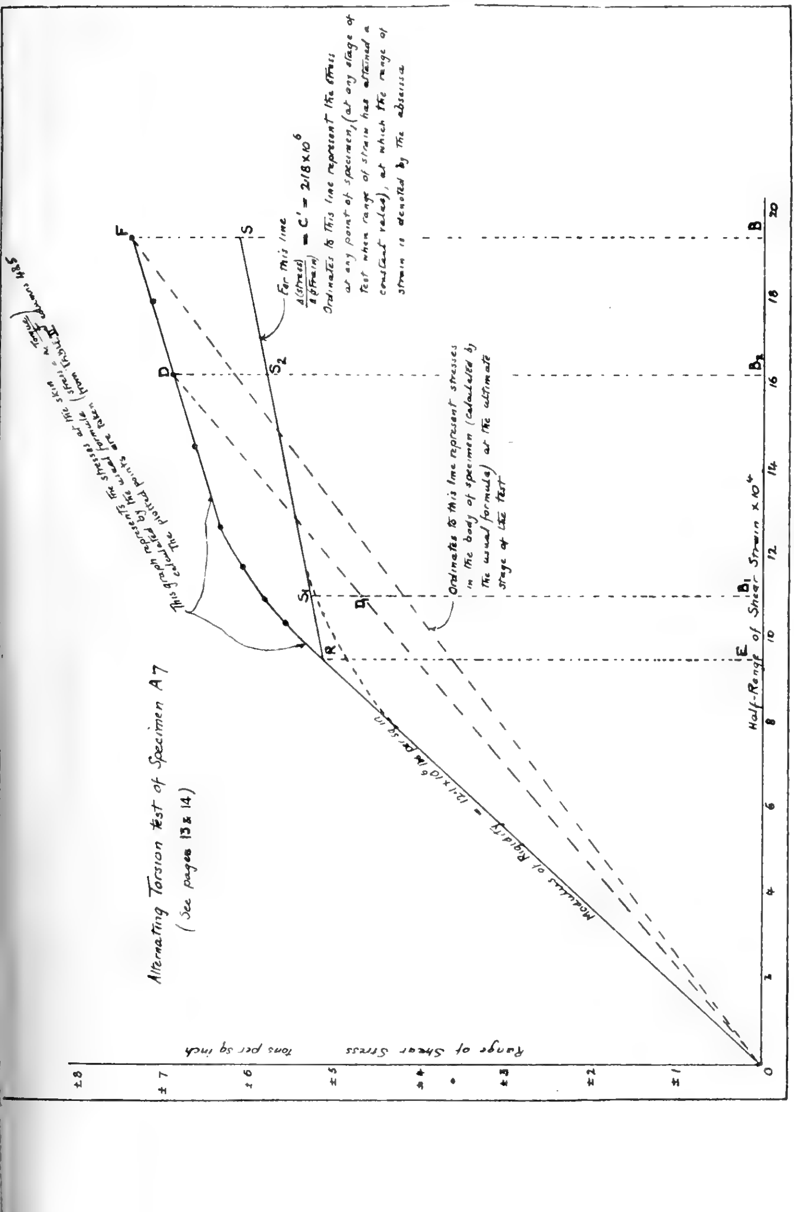

Alternating Torsion test of Specimen A 7
(See pages 13 & 14)
Range of Shear Stress tons per sq inch
Half-Range of Shear Strain × 10⁴
Modulus of Rigidity = 12·1 × 10⁶ lb per sq in
For this line Δ(stress)/Δ(strain) = C' = 2·18 × 10⁶
Ordinates to this line represent the stress at any point of specimen, (at any stage of test when range of strain has attained a constant value), at which the range of strain is denoted by the abscissa
Ordinates to this line represent stresses in the body of specimen (calculated by the usual formula) at the ultimate stage of the test
F
S
D
S2
S1
D1
R
B
B2
B1
E
O
±1
±2
±3
±4
±5
±6
±7
±8
2
4
6
8
10
12
14
16
18
20

FIG. 20

found under torsional alternating cycles, and then the full alternating torque was applied for a large number of cycles. The elastic limits of the other two were not found; alternating torque of one constant range only was applied and continued until the test was completed. In all four tests a constant range of strain was attained long before the cycles of torque were discontinued or long before the specimen broke, as the case might be. It will be observed that one hollow and one solid specimen fractured, and that the limiting fatigue range must presumably lie between the real stress of the unbroken and the broken specimens.

What will be called, provisionally, the 'real' stress at the skin of the hollow specimens was calculated by a method similar to that employed (see p. 389) for the other hollow specimens (see Appendix I.), the only difference between the methods being that various values of the ratio $\frac{C'}{C}$ (p. 392) were now taken, and a position of the RS line (see fig. 19) was found by equating the range of resisting moment, for each value of $\frac{C'}{C}$, to the range of the applied torque. Any one of the RS lines so found satisfies the essential condition of equality of range of applied torque and range of resisting moment; but, of course, the values of (*a*) the ultimate range of 'real' stress and (*b*) the range of elastic limit stress at the internal surface of elastic break-down vary widely according to the value of $\frac{C'}{C}$. The values of (*a*) and (*b*) are given respectively in Tables IV. and V. An examination of these tables leads to the conclusion that the most probable value of $\frac{C'}{C}$ for this steel is about 0·30, because this value of $\frac{C'}{C}$ makes the ultimate ranges of stress of the fractured hollow and solid specimens agree, and it makes the highest ranges of the unbroken hollow and solid specimens also very close (Table IV.). This value of $\frac{C'}{C}$ also (see Table V.) brings the stresses in the solid specimens at the locality R, where the modulus changes, approximately to the elastic limit 7·0 tons per sq. in. observed during two of the tests. Thus the stress at R for the broken solid specimen appears as $\pm 7 \cdot 25$ tons per sq. in., and the stress at R for the unbroken solid one as $\pm 6 \cdot 82$ tons per sq. in. Thus the value $\frac{C'}{C} = 0 \cdot 30$ brings the tests of hollow and solid specimens into substantial correspondence with each other. Table IV. gives the comparison of the ultimate ranges of stress for the torsion specimens for various values of $\frac{C'}{C}$, and Table V. gives the stresses at the point R for these various values of $\frac{C'}{C}$. It appears that the value 0·18 for $\frac{C'}{C}$ previously obtained is the most probable value $\frac{C'}{C}$ for the steel of 0·12 per cent. carbon. It will be observed that not only does the value $\frac{C'}{C} = 0 \cdot 18$ make the ultimate and elastic limit ranges of stress very approximately the same for A7 as for the hollow specimens of the same material, but that the curves of distribution of stress at the ultimate range for A7 and the hollow specimens, while not in exact coincidence, are in fair agreement.

The author thinks these results confirm in a rather striking manner the validity of the assumption provisionally adopted as to the distribution of stress in a round bar under alternating torsion when the range of strain has become constant.

It is of some interest to compare for the three solid specimens the ratio of the ultimate stresses (*a*) calculated on the author's assumption of stress distribution and (*b*) calculated on the assumption of perfect elasticity.

A7.	0·12 per cent. C broken $\frac{C'}{C} = 0 \cdot 18$	$\frac{\text{stress }(a)}{\text{stress }(b)} = \frac{6 \cdot 14}{7 \cdot 40} = 0 \cdot 83$
0·1.	0·35 per cent. C unbroken $\frac{C'}{C} = 0 \cdot 30$	,, $= \frac{8 \cdot 67}{10 \cdot 0} = 0 \cdot 865$
1–2.	0·35 per cent. C broken $\frac{C'}{C} = 0 \cdot 30$	,, $= \frac{9 \cdot 09}{10 \cdot 5} = 0 \cdot 865$

Round Specimens under Alternating Bending.

The distribution of stress under alternating bending is more difficult to treat, because, unlike hollow specimens in torsion, the stresses in hollow specimens cannot directly be even approximately estimated. The author has used some data obtained in tests[1] of hollow and solid specimens bent to and fro under ranges of alternating bending moment, and has calculated the ultimate ranges of stress at the skin and throughout the specimen on the same assumption as that made use of for torsion.

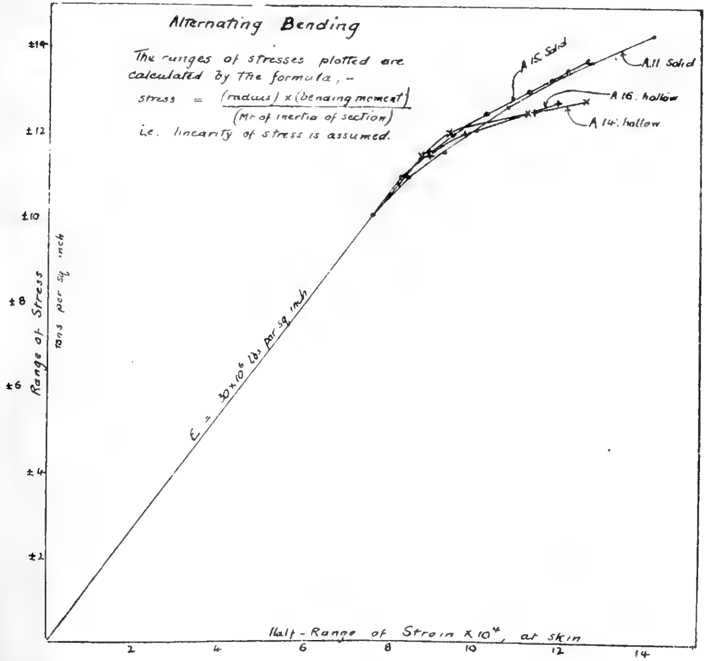


FIG. 21

Briefly stated, the method has been: To assume a stress distribution (at ranges of bending moment continued long enough to give constancy of range of strain) like that of fig. 19; to calculate the ranges of stress at the skin for various values of $\frac{E'}{E}$ (E' and E being the moduli corresponding to the lines OP and RS (fig. 19); and, by equating the range of resisting moment to the applied bending moment, to ascertain which value or values of $\frac{E'}{E}$ give approximately the same ultimate skin stress for hollow specimens on the one hand and for solid specimens on the other. Then, finally, to see if the curves of 'true' stress and strain for hollow and solid specimens coincide.

Table VI. gives data concerning the specimens, two of which are hollow and two solid. In calculating the bending strains from the observed ranges of bending in cms. on scale, 30×10^6 per sq. in. has been taken as the elastic modulus. The curves of fig. 21 have been plotted from columns 2 and 5 of Table VI. It will be observed

[1] *Proc. Inst. Mech. Eng.*, Feb. 1917.

that the upper five plotted points of specimen A15 lie on a straight line—correspondingly to the torsion specimens—but that the upper part of the curve of A11 is not quite a straight line. The upper three points of A16 and the upper two points of A14 lie on straight lines. It may be assumed that the range of strain had become approximately constant for those upper points that lie on a straight line. The bend at the elastic limit is not so sharp as in the case of torsion.

The formulæ for, and method of, calculating the ultimate ranges of stress, and the range of stress at the point in the specimen where the modulus changes, are given in Appendix II.

Tables VI. and VII. show the result of the calculations; fig. 22 represents these results graphically. It appears (Table VII. and fig. 9) that the elastic limit point R for all values of $\frac{E'}{E}$ is below the elastic limits observed in making the tests. Even for $\frac{E'}{E} = 0$ (*i.e.* RS horizontal), which gives the highest value of elastic limit stress in the body of the specimen, this is the case. Of course the stress-strain curve will be rounded off in the neighbourhood of R. This rounding off will have most effect on the calculations (*i.e.* in equating of resisting moment to applied moment) in the case of the solid specimen A15. The curved line in fig. 23 shows a hypothetical rounding off for A15 for the case of $E' = 0$; the effect is to raise the right-hand part of RS by a stress of 0·28 tons per sq. in. The effect for the other specimens would be less, and for other values of $\frac{E'}{E}$ the raising of the line RS will be smaller as $\frac{E'}{E}$ increases. It is clear, then, that the main issue, viz. the position of the line RS, is little affected by rounding off in the neighbourhood of R.

It will be observed (fig. 22) that the line RS for specimen A16 (which has the thinner wall of the two hollow specimens tested) is always above the RS lines for the other specimens for all values of $\frac{E'}{E}$. So far as the author knows, this test has to be considered as having equal probable weight with the others. The effect of rounding off will be to raise the RS line of this specimen less than the raising of the others, but this consideration does not account for more than about one-third of the difference in stress between the RS line of A16 and that of the others.

Further examination of the RS lines of fig. 22 shows that while a value of $\frac{E'}{E}$, somewhere between 0·2 and 0·3, makes the RS lines come nearest together, this value is apparently about the middle of the wide range of $\frac{E'}{E}$ from 0 to 0·5, all values between these limits bringing the RS lines fairly close together. Considering the ultimate ranges of stress which produced fracture, the agreement between these is closest for values of $\frac{E'}{E}$ from 0·2 to 0·3. The assumption of a definite value of $\frac{\Delta\,(\text{stress})}{\Delta\,(\text{strain})}$ for bending thus leads to results that are somewhat indefinite, in contrast to the results for torsion. One reason for the uncertainty of this result obviously lies in the circumstance that the area of layers of the circular section (providing resisting moment to bending) diminishes rapidly towards the skin farthest removed from the neutral axis of bending. It seems clear, however, that although $\frac{\Delta\,(\text{stress})}{\Delta\,(\text{strain})}$ may not be an absolute constant, the general inclination of the RS stress-strain line through the outer part of the body of the specimen will most probably not be greater than 0·4. The extreme value of $\frac{E'}{E} = 1$, *i.e.* the assumption of linearity of stress from axis to skin, which is usually adopted for calculating the skin stresses, is palpably wrong.

Some idea of the probable amount of the error made by calculating skin stresses of fatigue tests on the assumption of linearity of stress from the axis outwards may be obtained from Table VIII.

Taking 0·3 as the most probable value of $\frac{E'}{E}$, the error for hollow alternately bent specimens would be about 15 per cent., and for alternately bent solid specimens

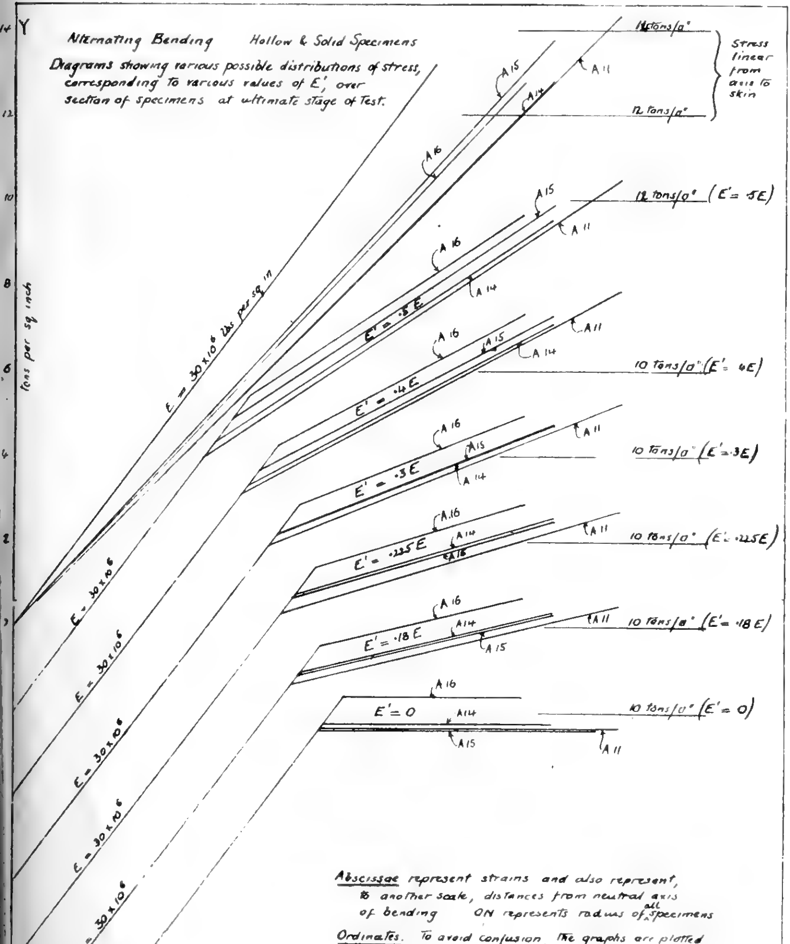

Alternating Bending Hollow & Solid Specimens
Diagrams showing various possible distributions of stress, corresponding to various values of E', over section of specimens at ultimate stage of Test.
14 tons/□"
12 tons/□"
Stress linear from axis to skin
12 tons/□" (E' = ·5E)
10 tons/□" (E' = ·4E)
10 tons/□" (E' = ·3E)
10 tons/□" (E' = ·225E)
10 tons/□" (E' = ·18E)
10 tons/□" (E' = 0)
$E = 30 \times 10^6$ lbs per sq in
E' = ·5E
E' = ·4E
E' = ·3E
E' = ·225E
E' = ·18E
E' = 0
$E = 30 \times 10^6$
A 11
A 14
A 15
A 16
tons per sq inch
Y
Half-Range of Strain $\times 10^4$
N
X
2
4
6
8
10
12
14
Abscissae represent strains and also represent, to another scale, distances from neutral axis of bending ON represents radius of all specimens
Ordinates. To avoid confusion, the graphs are plotted with a different origin for each value of E', all the origins being on OY
Each graph represents a distribution of stress, for each of four specimens, as follows,-
from axis for a portion of the radius $E = 30 \times 10^6$
for remaining portion of radius $\frac{\Delta(\text{stress})}{\Delta(\text{strain})} = E'$,
with values of E' as marked on the graph

FIG. 22.

about 24 per cent. These figures refer not to alternate bending of a Wöhler rotating specimen, but to alternate to-and-fro bending about a fixed axis. The error introduced, by calculation on the usual assumption, of the skin stresses of a Wöhler test will be less than the above, because the magnitude of the extra-elastic strain in the Wöhler test is less when the bending is to-and-fro about a fixed axis. The magnitude of the probable error of the calculated skin stresses in a Wöhler test is very difficult to calculate, because the whole of the material outside some radial distance from the axis is impaired elastically.

A deduction of the above percentage amount from the calculated (on usual assumption) ultimate skin stress of a fatigue test by alternating bending will, for steel of the mildness of the author's specimens, bring the skin stress down to a value very little greater than the elastic limit determined by increasing the alternating bending upon a specimen previously unstrained. This would not be surprising,

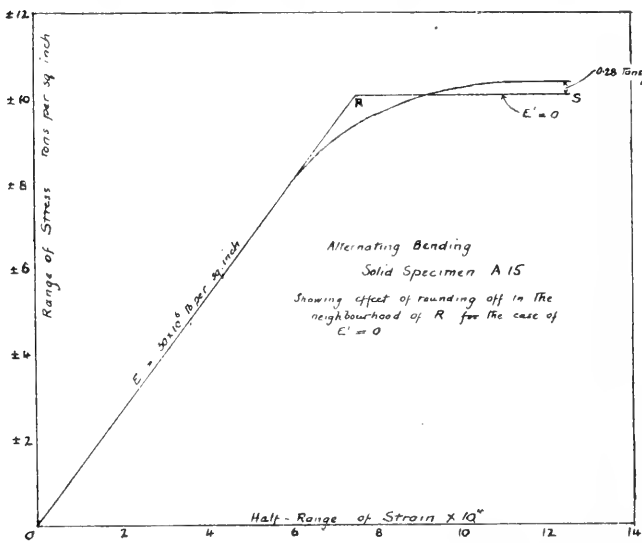


FIG. 23.

in view of the preceding results for torsion, and also for results of alternating direct stress.

A point arises here with regard to the known effect of 'understressing' in fatigue tests by bending. The author is inclined to believe, in view of the foregoing results, that the extent of raising of a fatigue limit by 'understressing' may be overestimated in a bending test.

When a range of torque or bending is imposed that will lead ultimately to fracture, the stresses on the specimen at the first outset will be nearly those calculated by the usual formula, whereas the range of real stress at fracture will be considerably less than the range of stress initially induced by that same constant range of bending moment. Damage may be done by the higher initial stresses, and such damage may be consummated in fracture at the lower stresses in the ultimate stage of the test. Some carefully made Wöhler tests, which gave lower fatigue ranges when the whole load was put on in a few seconds, would be explained by an initial 'overstressing effect' of this kind. If the range of bending moment is imposed by increments up to the fracture range, the range of real stress will never attain the higher real value reached when the full bending moment is put on the (mild) steel in its primitive elastic condition.

The author does not, of course, put forward initial 'overstressing' in bending tests as an explanation of 'understressing,' which is a phenomenon observed also in alternating direct loading. Initial overstressing of the above kind would cause overestimation of the effect of 'understressing' in torsion and bending tests.

The author is indebted to Mr. N. P. Inglis, B.Eng., for making the torsion tests of the A.R.C. steel.

APPENDIX I.

Calculation of the Resisting Moment of the Section of a Solid Round Bar on which the Shear Stress due to Torsion has a Distribution like that shown in Fig. 5.

Referring to fig. 18—

Let C be the elastic modulus corresponding to the line OP;

C′ be the modulus corresponding to RS—

$$i.e.\ C' = \frac{\Delta\,(\text{stress})}{\Delta\,(\text{strain})},\ \text{between R and S.}$$

$$\text{Resisting moment of the section} = \int_0^N 2\pi \,.\, r \,.\, dr \,.\, q \,.\, r,$$

where q is the stress at radius r.

With linearity of *strain* throughout body, and distribution of stress as in fig. 18—

$$\textit{Between O and R, stress} = Ce \qquad (1)$$
$$= C \,.\, k \,.\, r,$$

where e is the strain at radius r and $k = \frac{e}{r}$.

$$\textit{Between R and S, stress} = C \,.\, k \,.\, r_e + C' \,.\, k \,.\, (r - r^e)$$
$$= (C - C')\,k \,.\, r_e + C' \,.\, k \,.\, r \qquad (2)$$

where r is the radius at which the modulus changes from C to C′.

The above expression for the resisting moment may now be written as:

$$2\pi \,.\, C \,.\, k \int_0^{r_e} r^3 dr + 2\pi\,(C - C') \,.\, k \,.\, r_e \int_{r_e}^{r_0} r^2 dr + 2\pi \,.\, C' \,.\, k \,.\int_{r_e}^{r_0} r^3 dr$$

$$= 2\pi \,.\, C \,.\, k \frac{r_e^4}{4} + 2\pi \,.\, (C - C') \,.\, k \,.\, r_e \frac{r_0^3 - r_e^3}{3} + 2\pi \,.\, C' \,.\, k \,.\, \frac{r_0^4 - r_e^4}{4}$$

where r_0 is the outside radius.

The resisting moment, calculated on the usual assumption of linear distribution of *stress* from axis to skin

$$= \frac{\pi r_0^3}{2} \,.\, q_c,$$

where q_c is the stress at the skin calculated in this manner.

Equating the two expressions for the resisting moment we obtain

$$\frac{q_e}{e_0} \cdot \frac{1}{C - C'} - \frac{C'}{C - C'} = \frac{4}{3}\frac{r_e}{r_0} - \frac{1}{3}\left(\frac{r_e}{r_0}\right)^4 \quad . \quad . \quad . \quad . \quad (3)$$

e_0 being the strain at skin, *i.e.* for $r = r_0$.

For the distribution of stress as fig. 18—

Let q_0 = stress at r_0;

q_e = stress at r_e;

e_e = strain at r_e.

Equation (2) may now be written—

$$q_0 = q_e + C'(e_0 - e_e) \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Thus, given q_e, e_0, q_0, and C, equations (1), (3), and (4) determine C′ and the remaining quantities; this was done in the case of specimen A7.

Since the values q_e and q_0 were required for a number of values of C′ (see Table IV.), it was found convenient to plot a graph of the function on the right-hand side of equation (3) against values of $\frac{r_e}{r_0}$ as abscissæ, and to solve (3) graphically.

APPENDIX II.

Calculation of the Resisting Moment of a Circular Section on which the Direct Stress due to Bending has a Distribution like that shown on Fig. 5.

Referring to fig. 18—

Let E = Young's modulus, corresponding to the line OP;

„ E′ = modulus corresponding to RS, *i.e.* $E' = \frac{\Delta(\text{stress})}{\Delta(\text{strain})}$ between R and S;

„ e be the strain at distance y from neutral axis of bending;

„ e_e be the strain at y_e, y_e being the distance from the neutral axis at which the modulus changes from E to E′;

„ e_0 be the strain at the skin, *i.e.* at radius r_0, r_0 being the external radius of the specimen.

Assuming linearity of *strain*, and that the material behaves similarly in tension and compression, then $e = k.y$, $e_e = k.y_e$, $e_0 = ky_0$.

Between O and R, stress $= E.k.y$ . . . . (1)

„ R and S, stress $= E.k.y_e + E'(ky - ky_e) = (E - E')k.y_e + E'.k.y$. (2)

The resisting moment of the section

$$= 2\int_O^R b.dy.k.y.\ E.y + 2\int_R^S b.dy.k.y_e\ E.y + 2\int_R^S b.dy.k\,(y - y_e)\ E.y$$

('b' being the breadth at distance y from the neutral axis)

$$= 2.k.E\int_0^{y_e} by^2dy + 2k.y_e.(E - E')\int_{y_e}^{r_0} bydy + 2k.E'.\int_{y_e}^{r_0} by^2dy.$$

Now, calculated on the assumption of linearity of *stress* from axis to skin—

$$\text{Resisting moment} = \frac{\pi r_0^3}{4} p_c \text{ for a solid section ;}$$

$$\text{,, \quad ,,} = \frac{\pi (r_0^4 - r_1^3)}{4} p_c \text{ for a hollow section of internal radius } r_1,$$

where p_c is the stress at the skin calculated on that assumption.

Equating the two expressions for resisting moment—

For a solid section—

$$\left.\begin{aligned} \frac{\pi r_0^3}{4} p_c = 4k.\mathrm{E}.\frac{r_0^4}{8}\left(\theta - \frac{\sin 4\theta}{4}\right)_{\theta=0}^{\theta=\sin^{-1}\frac{y_e}{r_0}} \\ - 4k\dot{y_e}(\mathrm{E}-\mathrm{E}')\frac{r_0^3}{3}\Big[\cos^3\theta\Big]_{\theta=\sin^{-1}\frac{y_e}{r_0}}^{\theta=\frac{\pi}{2}} \\ + 4.k.\mathrm{E}'\frac{r_0^4}{8}\Big[\theta - \frac{\sin 4\theta}{4}\Big]_{\theta=\sin^{-1}\frac{y_e}{r_0}}^{\theta=\frac{\pi}{2}} \end{aligned}\right\} \quad . \quad . \quad . \quad (3)$$

whence

$$\frac{\pi}{4}\left\{\frac{p_c}{e_0}\cdot\frac{1}{\mathrm{E}-\mathrm{E}'} - \frac{\mathrm{E}'}{\mathrm{E}-\mathrm{E}'}\right\} = \frac{1}{2}\sin^{-1}\frac{y_e}{r_0} - \frac{1}{8}\sin\left(4\sin^{-1}\frac{y_e}{r_0}\right) + \frac{4}{3}\frac{y_e}{r_0}\cos^3\left(\sin^{-1}\frac{y_e}{r_0}\right) \quad (4)$$

For a tubular section—

provided that $y_e < r_1$, resisting moment

$$= \frac{\pi}{4}\frac{r_0^4 - r_1^4}{r_0} p_c = \begin{pmatrix}\text{right-hand side} \\ \text{of equation (3)}\end{pmatrix} - \begin{pmatrix}\text{same expression as right-hand side of (3), but} \\ \text{with } r_1 \text{ written instead of } r_0 \text{ throughout}\end{pmatrix}$$

whence

$$\frac{\pi}{4}\left(1 - \frac{r_1^4}{r_0^4}\right)\cdot\frac{1}{\mathrm{E}-\mathrm{E}'}\cdot\left(\frac{p_c}{e_o} - \mathrm{E}'\right)$$

$$= \frac{1}{2}\sin^{-1}\frac{y_e}{r_0} - \frac{1}{8}\sin\left(4\sin^{-1}\frac{y_e}{r_0}\right) + \frac{4}{3}\frac{y_e}{r_0}\cos^3\left(\sin^{-1}\frac{y_e}{r_0}\right)$$

$$-\left(\frac{r_1}{r_0}\right)^4\left[\frac{1}{2}\sin^{-1}\left(\frac{y_e}{r_0}\cdot\frac{r_0}{r_1}\right) - \frac{1}{8}\sin 4\left\{\sin^{-1}\left(\frac{y}{r_0}\cdot\frac{r_0}{r_1}\right)\right\} + \frac{4}{3}\frac{y_e}{r_0}\cdot\frac{r_0}{r_1}\cos^3\left\{\sin^{-1}\left(\frac{y_e}{r_0}\cdot\frac{r_0}{r_1}\right)\right\}\right] (5)$$

Given p , e_0, E, and E′, equations (1), (2), and (4) serve to determine e_e, p_e, and p^0 for the case of a solid section; and equations (1), (2), and (5) determine the same quantities for a tubular section.

Since the values of p and p_0 were required for a number of values of E′, it was found convenient to plot graphs of the right-hand side of equation 4, and also of the right-hand side of 5, both against values of $\frac{y_e}{r_0}$ as abscissæ. The value of $\frac{y_e}{r_0}$ which satisfied (4) or (5), as the case might be, could then be found from the graph. Having got $\frac{y_e}{r_0}$, the values of p_e and p_0 can be found from equations (1) and (2).

TABLE I.

ALTERNATING TORSION TESTS OF HOLLOW SPECIMENS OF 0·12 PER CENT. C STEEL.

Calculation of Ranges of Strain and Stress at Middle of Tube-wall.

Data*					6	7	8	9	10
1 Specimen	2 Range of Stress at Elastic Lt.	3 Mean radius / External rad. = a	4 Range of Stress at Skin† = qc	5 Range of Strain at Skin. Cm. on scale = S	F (See p. 389)	Range of Shear Strain at Skin = S × F	$\frac{3}{4} \times \frac{\left(1 - \frac{r_1^4}{r_0^4}\right)}{\left(1 - \frac{r_1^3}{r_0^3}\right)}$ ‡ = b	Range of Shear Strain at Middle of Wall = S × F × a	Actual Range of Stress at Middle of Tube-wall = $qc \times b$
	Tons sq. in.		Tons sq. in.						Tons sq. in.
A10	±5·40	0·948	±6·00	7·00	1·65 × 10⁻⁴	11·55 × 10⁻⁴	0·95	10·95 × 10⁻⁴	±5·69
			±6·50	9·75		16·05 × ,,		15·2 × ,,	±6·17
B22	±5·40	0·948	±5·62	6·90	1·58 × 10⁻⁴	10·9 × 10⁻⁴	0·95	10·35 × 10⁻⁴	±5·33
			±6·25	10·72		16·95 × ,,		16·05 × ,,	±5·92
B27	±5·05	0·952	±5·35	7·48	1·535 × 10⁻⁴	11·5 × 10⁻⁴	0·957	10·9 × 10⁻⁴	±5·10
			±5·60	9·06		13·9 × ,,		13·25 × ,,	±5·34
			±5·80	10·15		15·6 × ,,		14·85 × ,,	±5·58
			±6·10	11·36		17·45 × ,,		16·55 × ,,	±5·85
A2	—	0·876	±6·10	7·98	1·495 × 10⁻⁴	11·95 × 10⁻⁴	0·892	10·45 × 10⁻⁴	±5·43
			±6·60	11·30		16·9 × ,,		14·8 × ,,	±5·88
			±6·85	12·95		19·35 × ,,		16·9 × ,,	±6·10

* See pages 136–139 *Proc. Inst. Mech. Eng.*, Feb. 1917.

† Calculated by usual formula for perfectly elastic conditions.

‡ r_1 = internal radius; r_0 = external radius.

NOTE.—Fig. 17A is plotted from the quantities in columns 9 and 10.

TABLE II.

ALTERNATING TORSION. SOLID SPECIMEN A7 (0·12 PER CENT. CARBON STEEL).

Ranges of Strain (at Skin) which had become constant at certain Ranges of Stress.*
Quantities in columns 4 and 5 are plotted in Fig. 20.

1 Elastic Limit Stress. Tons per sq. in.	2 Range of Strain at Skin Cms. on scale = R	3 F (see p. 389)	4 Range of Shear Strain at Skin = F × R	5 Calculated Range * of Strain at Skin = q_c. Tons per sq. in.
5·60 about	9·56	$1{\cdot}32 \times 10^{-4}$	$1{\cdot}26 \times 10^{-3}$	±6·35
	10·96		1·445 × ,,	6·65
	12·24		1·615 × ,,	6·90
	13·55		1·785 × ,,	7·15
	14·67		1·936 × ,,	7·40

* Ranges of stress calculated by usual formula for perfectly elastic condition.
For data of columns 1, 2, and 5, see *Proc. Inst. Mech. Eng.*, Feb. 1917.

TABLE III.

ALTERNATING TORSION. A.R.C. STEEL SPECIMENS (ABOUT 0·35 PER CENT. C).

1 Specimen	2 Inner Diameter $= r_1$	3 Outer Diameter $= r_0$	4 Range of Stress at Elastic Limit. Tons per sq. in.	5 Ultimate Range of Stress * $= q_c$. Tons per sq. in.	6 Range of Stress at Middle of Tube-wall $= q_c \times \frac{3}{4} \times \frac{1 - \frac{r_1^4}{r_0^4}}{1 - \frac{r_1^3}{r_0^3}}$ Tons per sq. in.	7 Range of 'Strain' at Skin=R. Cm. on scale	8 F (see p. 389)	9 Range of Shear Strain at Skin $= R \times F$	10 Cycles endured at Range of col. 5. Millions
	Inch	Inch							
3–4 hollow	0·4395	0·501	±7·00	± 9·25	±8·94	14·22	$1·748 \times 10^{-4}$	$2·485 \times 10^{-3}$	1·15 broken
4–5 ,,	0·4395	0·501	—	± 9·00	±8·70	12·33	1·740 × ,,	2·145 × ,,	5·04 unbroken
0–1 solid	—	0·438	—	±10·00	—	17·20	1·395 × ,,	2·40 × ,,	2·70 unbroken
1–2 ,,	—	0·438	±7·00	±10·50	—	17·55	1·410 × ,,	2·48 × ,,	3·90 broken

NOTE.—After increasing the range of stress on specimens 3–4 and 1–2 up to the elastic limit, the full range of torque (see col. 5) was imposed and maintained constant until fracture.

The full range of torque was imposed, on specimens 4–5 and 0–1, at the commencement of test, and kept constant until the tests were discontinued.

* Calculated by the usual formula for elastic conditions, viz. stress = radius × $\frac{\text{torque}}{J}$, where J=Moment of Inertia of Section.

TABLE IV.

ALTERNATING TORSION. SOLID AND HOLLOW SPECIMENS.

This table gives the ultimate ranges of stress at the skin calculated on the assumption that the stress has a distribution, throughout specimen, as shown in fig. 18.

Specimen		Ultimate Range of Stress at Skin				
		Tons per sq. in.				
B22 hollow	0·12% C steel. (See *Proc. Inst. Mech. Eng.*, Feb. 1917, pp. 136–138.)	†6·00	Mean value = 6·14 tons per sq. in.			
B27 ,,		†5·92				
A10 ,,		†6·27				
A 2 ,,		†6·35				
		Ultimate range of stress at skin calculated for various values of $\frac{C'}{C}$.‡				
		for *$\frac{C'}{C}=\cdot18$	for $\frac{C'}{C}=\cdot21$	for $\frac{C'}{C}=\cdot25$	for $\frac{C'}{C}=\cdot30$	for $\frac{C'}{C}=\cdot4$
A7 solid		±6·14	±6·21	±6·30	±6·40	±6·63
3–4 hollow	A.R.C. 0·35% C steel. (See Table III.)	±8·91	±8·94	±9·00	±9·07	±9·17
4–5 ,,		8·68	8·70	8·77	8·84	8·93
0–1 solid		8·34	8·40	8·54	8·67	8·90
1–2 ,,		8·80	8·85	8·96	9·09	9·34

* C = elastic modulus. $C' = \frac{\Delta\ (\text{stress})}{\Delta\ (\text{strain})}$ for extra elastic conditions.

† Obtained from graphs of fig. 17B.

‡ For method of calculation, see Appendix I.

TABLE V.

ALTERNATING TORSION. SOLID SPECIMENS AT ULTIMATE RANGE OF STRESS.

Distribution of stress as shown in fig. 18.

Stress at R (fig. 18), where modulus changes, for various values of $\frac{C'}{C}$.

Specimen. (See also Table IV.)	Elastic Limit *	Stress at R				
		for C′= ·18C	for C′= ·21C	for C′= ·25C	for C′= ·30C	for C′= ·4C
	Tons per sq. in.	Tons per sq. in.	Tons per sq. in.	Tons per sq. in.	Tons per sq. in.	Tons per sq. in.
A7 0·12% C (broken)	±5·30	±5·15	±5·08	±4·92	±4·66	±4·08
01 0·35 % C (unbroken)	7·00	7·33	7·20	7·06	6·82	6·17
1–2 ,, (broken)	7·00	7·80	7·65	7·48	7·25	6·63

* Under alternating torsion.

TABLE VI.

ALTERNATING BENDING. HOLLOW AND SOLID SPECIMENS. (0·12 PER CENT. C STEEL.)

Ranges of Strain and Stress at Skin at Ultimate Stage of Test.

Specimen *	Range of Stress at Skin calculated by Usual Formula for perfectly Elastic Conditions	Range of Strain at Skin. Cm. on scale	F (see p. 389)	Range of Strain at Skin	Skin Stresses, in tons per sq. in., calculated on Basis of Stress Distribution as shown in Fig. 19					
					for $E'=0$	for $E'=\cdot18E$	for $E'=\cdot225E$	for $E'=\cdot30E$	for $E'=\cdot4E$	for $E'=\cdot5E$
	Tons per sq. in.									
A14 hollow	±12·75	9·00	$1\cdot392\times10^{-4}$	$12\cdot55\times10^{-4}$	± 9·71	±10·34	±10·56	±10·75	±11·12	±11·53
A16 ,,	±12·75	8·18	1·452×10 ,,	11·90×10 ,,	±10·35	10·70	10·87	10·97	11·33	11·65
A11 solid	±14·30	11·97	1·183×10 ,,	14·15×10 ,,	± 9·60	10·52	10·73	11·24	11·88	12·50
A15 ,,	±13·75	10·33	1·218×10 ,,	12·60×10 ,,	± 9·57	10·32	10·45	10·80	11·30	11·86

TABLE VII.

ALTERNATING BENDING. HOLLOW AND SOLID SPECIMENS OF TABLE VI.

Distribution of Stress as shown in Fig. 18. Stress at Elastic Limit; and stress at R (Fig. 19), where modulus changes for various values of $\frac{E'}{E}$.

Specimen *	Elastic Limit Range of Stress Tons per sq. in.	Range of Stress at R (tons per sq. in.)					
		for $E'=0$	for $E'=\cdot18E$	for $E'=\cdot225E$	for $E'=\cdot30E$	for $E'=\cdot40E$	for $E'=\cdot50E$
A14 hollow	about ±10·5	±9·71	±8·93	±8·72	±8·16	±7·32	±6·30
A16 ,,	,, ±10·5	10·35	9·56	9·40	8·84	8·27	7·38
A11 ,,	,, ±10·5	9·60	8·65	8·30	7·90	7·11	5·92
A15 ,,	,, ±11·0	9·57	8·88	8·70	8·18	7·65	6·83

* For details of test see *Proc. Inst. Mech. Eng.*, Feb. 1917, pp. 142–144.

TABLE VIII.

ALTERNATING BENDING.

Values of $\frac{p_o}{p_c}$

where p_o = skin stress at ultimate stage of test calculated for a distribution of stress as in fig. 18.

p_c = skin stress at ultimate stage of test calculated on usual assumption of linearity of stress from axis throughout specimen.

Specimen	Value of $\frac{p_o}{p_c}$					
	for $\frac{E'}{E}=0$	for $\frac{E'}{E}=0\cdot18$	for $\frac{E'}{E}=0\cdot225$	for $\frac{E'}{E}=0\cdot3$	for $\frac{E'}{E}=0\cdot4$	for $\frac{E'}{E}=0\cdot5$
A14 hollow	0·76	0·81	0·83	0·845	0·87	0·905
A16 ,,	0·81	0·84	0·855	0·86	0·89	0·915
A11 solid	0·67	0·735	0·75	0·785	0·83	0·87
A15 ,,	0·67	0·72	0·73	0·755	0·79	0·83

VI.

The Repeated Bending of Steel Wire.

By WALTER A. SCOBLE.

As a preliminary to the testing of complete wire ropes, single wires were taken from the cables and tested by repeated bending, under several tensions, over pulleys of different diameters.

The wire was special acid patent steel left black. Two sizes of wire were used, of 0·021 and 0·036 in. diameter. The elastic limit stress was 64 and the breaking stress was 85 tons per sq. in.

Under test a wire passed over a freely running pulley and was given a reciprocating motion. It passed from the straight on to the pulley, then it moved back into the straight again. Pulleys of different diameters were used. Direct tension could be applied to the wire under test, and experiments were made at several tensions on each pulley.

The wire was stressed by bending it to the radius of the pulley, and it was anticipated that an additional direct tension would reduce the number of bends necessary to produce fracture. The endurance of stranded wires is reduced on a given pulley if the tension is increased.

The results obtained from the 0·021 in. were confirmed by the tests of the 0·036 in. diameter wire, therefore attention will be directed particularly to the former. The usual formula used to obtain the outside fibre stress in the bent wire is, $f = Ed/D$, and if 'f' be taken as the yield stress of the wire in tension, 64 tons per sq. in., and 'E' as 13,400 tons per sq. in., it appears that the wire would be stressed to its yield point when bent on a pulley of 4·4 in. diameter without an added longitudinal tension. Under simple tension this wire yields at 50 and fractures at 66 lb. approximately.

The experimental results may be divided into four sections according to the pulley diameter. On a pulley which was much too small for the wire the number of bends to fracture was low but approximately constant up to a particular tension, above which the number of bends was negligible. This is illustrated by :

Test on 1-inch Diameter Pulley.

Tension on wire, lb.	10	15	30	35	40
Number of bends to fracture	2662	2630	2240 142	34	148 62

Test on 2-inch Diameter Pulley.

Tension on wire, lb.	10	20	30	40	50
Number of bends to fracture	9350 12,009	8526	10,304	5733 8269	61

The next stage took the pulley diameter up to the theoretical minimum, and here the number of bends to fracture was not greatly reduced at pulls equal to or greater than the yield-point tension of the wire. For example:

Test on 3-inch Diameter Pulley.

Tension on wire, lb.	10	20	30	40	50
Number of bends to fracture	34,437	32,595	35,452	39,742	29,127

Test on 4-inch Diameter Pulley.

Tension on wire, lb.	15	30	40	50	60
Number of bends to fracture	67,348 59,826	63,737 91,600	105,172 63,315	78,050	53,627

When the pulley diameter slightly exceeded the critical value, 4·4 in., the unexpected result was obtained that the number of bends necessary to fracture the wire increased with the tension to which it was subjected. The following furnishes an example of this character:

Test on 6-inch Diameter Pulley.

Tension on wire, lb.	10	20	30	40	50
Number of bends to fracture	107,359	163,232	214,747	268,693	468,351

On still larger pulleys this wire was not in general broken after a million cycles; in all cases the endurance was very considerable, and it appeared that the bending stresses had been so far reduced that they were negligible for single wires.

The apparent inconsistencies in the results, illustrated where an experiment was repeated, were doubtless caused by the inequalities which were known to exist along a length of drawn wire, particularly in the finer gauges.

No satisfactory explanation of this behaviour of wire under repeated bending is given here. The consideration of a single case on the usual lines is attempted, because it appears to show that these and the allied phenomena are not understood.

The example chosen is the test of the 0·021-in. wire over a 6-in. pulley under a tension of 50 lb., in which it required nearly half a million bends to break the wire. In fig. 24 the strain in tension and compression is graphed against the diameter of the wire for the case when the wire is bent round the pulley under no tension. The next portion of fig. 24 shows the strain deduced as follows. As an approximation it is assumed that when the metal yields the stress remains constant. This is not quite correct, but it does not materially affect the conclusions. The wire was under the yield-point tension, consequently it appears that it was under this tension right across the section to allow the total tension in the metal to equal the pull on the wire. Therefore, it is concluded that the bending caused yield all over the section. The next stage was the straightening of the wire under tension, which, reasoning in a similar fashion, seems to have caused further tensile yield, equalising it across the wire. The wire had 1·4 per cent. elongation right across the section from one complete cycle of bending, yet it withstood half a million such bends. It is clear that this line of reasoning must be seriously at fault. Alteration of the mechanical properties of the wire, such as raising the yield-point stress, can hardly be assumed, because load-extension diagrams for the wire, taken on a specially built machine, showed little difference between wire when it was new and after it had been bent over a pulley many times.

The usual wrapping test for wire demands that it shall be closely wound round itself and be re-straightened without failure. If the radial diameter is unchanged the wire must elongate on the outside and shorten on the inside 50 per cent. If a bar of steel be taken large enough to be marked off by circumferential lines and others

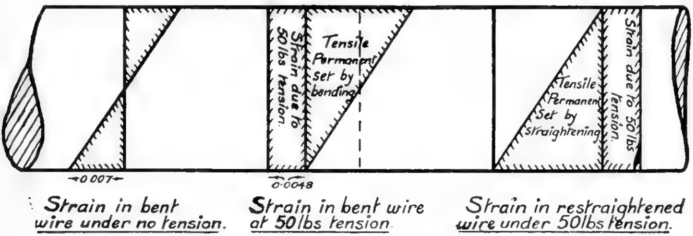


FIG. 24.

parallel to the axis, after it is bent it can be seen that changes of length of this order actually occur, but the percentage elongation at fracture of such steel in tension is probably about sixteen times that of this wire, for which the value is about 1·6.

In a recent paper (*Engineering*, June 15, 1923) Sir Alex. Kennedy shows that when metals are tested by bending to yield the calculated stresses are greater than those obtained from tension tests, particularly when the region of maximum stress is reduced. He offers alternative suggestions, either that the maximum stress under bending actually exceeds the tenacity of the material, or that the accepted formulæ must be radically modified to allow for an altogether different distribution of stress intensity.

The further results given here appear to indicate that the boundary of an unexplored region has been reached, that in which the strains vary from point to point, and are not entirely elastic.

The Distribution of Bronze Age Implements.—*Interim Report of Committee* (Professor J. L. Myres, *Chairman*; Mr. Harold Peake, *Secretary;* Mr. Leslie Armstrong, Dr. G. A. Auden, Mr. H. Balfour. Mr. L. H. D. Buxton, Mr. O. G. S. Crawford, Sir W. Boyd Dawkins, Professor H. J. Fleure, Mr. G. A. Garfitt, Professor Sir W. Ridgeway).

The Committee has had throughout the assistance of Dr. H. S. Harrison, representing the Royal Anthropological Institute, and Lord Abercromby, representing the Society of Antiquaries of Scotland.

The Committee's draughtsman, Mr. C. H. Howell, was ill for several months and unable to work, and the number of cards completed during the year is proportionately less. On the other hand the amount of voluntary assistance received has been considerable, for many Curators of Museums have made sketches of implements in their keeping or arranged for someone to do so ; others have forwarded their specimens to the Secretary. In cases where this could not be arranged, Mr. Graham Gordon has visited Museums for this purpose, and some further paid work has been arranged for elsewhere. But the vast majority of such work has been performed by voluntary helpers, and much of this is still in progress.

The number of cards completed on July 14 was 6,570, and the number of sketches completed but not yet copied was 795 ; most of these will have been copied on cards by the end of September, by which date several hundred more may be expected.

All the Museums in England and Wales have been dealt with except 17, and in the case of 11 of these the work is in progress or has been promised. Besides the latter, which contain an estimated number of 1,450 implements, there remain five Museums, with an estimated number of 900 implements, and about 800 specimens in the British Museum. To these must be added implements in private collections estimated at 425, bringing up the total number outstanding in England and Wales to 3,575. There are about 1,000 still to be done in Scotland.

These figures are necessarily tentative, as it has been found impossible in many cases to ascertain the exact numbers, and fresh specimens, sometimes in considerable numbers, are acquired each year ; new and unexpected private collections are also coming to light.

It will take at least another year to complete the work in England and Wales, and this work cannot be completed by Michaelmas 1924, unless an extra expert draughtsman be employed to draw on cards the remaining specimens in the British Museum, and paid workers be employed to make sketches in the five other Museums not yet arranged for. The total cost of this, including travelling and administrative expenses, is estimated at not less than 315*l.* from July 14, 1923, to September 30, 1924, of which the sum of about 55*l.* is in hand, leaving a balance of about 260*l.* to be found. The following sums have been received :—

	£	*s.*	*d.*
The British Association	100	0	0
The Society of Antiquaries	5	0	0
The Lord Abercromby	10	0	0
R. Vernon Favell, Esq.	10	0	0
Richard F. Nicholson, Esq.	10	0	0
The Earl Iveagh	5	0	0
Robert Mond, Esq.	5	0	0
A. C. R. Carter, Esq.	2	2	0
George Cadbury, Esq., Junr. . . .	2	0	0
Parker Brewis, Esq.	2	0	0
The Lord Leverhulme	1	1	0
Thomas G. Barnett, Esq.	1	1	0
James Boothe, Esq.	1	1	0
Henry R. Beeton, Esq.	1	1	0
J. Reid Moir, Esq.	1	1	0
Frank R. East, Esq.	0	10	6
	156	17	6
Balance brought forward .	42	8	2
Total receipts	199	5	8

The expenditure has been :—

C. H. Howell, salary	96 10 0	
G. Gordon, daywork	16 0 0	
C. G. Whitlock, piecework	3 3 0	
O. Kew, piecework	0 8 3	
		£116 1 3
C. H. Howell, expenses	6 15 2	
G. Gordon, expenses	9 15 7	
		16 10 9
Globe-Wernicke Co., cards	8 19 0	
A. Chivers, boxes	1 16 0	
Cheque-book	0 4 2	
		10 19 2
Total expenditure		£143 11 2

Total receipts	199 5 8
Total expenditure	143 11 2
Balance, July 14, 1923	£55 14 6

Committee to co-operate with Local Committees in Excavations on Roman Sites in Britain.—Sir W. Ridgeway, *Chairman*; Mr. Harold Peake, *Secretary*; Dr. T. Ashby, Mr. Willoughby Gardner, Professor J. L. Myres.

Owing to the high cost of labour, excavations were again suspended during 1921 in the Dinorben Hill Fort, which was being examined by the Abergele Antiquarian Association, the Cambrian Archæological Association, and the Board of Celtic Studies in co-operation with this Committee.

Work was continued by Mr. Willoughby Gardner upon the site during 1922, but too late to bring before the Hull Meeting; his Report is now presented.

The Committee asks to be re-appointed.

Abstract of Report on Further Excavations in Dinorben, the Ancient Hill Fort in Parch-y-Meirch Wood, Kinmel Park, Abergele, N. Wales, during 1922.

By Willoughby Gardner, *F.S.A.*

The exploration of this native hill-fort (see Reports of the British Association, 1912, 1913, 1915 and 1920) was continued during a period of five weeks in 1922. The principal objective was to endeavour to reach and to uncover the remains of the earliest hill-fort erected upon the site, but now buried deep beneath the accumulated ramparts of three later constructions. These remains have now been excavated in five different sections, proving that the defences of the first hill-fort consisted of a stone-faced rampart with a rock-cut ditch in front, and, at one point on the south-west side, a second similar ditch. In the first section cut the rampart was found to be completely thrown down into the ditch; in the second, its ruined wall face stood from one to three feet high; in the third, it stood four feet high, showing reparations, and in the fourth and fifth, one course of stones only remained; in every case the ditch in front was filled with the stones and earth forcibly thrown down from the ramparts behind.

Unfortunately, the relics found in connection with this earliest fort were few, and consisted principally of such undatable objects as broken bones of animals consumed for food, boiling pebbles, pounding stones, charcoal, and several sawn antler picks; but on the berm, between the ruined wall and the ditch, an iron axe-head was unearthed of a native type current in Britain during the centuries immediately before and subsequent to A.D. In the hope of finding something more datable, two stretches, thirty-five and forty feet long respectively, of the ditches belonging to this first hill-fort were completely emptied, but without better success.

In a section cut immediately west of the south-east entrance, a new feature was revealed in a half-moon, bastion-like projection of the wall belonging to the hill-fort of the second period; this was built against the ruins of the wall of the first hill-fort and curved round to form a previously undiscovered sidewall of an entrance also belonging to the second period. Four roadways had already been found in this main entrance of the hill-fort, three superincumbent and one a few yards to the east. But definite ruined sidewalls belonging to three only of these roadways had been previously discovered. Now, the existence of four consecutive main entrances is proved by ruined sidewalls as well as by roadways.

Further patches in the interior area of the hill-fort were also excavated. Here many relics belonging to the last occupation were unearthed, similar to those previously described; also, on the same horizon, for the first time upon the site, several pieces of native hand-made pottery, showing that this rude ware continued to be made here after the importation of the better Romano-British vessels.

To sum up the results of the excavations made in this hill-fort during five seasons. They show that—

1. There were dwellers upon this hilltop before its fortification, as proved by relics found.

2. There were four successive hill-forts built by the natives upon the hilltop, the ruins of which have been brought to light.

3. Each of these four hill-forts in turn suffered attack and forcible destruction from the hands of an enemy.

4. The first hill-fort was defended by a stone-faced rampart with a deep ditch cut in the rock some ten feet in front of it. Its destruction was shown by relics to be during the later Iron Age, and it was so complete that one can hardly doubt that it was the work of Roman legionaries invading the district. The remarkable Late-Celtic bronze horse-trappings found with quantities of human bones at the foot of the precipice at the west side of the hill-fort would seem to synchronise with this.

5. The native builders of the second hill-fort constructed oblong guard houses at the main entrance. This apparently points to an acquired knowledge by this time of Roman methods.

6. The second and also the third construction at Dinorben, like the neighbouring hill-fort at Pen-y-Corddyn, were apparently occupied for short periods only, as shown by the small amount of silting found at the bottom of the ditches and by the paucity of relics left behind by the occupiers.

7. The destructions of both the second and third hill-forts occurred before peaceful trading relations between the natives of this district and the Romans were established, as shown by the absence of Roman objects in the layers of occupation of these periods, so far as they have been uncovered.

8. The natives returned in numbers to the hilltop later; they refortified themselves there and occupied the stronghold continuously during the third and fourth centuries A.D. During this period they traded extensively with the Romans.

9. Apparently about the close of the fourth century the stronghold met with its final destruction, probably at the hands of Irish and other raiders from overseas.

Lake Villages in Somerset. — *Report of Committee* (Sir W. Boyd Dawkins, *Chairman*; Mr. Willoughby Gardner, *Secretary*; Mr. H. Balfour, Mr. A. Bulleid, Mr. F. S. Palmer, Mr. H. J. E. Peake) *appointed to investigate the Lake Villages in the neighbourhood of Glastonbury in connection with a Committee of the Somerset Archæological and Natural History Society.*

The Committee for exploring the Lake Villages in Somerset beg to report that the excavations were reopened on Monday, August 28, 1922, under the direction of Messrs. Bulleid and H. St. George Gray, and were continued for two weeks.

The Meare Lake Village consists of two distinct groups of mounds, extending over portions of six pasture fields and estimated roughly to consist of one hundred dwellings. The field in which the excavations were carried on is one of four occupied by the western group of mounds, and the ground opened up was directly continuous with that explored in 1921.

The following dwelling mounds were examined :—

Mound XXI, a large and important dwelling site, partly explored in 1921, was completed, and about one-half of Mounds XXIV, XXVI, and XXXIX. Mound XXI consisted of three superimposed clay floors supported by a well-arranged timber foundation, the lowest layer of which was 7 feet below the surface.

Mound XXVI consisted of five superimposed floors supported by a foundation of timber and brushwood; the total thickness of clay near the centre of the dwelling measured 6 feet. The hearths, central posts, and other structural features were of much interest and will be described in detail in the final description of the village.

Among the smaller objects of interest discovered the following may be mentioned :—

Bronze.—A few fragments of bronze and one fibula of La Tene III type.

Tin and Lead.—Flat ring of tin, diam. 35 mm. Piece of lead ore.

Iron.—Parts of a sickle and of a knife; awl of round section at one end, square at the other.

Crucibles.—Large crucible, highly coloured, and parts of other crucibles.

Glass.—Three ring-beads of opaque yellow paste, and another bead of pale blue glass.

Kimmeridge Shale.—Parts of five plain armlets, and a bead (diam. 18 mm.).

Antler.—Two weaving combs and parts of two others; several pieces of sawn red-deer antler and one piece of roe-deer antler.

Bone.—Eleven worked and perforated *scapulæ* of ox and horse; perforated tarsal bones of sheep; and a modelling tool.

Pottery.—In some quantity, including a large number of parts of pots finely ornamented.

Spindlewhorls.—Three stone spindlewhorls.

Querns.—Parts of a few saddle querns; also some whetstones.

Flint.—Five scrapers and a knife.

Human Remains.—Parts of a child's skull found in the foundation.

Cereals.—This season we came across, especially in Mounds XXIV and XXXIX, Floor I, a quantity of grains of barley and also a few oat grains. These cereals are proving of considerable interest and are being examined by Prof. R. H. Biffen, of the School of Agriculture, Cambridge.

Progress of Anthropological Teaching.—*First Report of Committee* (Dr. A. C. HADDON, *Chairman*; Professor J. L. MYRES, *Secretary*; Professor H. J. FLEURE, Dr. R. R. MARETT, Professor C. C. SELIGMAN).

THIS Committee was appointed at the Hull Meeting, 1923, 'to report on the progress of anthropological teaching in the present century.' The materials collected by a former Committee of the Association (which reported at the Cambridge Meeting, 1904) have been placed at its disposal, and will be incorporated in its eventual retrospect. Some progress has been made in collecting the required information from institutions in the Dominions and in foreign countries; but in compliance with a request from the Royal Anthropological Institute's Joint Committee on Teaching and Research for a summary of the present facilities offered by British institutions, this section of the report, which was already practically ready, has been completed and submitted in advance of the rest. It is hoped that it may be of use to research students as a guide to the principal collections of material and centres of anthropological study.

Provision for Anthropological Teaching and Research in Universities and other Institutions in Great Britain.

This information is presented in alphabetical order of the principal centres of study in England, Wales, and Scotland. No answers have been received to any inquiries addressed to similar institutions in Ireland.

England and Wales.

Bristol.—The University has a small collection of representative crania and casts. The archæological and ethnological collections of the Bristol Museum, adjacent to the University, are open to research students, by permission of the Director. The library is open to registered students and, by permission of the Librarian, to others, and there is ample accommodation for research students.

The Professor of Anatomy, Dr. E. Fawcett, gives instruction in Physical Anthropology, which is included in the curriculum for the degree of B.Sc. in Human Morphology. There is an independent Department of Geography under a Lecturer, and the Bristol Museum has a Curator of Ethnological Collections.

The Bristol Spelæological Society conducts explorations and assists students in their fieldwork.

Cambridge.—The University has important collections in Physical Anthropology, Ethnography (especially those of the Torres Straits Expedition), and Archæology (especially local and other British antiquities). There is laboratory accommodation for research students in all branches of anthropology, and students are admitted to departmental libraries on the same terms as to the University Library.

Besides the Professor of Human Anatomy, Dr. J. T. Wilson, there is a Reader in Human Anatomy, Dr. W. H. L. Duckworth, who gives anthropological instruction; a Reader in Ethnology, Dr. A. C. Haddon, F.R.S.; and the Disney Professor of Archæology, Sir W. Ridgeway, F.B.A., gives instruction in prehistoric archæology. There are also 'recognised lectures' in Cultural Anthropology and Prehistoric Archæology, and the Bronze and Early Iron Ages; and there is an independent Department of Geography, under a Reader.

A Board of Archæological and Anthropological Studies is generally responsible for teaching and research in these subjects, which qualify for the degree of B.A. (in the Second Part of the Tripos), for the degrees of Ph.D. and M.Sc., and for a Diploma, according to the length and nature of the course.

The Cambridge Antiquarian Society has records of local finds, and assists students in regional surveys and other fieldwork.

Durham.—The University has no anthropological collections, except a few skulls of different races in the College of Medicine, which is at Newcastle-on-Tyne.

The Professor of Philosophy, Dr. F. B. Jevons, gives instruction in Social Anthropology, which is an optional subject (under the head of Comparative Science of Religion) for the degree of B.A.

Exeter.—The Royal Albert Memorial University College for the West of England has no collections, but utilises those of the City Museum, which is established in the same building.

There is no course in Anthropology, but instruction in human distributions is given as required in the Department of Geography.

Liverpool.—The University has the following collections: in its museums of Zoology and Anatomy, collections of skulls and other material; in the Museum of Zoology, ethnographical collections from the Malay States; in the Museum of Geology, a collection of prehistoric implements; in the Museum of Public Health, illustrations of Roman drainage systems; in the Institute of Archæology, Classical, Egyptian, and Central American antiquities. The Museum of the City of Liverpool has the Mayer Collection of Egyptian and other antiquities, and large ethnographic collections from West Africa and elsewhere.

There is laboratory accommodation for research students in all the departments to which anthropological studies are related. Students who are not members of the University may be recommended for admission to the departmental libraries.

Instruction is given in Physical Anthropology by the Lecturer, Dr. W. H. Broad; there is also a Lecturer in Palæontology, Mr. E. Neverson, M.Sc.

There is no Department of Ethnography, but an Honorary Lecturer, Dr. H. W. Williams, gives instruction in the Ethnography of the Russian Empire. At the University Institute of Archæology courses of lectures are given in Classical Archæology by Professor J. P. Droop; in Egyptology and Assyriology by Professor T. E. Peet; and in the methods and practice of Archæology by Professor J. Garstang (who is also Director of the British School of Archæology in Jerusalem). There are also non-resident Readers in Egyptian Art (Professor P. E. Newberry), Mediæval Archæology (Dr. F. P. Barnard), and Lecturers in Central American Archæology (Dr. T. W. F. Gann) and Numismatics (Mr. J. G. Milne. There is a fully equipped Department of Geography, under Professor P. M. Roxby.

Archæology may be offered as a subject in the course for the degree of B.A., and in the Honour School of Ancient History, and is an approved department for research for the degree of Ph.D. The University also gives a Diploma and Certificate in Archæology.

London.—The multiplicity of provision for teaching and research of all kinds makes it necessary to reclassify the information received from each institution under the principal divisions of the subject.

Physical Anthropology.—The Royal College of Surgeons has a large collection of skulls, skeletons, brains, and in some cases dissections, representing all races and the people of all countries; it contains about 5,000 specimens, numerous remains of ancient man and (in rare cases) of his handiwork. There is accommodation for research students in the Museum itself and its workrooms. Students are admitted to the Library on the recommendation of a member or a Fellow of the College. A research worker endowed by the Department of Scientific and Industrial Research is preparing a new catalogue of the Anthropological collection. No formal teaching is given.

University College has collections of material in the Edwards Library of Egyptology, in the Galton Laboratory of Eugenics, and in the Rockefeller Institute. All these have departmental libraries and laboratory accommodation for research students. Instruction is given by the Professor of Anatomy, Dr. G. Elliot Smith, F.R.S.; by the Professor of Eugenics, Dr. Karl Pearson, F.R.S.; and by their demonstrators.

King's College has anthropological material in its Department of Anatomy, and laboratory accommodation for research students. Instruction is given by the Professor of Anatomy, Dr. E. Barclay-Smith, and the Reader in Anthropology and Morphology, Mr. R. J. Gladstone.

The Francis Galton Laboratory for National Eugenics is especially designed for the *statistical* study of man's heredity, mentality, physique, and capacities in the race or mass. It has about 5,000 crania of various races, nearly 700 skeletons, casts of the chief palæolithic finds, palæolithic reconstructions, and a considerable collection of flint implements. There is laboratory accommodation for 12-18 research students, but as a rule only a few research workers are occupied with anthropology. There is a studentship for anthropometry and craniometry. The library contains most of the foreign transactions and journals on anthropology, and memoirs on anthropometry and craniometry. In the anthropometric laboratory, which is one of the most complete of its kind, physical, mental, and medical measurements are made under a special medical officer. In anthropometry and craniometry provision is only made for graduate workers; but undergraduate students of anthropometry are admitted occasionally, and a complete course of anthropometry could easily be organised if there were any demand for it.

The Natural History Department of the British Museum, in South Kensington, has important collections of early remains of man and associated handiwork, as well as of typical modern crania; research students may be permitted to use the Departmental Library and workrooms.

Ethnography and Archæology.—The national collections of ethnographical and archæological material and literature are in the British Museum, in Bloomsbury. The India Museum at South Kensington and the Horniman Museum have considerable ethnographic and archæological collections.

University College has a collection of Egyptian antiquities in the Edwards Library, but in view of the proximity of the British Museum in Bloomsbury, this and other collections of anthropological material at University College are intended for teaching and demonstration rather than for comprehensive study. Instruction is given in Egyptology by the Edwards Professor, Sir Flinders Petrie, F.R.S., and by the Senior Lecturer, Miss M. A. Murray; in Archæology by the Yates Professor, Dr. E. A. Gardner, and by the Lecturer in Comparative Art, Mr. H. G. Spearing. The Department of Economic Geography has occasional courses in general ethnography.

King's College has special libraries and research material for Slavonic countries, Spanish-speaking regions, and mediæval and modern Greece.

The School of Oriental Studies at the London Institution is mainly concerned with languages and literatures, but has a general library and a small collection of anthropological photographs. In the examination for the Diploma in Bantu Languages a paper is set on Anthropology and Ethnology.

The London School of Economics and Political Science has a considerable teaching collection of ethnographical specimens, casts, photographs, and lantern slides. The Professor of Ethnology in the University, Dr. C. G. Seligman, F.R.S., gives instruction at the School in Ethnography, including Technology; and Mr. T. A. Joyce gives instruction in Ethnography at the School and demonstrations in the British Museum. Professor Seligman also lectures on European Prehistory, and gives special courses on Human Geography, intended for teachers. Laboratory accommodation is not provided, but there are rooms for research students, and the General Library of the School is open to students duly recommended.

Social Anthropology.—University College has a Reader in Cultural Anthropology, Mr. W. J. Perry; and instruction is also given in special aspects of the subject by the Quain Professor of Comparative Law, Mr. J. E. G. de Montmorency, and by Miss M. A. Murray in the Department of Egyptology.

The Martin White Professors of Sociology, Dr. L. T. Hobhouse and Dr. E. Westermarck, and the Reader in Social Anthropology, Dr. B. Malinowski, give instruction at the London School of Economics; the courses of the Professor of Ethnography include instruction in fieldwork, intended for officials, missionaries, and others going among primitive and barbarous peoples. At the Imperial Institute special courses in Ethnology form part of the Tropical Services course for officers of the African Civil Service.

Besides the Libraries of the British Museum and the constituent Colleges of the University, of the India Office, Colonial Office, and other Government Departments, and of learned Societies such as the Royal Anthropological Institute, the Royal Colonial Institute, the Royal Asiatic and Royal Geographical Societies, the Folk-Lore Society, Japan Society, and the like (which are open to students duly recommended, as well as to their own members or Fellows), there is much valuable material in the Library of the London School of Economics and Political Science, which includes a special section for Social Anthropology, open to recommended students. At Leplay House (65 Belgrave Road, Westminster) there is, in addition to the library of the Sociological Society, a collection of material for regional surveys of present-day communities, and the Department of Surveys contemplates the training of survey workers.

Academic Status of Anthropology and General Facilities for Study and Research.—In the University of London, Anthropology may be offered in Honours and Pass Examinations for the degrees of B.A. and B.Sc., and as an optional subject in the B.A. Honours course in Geography; it is recognised as a subject for the degrees of M.A., M.Sc., D.Litt., D.Sc., and Ph.D., for the Diploma of Psychology, and for the College Certificate in Egyptology. An attempt is now being made by the constituent Colleges to make full provision for teaching and research in all departments of Anthropology. The Royal Anthropological Institute, on the invitation of the British Association and other bodies interested in anthropological studies, has established a joint committee, on which such bodies are entitled to be represented, with the object of ensuring to students from the Dominions and foreign countries all needful facilities for their researches, and information as to material available in public archives and in private collections.

Manchester.—The Victoria University has a small collection of typical crania, a large collection illustrating the arts and crafts of primitive peoples, and important Egyptian material. Laboratory accommodation can be provided for research students, but there is no Department of Anthropology, nor recognised teachers; occasional courses of lectures are given, however, on some branches of the subject.

Nottingham.—The University College has a working collection of human osteology and of stone implements. The Professor of Geology, Dr. H. H. Swinnerton, and the Lecturer in Physiology, Miss H. J. Hutchinson, give instruction on Physical Anthropology, and the Lecturer in Geography, Mr. C. G. Beasley, in Ethnography and Social Anthropology. The Distribution of Man is a subject in the Honours Course in Geography for the degree of B.A.

Oxford.—The University has important collections of Physical Anthropology, in its Department of Human Anatomy; of ethnographical material, in the Pitt-Rivers Museum and the Indian Institute; and of the antiquities of the Mediterranean and ancient East and of the Oxford district, in the Ashmolean Museum. There is laboratory accommodation for research students in the Departments of Human Anatomy and Social Anthropology. The Bodleian and Radcliffe Libraries, the Tylor Library of Anthropology, and the departmental libraries of the Ashmolean, Pitt-Rivers Museum, and School of Geography are open to members of the University and to other students duly recommended.

Research students desiring facilities for their work, or information on the subject of it, should communicate with the Secretary of the Committee for Anthropology.

Regular courses are announced in Physical Anthropology by the Professor of Anatomy, Dr. A. Thomson, and by the Lecturer in Physical Anthropology, Mr. L. H. Dudley Buxton; in Ethnography, by the Curator of the Pitt-Rivers Museum, Mr. Henry Balfour; in Prehistoric Archæology, by Mr. E. T. Leeds, Assistant Keeper of the Ashmolean Museum; and in Social Anthropology, by the Reader, Dr. R. R. Marett. Informal instruction is given and occasional public courses are offered on the anthropological aspects of their respective subjects by University teachers of Geology, Geography, Ancient History, Jurisprudence, Prehistoric and Classical Archæology, Egyptology, Assyriology, and the principal Oriental languages. These are announced in the terminal programmes of the Committee for Anthropology, and in the lecture lists of the Faculties of Literæ Humaniores, Law, Oriental Languages, and Natural Science. The Oxford Architectural and Historical Society has its library and records in the Ashmolean Museum, and assists students in regional survey work.

There is no Honour Course in Anthropology for the degree of B.A., but the Diploma in Anthropology is awarded on courses of study of at least one year, and this Diploma is reckoned as equivalent to two of the three subjects required for the ordinary degree; the third subject must be one of the languages prescribed by regulations. Separate Certificates are awarded for proficiency in Physical and in Cultural Anthropology (Technological *or* Social), each equivalent to one such subject for the degree of B.A. Anthropological research is admissible for the degrees of B.Litt., B.Sc., and Ph.D.

Special provision has been made from time to time for officers of the public services who have been sent by the Colonial Office for short courses of anthropological study, and for candidates and probationers of the Indian Civil Service.

Sheffield.—The University has a type collection of crania and skeletons, and there is archæological material in the City Museum. There is laboratory accommodation for research students. There is no teacher of Anthropology, but the Professor of Anatomy, Dr. C. J. Patten, gives instruction in Physical Anthropology as required, and there is a fully equipped Department of Geography.

Wales.—In the University of Wales, Anthropology is an important part of the Honours Course in Geography for the degree of B.A., and is a recognised subject of research for the post-graduate diploma in Geography and for the degrees of M.A. and M.Sc.

The University College at Aberystwyth has a teaching collection of Physical Anthropology, Ethnography and Archæology, and a special library for Ethnography and Anthropology in the Department of Geography. Instruction is given by the Professor of Geography and Anthropology, Dr. H. J. Fleure; special attention is given to anthropological surveys and other regional work, with the help of graduate students in various parts of Wales; and important correlation-data are already available in the School of Geography for the use of qualified students. Training is given in excavation and other branches of fieldwork.

The University College at Cardiff has a teaching collection for Physical Anthropology, and the departmental Library of Anatomy is open to qualified students. The Professor of Anatomy and Anthropology, Dr. D. Hepburn, C.M.G., F.R.S.E., gives instruction in Physical Anthropology, which is a compulsory subject for students of Medicine in the course for the degree of B.Sc. There is no recognised teacher in other branches of Anthropology, but lectures and instruction in Archæology are given as required by Dr. E. R. M. Wheeler, of the National Museum of Wales.

Scotland.

Aberdeen.—The University of Aberdeen has Museums of Anatomy and Anthropology and an Anthropometric Laboratory. There is an illustrated catalogue of the anthropological and archæological collections (1912, price 1s.), with a supplementary catalogue of the ethnographical collections of Sir William Macgregor. The Library is open to students. The Professor of Anatomy, Dr. R. W. Reid, F.R.S., gives instruction in Physical Anthropology, which is a subject qualifying for the degree of B.Sc. There is no special teacher of Ethnography, Archæology, or Social Anthropology, but lectures are given on Greek Sculpture and the History of Architecture. These subjects qualify for graduation in Arts (M.A.).

A Students' Anatomical and Anthropological Society, founded in 1899, meets at least once a month during the winter session for discussions and for addresses by experts in these subjects.

St. Andrews.—The University of St. Andrews has a small collection of crania, fairly representative. The library is open to matriculated students and research workers. There is laboratory accommodation for research students in Physical Anthropology, which is included in the Department of Anatomy. The Professor of Anatomy, Dr. D. Waterston, F.R.S.E., gives instruction in Physical Anthropology, which may be taken as part of the course for the degrees of M.A. and B.Sc.

There are no collections or courses of instruction in other branches of Anthropology.

Edinburgh.—The University of Edinburgh has a collection of over 1,900 crania (of which 298 are Australian) and a large number of other bones of various races. The departmental Library of Anatomy is used as a research room and is fully equipped; it is open to all students who wish to do research.

The Professor of Anatomy, Dr. A. Robinson, gives instruction in Physical Anthropology, which is a subject qualifying for the degree of B.Sc.

The University has no collections or systematic teaching in other branches of Anthropology, but the Munro Lecturer gives ten lectures each year on Anthropology or Prehistoric Archæology.

The Royal Scottish Museum and the Scottish National Museum of Antiquities have important collections of Scottish and other antiquities, and the Museum of the Royal College of Surgeons a large collection of anatomical material.

Glasgow.—The University has a fair teaching collection for Physical Anthropology with about 300 skulls, representing most of the racial groups. The Hunterian Museum contains the considerable Turner collection of ethnographical material from the South Seas; a representative collection of Scottish antiquities, prehistoric and Roman; an important collection of ancient coins, and other classical and Egyptian material. The Library is open to matriculated students, and research students also may be admitted. Laboratory accommodation for research students is provided as required.

The Professor of Anatomy, Dr. T. H. Bryce, F.R.S., gives instruction in Physical Anthropology, and the Hon. Curator of the archæological and ethnographical collections of the Hunterian Museum. There is an independent Department of Geography, under a Lecturer; and instruction in Classical Archæology is given in the Departments of Greek and Latin.

Except in Physical Anthropology, no ordinary degree or diploma of the University includes anthropological studies; but a research student may present a thesis in any branch of Anthropology for the degree of Ph.D. after three years' research in the University or in a College affiliated thereto.

Oenothera, &c.—*Final Report of Committee* (Dr. A. B. RENDLE, *Chairman*; Prof. R. R. GATES, *Secretary*; Prof. W. BATESON, Dr. W. BRIERLEY, Prof. O. V. DARBISHIRE, Dr. M. C. RAYNER) *appointed to continue Breeding Experiments on Oenothera and other Genera.*

Correlated cytological and genetical experiments with a number of genera have been continued at the Royal Botanic Gardens, Regent's Park, during the past year. These genera include Oenothera, Celosia, Lathyrus, Brassica, Tiarella, and Lactuca. In Celosia the inheritance of several colour varieties and of fasciation is being studied. In Lathyrus the investigations include a cytological study of the pollen development, with particular reference to (*a*) the dominance of long pollen; (*b*) the inheritance of pollen sterility; (*c*) the cytological basis of crossing over. With wild cabbages a study is being made of the variability, the effects of cultivation, and the self-sterility. In *Tiarella cordifolia*, a form with orange anthers is found to be usually almost wholly sterile in its pollen, and the ovules are also often imperfectly formed. Further studies of this condition are being made. Numerous species of Lactuca are being grown for a comparative study of their chromosomes and external characters.

In the Oenotheras, which probably show more genetic and cytological peculiarities than any other groups of organisms, a number of problems have reached definite conclusions which link up their behaviour in various ways with the more usual Mendelian inheritance. In a paper on present problems of Oenothera research which is now in the press in the Mendel Memorial Volume of the Prague Celebration, it is pointed out that the differences between the twin hybrids frequently obtained in crosses are probably all determined by a single pair of chromosomes. Much of the differentiation of the group appears to have been concerned with this pair. The well-known gametic and zygotic sterility of this group can also be accounted for, as well as the persistent heterozygous condition of the species, by the presence of a pair of zygotic lethal factors and a pair of gametic lethal factors in different pairs of chromosomes. This obviates the necessity for assuming that crossing-over occurs, a hypothesis for which there is no cytological basis in Oenothera, although there *is* evidence of such a process in Lactuca. The usual presence of 50 per cent. of empty seeds and functionless pollen and megaspores can thus be explained by the presence of lethal factors arising, as in Drosophila, through mutations. The presence of these conditions of sterility is thus not necessarily a proof of crossing in the ancestry. It is at least equally reasonable to suppose that the persistently heterozygous condition which is characteristic of various Oenothera species, including some of the small-flowered self-pollinating forms, has resulted from the development of lethal factors by mutation.

A study has been made of the reduction divisions in *Oenothera rubricalyx* × *Oe. gigas.* The behaviour of the chromosomes in this triploid hybrid explains the origin of the wide range of chromosome numbers found in the offspring of such hybrids. This paper is now in the press in the *Annals of Botany*, as well as another on 'The Trisomic Mutations of Oenothera.' In the latter paper a new mutation with fifteen chromosomes is investigated, and the numerous forms having an extra chromosome are discussed. An explanation of their origin, their peculiar genetic behaviour, and their unique relationships to each other, is put forward, based on the behaviour of the chromosomes. The fact that certain forms with fifteen chromosomes can give rise to others with the same number, and that certain of these may in turn give rise to the first, can be explained by double non-disjunction. This behaviour, as well as other facts, such as the paucity of Mendelian mutations, leads to the view that the chromosomes of Oenothera are probably less highly differentiated from each other than in some other organisms.

A study of the inheritance of petal-size in four generations of an Oenothera hybrid ('A peculiar type of variability in plants,' *Journ. of Genetics*, 13, 13-45, fig. 24) shows a new type of behaviour, which is in some respects intermediate between Mendelian inheritance and fluctuation. Fixed size units are apparently not involved, various irregular sizes of petals being obtained on the same plant and even in the same flower. It is suggested that these size differences may be determined in part by the cytoplasm rather than the nucleus, which would account for the irregularity in their behaviour. A general explanation of the size inheritance of repeated parts is offered as an alternative to the current hypothesis of multiple size factors.

A number of apparently unrelated cytological and genetical features of Oenothera behaviour are thus being brought under one co-ordinated point of view, and the innumerable complexities of Oenothera genetics are being explained by hypotheses which apply also to other genera of plants and animals. The Committee do not seek reappointment, as other sources of funds are found to be sufficient for present purposes.

Training in Citizenship. — *Report of Committee* (Right Rev. Bishop WELLDON, D.D., *Chairman;* Lady SHAW, *Secretary;* Mr. C. H. BLAKISTON, Mr. G. D. DUNKERLEY, Mr. W. D. EGGAR, Dr. J. C. MAXWELL GARNETT, C.B.E., Sir RICHARD GREGORY, Mr. SPURLEY HEY, Miss E. P. HUGHES, LL.D., Sir THEODORE MORISON).

THE Committee have met twice during the current year, and beg leave to report that they have now completed the work for which they were originally appointed.

Considerable interest has been aroused throughout the country, and many experiments are being tried with the object of fitting persons of all ages for the performance of their duties as good citizens at home and abroad.

The Committee desire to emphasise the opinion that training in citizenship depends as much upon environment and example as upon positive teaching. It is in the atmosphere created by the teacher that the spirit of citizenship is born and flourishes. The Committee express their sympathy with those teachers who are suffering disabilities, but deprecate unconstitutional methods in the search for remedies. The Committee therefore urge the necessity for greater care in the appointment of educational authorities and the choice of persons to serve in the schools.

The work among adults and in the higher classes of the schools is of paramount importance in the direct teaching of civics, and the Committee would urge this upon all associations which are formed for the instruction or recreation of the people. The formation of local parliaments, showing the practical work of the Government in the discussion and promotion of the laws, would be of inestimable value in the constituencies. Such parliaments could, by admitting the public as audience to their deliberations, demonstrate to the electors their individual responsibility for the framing of laws and for the observance of due decorum in public discussions.

The associations for young people—Scouts, Guides, Brigades of all denominations, Clubs—are invaluable; but a word of caution may be uttered against these institutions militating in any way against the home duties of the young citizens. Home life is the bedrock of civilisation; with adequate housing home life should reach a standard at present unattainable.

The Committee beg leave to lay a record of the year's work before the Education Section.

During the year 1,000 copies of the Committee's Report were presented at Hull, and 1,500 circulars advertising this and the two Reports already in circulation have been obtained; 1,335 circulars have been distributed and 165 sold. Three hundred and thirteen of the 1920 Report, 286 of the 1921 Report, and 239 of the 1922 Report have been sold. The sum realised by the sales is 21*l*. 8*s*. 11*d*.

At the Hull meeting a sum of 71*l*. 1*s*. 9*d*., the proceeds of the two years' sales of Reports, was handed to the British Association, and 50*l*. of this was granted to the Committee for the current year's expenses. A statement of accounts shows that 15*l*. 0*s*. 8*d*. has been spent, leaving 34*l*. 19*s*. 4*d*. With the amount realised by sales the balance in the bank is 56*l*. 18*s*. 4*d*. The Committee ask permission to use this balance, or such part of it as may be needed, in the preparation of an anthology illustrating the evolution and literary expression of the dominant ideas of citizenship in the course of the history of civilisation; they believe that such an anthology would be useful as supplementing the labours which the Committee have undertaken and accomplished in the preparation of their Reports.

The Committee ask for reappointment without further grant for one year, 1923-4, for the completion of the anthology.

SECTIONAL TRANSACTIONS.[1]

SECTION A.—MATHEMATICAL AND PHYSICAL SCIENCE.

(For references to the publications elsewhere of communications entered in the following list of transactions, see p. 503.)

Thursday, September 13.

1. **Joint Discussion** with Sections B and G on *Cohesion and Molecular Forces*, opened by Sir WILLIAM BRAGG, F.R.S.

2. Prof. C. G. DARWIN, F.R.S.—*The Recent Work of Prof. A. H. Compton on the Scattering of X-rays.*

3. Prof. C. G. BARKLA, F.R.S.—*X-ray Absorption and the J Discontinuities.*

4. Dr. W. M. SMART.—Lecture on *Navigation.*

Friday, September 14.

5. Senatore VITO VOLTERRA, For. Mem. R.S.—*Liquid Jets.*

Hitherto the case considered has been that of movements parallel to a plane, using the theory of functions. In the present research several cases are solved of symmetrical and unsymmetrical movements which are not plane movements.

6. SIR OLIVER LODGE, F.R.S.—*Matter and Radiation.*

Speculations as to the relation between radiation and matter and the possible generation of electrons by otherwise waste radiation. The momentum of a wave-front and some photo-electric phenomena are responsible for the suggestion, which has probably occurred to others. The velocity with which all matter is moving may also be taken into consideration.

In the theory of relativity, matter and energy are closely related, and an expression is forthcoming for the absolute energy of a moving body; whereas what has been always hitherto dealt with is the energy of relative motion. The absolute term in the expression for energy must be energy of constitution, and its form suggests a specialised portion of a turbulent ether circulating with the velocity of light. Turbulence confers upon an incompressible massive fluid the power of transmitting tranverse waves.

All ordinary motions could then be regarded as only local modifications of this general ethereal circulation, in the same sort of way as a wind is a modification of molecular motion. Ordinary motion would be equivalent to change of mass, and might be expressed as a slight addition to the individualised and specific portion of ethereal circulation which constitutes the original mass. What we call matter would be the way in which this kind of localised ether motion appeals to our senses. In the case of an electron, the absolute term in the expression for energy exhibits itself to us quantitatively as the energy of its electrostatic charge.

[1] Excursions which were arranged as part of the programmes of certain Sections, for the purpose of field work, &c., are recorded in these transactions. In addition, other items in the general programme of excursions were arranged with reference to the interests of particular Sections.

Light is also a motion in the ether, and an advancing wave-front is known to exhibit some of the properties of matter; it also ejects electrons in a curious way. The problem, not yet solved, is to find a method of converting wave-energy into stationary vortex motion, which may be the converse operation to that of exciting light or X-rays by accelerating electrons. When light is generated it has to advance at a certain speed. Whenever matter is generated, any surplus energy might account for its motion through space. All matter seems liable to be affected with considerable locomotive energy. If spiral nebulæ are dust-clouds, their high velocities appear significant.

If all the motion of matter is a modification of circulatory constitutional motion, and if we can represent energy as a change of mass, it seems possible to represent all material phenomena as changes in the intrinsic rotational motion of the ether of space. This would have the advantage of being absolute, having reference only to a universal stationary ether, instead of being relative to other pieces of matter, which is the appearance that things present to our senses. Rotation even of matter has always had an absolute appearance; but rotation of ether is probably the real absolute, and may ultimately be expected to serve as a fundamental representation of universal phenomena.

7. Mr. G. Stead and Miss B. Trevelyan.—*The Production of Triatomic Hydrogen (?)*

Hydrogen is subjected to intense electronic bombardment in a cylindrical thermionic tube with open grid and no anode. With a grid potential of 30 volts and over, a blue glow, consisting of primary and secondary hydrogen lines, is observed near the filament. The glow spreads progressively along the tube, the current increasing similarly till it suddenly falls to a small value, and the glow simultaneously runs back. A regular oscillation of the glow and current is maintained, and the pressure in the tube follows the current changes.

It appears that a polymerised modification of hydrogen is periodically formed and decomposed. If a tube surrounded by liquid air is attached no oscillation takes place, but nearly all the gas disappears rapidly. It is re-liberated on removing the liquid air, and is stable, but easily decomposed by electric discharge, showing an increase in volume in the ratio of 1.5 to 1. The decomposed gas shows bright primary and secondary spectra of hydrogen. The optimum pressure in the tube is about 0.05 mm. of mercury.

8. Capt. D. Brunt.—*Energy of the Circulation of the Atmosphere.*

The kinetic energy of the average circulation of the earth's atmosphere is estimated as of the order of 3.10^{27} ergs, while that of a particular but representative cyclone is given as 1.5×10^{24} ergs. The diameter of the latter being 1400 km., this represents an addition of 50 per cent. to the kinetic energy over the same area of the average circulation, assuming this uniformly distributed over the earth's surface.

The rate of dissipation of kinetic energy due to the effect of turbulence is considered in two parts. For the region from the ground up to the height where the gradient wind direction is realised, a formula is obtained which leads, under a set of representative natural conditions, to a rate of loss of kinetic energy of 3×10^{-3} kilowatts/(metre)^2. An examination of recorded wind distributions at greater heights leads to an average value for the layer, extending from the one just considered to the stratosphere, of 2×10^{-3} kilowatts/(metre)^2, so that the rate at which the kinetic energy of the earth's atmosphere is being dissipated by turbulence is of the order of 5×10^{-3} kilowatts per square metre of the earth's surface.

If this rate of dissipation were maintained for $1\frac{1}{6}$ days the whole kinetic energy of the general circulation would be destroyed in that time. Or, assuming the rate of dissipation to be proportional to the total kinetic energy, the total kinetic energy would be reduced to one-tenth its original value in three days.

This does not happen, and it is next shown that the conversion of a little over 2 per cent. of the effective incoming solar radiation into kinetic energy will maintain the level of the kinetic energy of the general circulation.

The means of conversion is not yet fully understood, but, following Sir

Napier Shaw, the ascent of only 0.1 $(\text{km.})^3$ of heated air per second over the tropics, rising to 15 km. moving polewards and descending in latitude 60°, would contribute work sufficient to make good the kinetic energy dissipated by turbulence.

9. Dr. A. T. Doodson.—*Meteorological Effects on Sea Level and Tides.*

The effect of the distribution of atmospheric pressure, statically and by the operation of the resulting wind, may have a magnitude of 3 feet or more on the sea-level at Liverpool. The greater part of the effect ζ can be expressed quantitatively by the relation

$$\zeta = \kappa B + \lambda E + \mu N + \text{constant},$$

where κ, λ, μ are constants, and B, E, N denote respectively the local atmospheric pressure and its gradients East and North. The constants are determined from observational data. The correlation between fluctuations of sea-level and atmospheric pressure is greatest when the sea-level is taken three hours earlier than the atmospheric pressure, whereas the correlation between sea-level and the easterly gradient of pressure, corresponding, roughly, to a south wind, is greatest when the mean sea-level is taken about fifteen hours later than the corresponding pressure gradient. For the northerly gradient (easterly wind) the time difference for maximum correlation is practically zero. At Liverpool a S.W. wind, and not one blowing directly into Liverpool Bay, is most effective in raising sea-level. A quantitative separation of the relative effects of winds in the Atlantic and in the Irish Sea shows that the former are 50 per cent. more effective than the latter for a given pressure gradient, and that the most effective wind for raising sea-level at Liverpool is almost due south when operating in the Atlantic, and almost due west when operating in the Irish Sea. On the British coast of the North Sea the most effective wind-directions for raising sea-level are also from the west (*i.e.* off-shore). Local configuration of coast-line plays only a small part in this phenomenon.

The height and time of high-water are affected in a somewhat complex way, and no simple law has yet been formulated.

10. Mr. T. Smith.—*Apocoptic Expansions.*

In the expansion of a general function, as by Taylor's theorem, it is customary to consider a number of leading terms and find limits between which the remainder lies for a definite range of the independent variable. The polynomial so obtained is in general not as close a representation of the function as is possible with a polynomial of that order. This and other expansions, as well as the usual formulæ for numerical interpolation, represent curves of order n, say, which pass through $n+1$ selected points on the fundamental curve. The polynomial of order n which represents the latter curve with the highest possible accuracy is constructed by causing it to pass through $2n+2$ points, none of which lie on this curve. The coefficients are functions of n as well as of the derivatives of the function represented.

11. Rev. A. L. Cortie.—*Series in Magnetic Disturbances.*

(1) The magnetic disturbance of 1923, March 24, during which the extreme range of declination was 66′, and in horizontal force 238γ, was the greatest since the exceptionally violent storm of 1921, May 13-15. It was accompanied by unusual earth-currents, and by displays of aurora borealis. It was preceded, at an interval of twenty-six days, by a disturbance somewhat less intense in 1923, February 26. This disturbance was also coincident with earth-currents and aurora borealis. These two were not isolated disturbances, for they were members of a series, at a mean interval of 27.2 days, from 1923, January 30 to June 13.

(2) The occurrence of this series of disturbances, and especially of the greater storm of March 24, is noteworthy, because the sun has been almost entirely free from spots and bright faculæ since the beginning of the year.

Of ninety-eight days of observation at Stonyhurst in the five months, January to May, 70 per cent. have been spotless. The mean area, too, of such spots as have been observed has been very small, not more than 32 millionths of the visible disc. The faculæ, though extensive, have been very faint. The minimum of solar activity in the cycle has almost been reached.

(3) But one small spot in latitude $-6°$ and longitude $3.2°$, observed 1923, April 19-29, is connected with the recent series of magnetic disturbances, and the faint faculæ observed have clustered about the same mean position. Moreover, this spot and the faculæ mark a patch or region of the sun's surface which has been intermittently disturbed since 1923, November. Similarly, the recent series of magnetic disturbances of 1923 is a continuation at each synodical solar rotation, with one period of magnetic calm excepted, of a long series beginning 1921, October 27, and extending altogether over 594 days.

(4) The mean synodical interval of this long series is exactly twenty-seven days. This corresponds to a mean daily rotation in arc on the sun's surface of $14.32°$, which is the rotation period, adopting a mean value from Carrington's and Spoerer's formula, for latitude $\pm 8.7°$. The mean value of the longitude of the sun's central meridian for all the days of this long magnetic series was $336.6°$. The mean value of the latitude of the intermittent solar disturbance was $-6.1°$, and of the longitude $343.5°$. There is, therefore, complete accord between the series of solar disturbances and the series of magnetic disturbances. Consequently, a definite region of the sun can affect the earth magnetically even when there are no visible disturbances upon it.

12. Mr. W. M. Mordey.—Lecture on *Some Recent Studies in Alternating Magnetism.* (Illustrated by Experiments and Lantern Slides.)

The following experiments, amongst others, were shown and described :—

(1) Repulsion from an alternate current multiphase magnetic field, of iron magnetite and other magnetic substances placed at a distance of several inches from the poles.

Attraction of these substances to the magnet when the distance is small.

(2) Steady movement or migration of these substances through the magnetic field, and repulsion from that field.

(3) Repulsion from a 1-phase magnet of specular hæmatite which forms a halo round and at a considerable distance from the poles.

Absence of lines of force in the halo.

(4) Illustration of lines of force in alternating fields of various substances, including Heusler alloys.

(5) Water containing certain magnetic materials driven uphill and discharged from a multiphase field—a surface tension effect.

(6) Separation of certain mineral substances from their gangue in multiphase fields.

(7) No movement of finely divided aluminium in these alternating fields, indicating that the above effects are not due to eddy currents, and that they are due to or associated with hysteresis.

13. Mr. S. G. Brown, F.R.S.—Demonstration of the '*Frenophone*,' or *Friction Operated Loud-Speaker.*

Apparatus in which very high magnification of the received signals or speech is obtained by means of the friction existing between a polished glass disc and a small cork pad rubbing upon its surface. The disc is rotated by clockwork. The received telephonic current is applied to the coils of a receiver of the reed type; the reed presses upon the pad, which in turn bears upon the disc. The vibratory pressure of the pad causes large vibratory changes in the frictional drag imparted to the pad; and by linking the pad to a telephone diaphragm, so that it is caused to vibrate as the result of the tangential vibrations due to the drag of the disc upon the pad, very loud speech, &c., is set up in the sound-emitting trumpet.

Monday, September 17.

14. Presidential Address by Prof. J. C. McLennan, F.R.S., on *Origin of Spectra.* (See p. 25.)

15. Prof. N. Bohr.—*The Correspondence Principle.*

The quantum theory of atomic constitution rests upon the following two postulates :—

I. Among the conceivably possible states of motion in an atomic system there exist a number of so-called "stationary states" which, in spite of the fact that the motion of the particles in these states obeys the laws of classical mechanics to a considerable extent, possess a peculiar mechanically unexplainable stability, of such a sort that every permanent change in the motion of the system must consist of a complete transition from one stationary state to another.

II. While in contradiction to the classical electromagnetic theory no radiation takes place from the atom in the stationary states themselves, a process of transition between two stationary states can be accompanied by the emission of electromagnetic radiation, which will have the same properties as that which would be sent out according to the classical theory from an electrified particle executing a harmonic vibration with constant frequency. This frequency ν has, however, no simple relation to the motion of the particles of the atom, but is given by the quantum relation

$$h\nu = E' - E'', \qquad (1)$$

where h is Planck's constant, and E' and E'' are the values of the energy of the atom in the two stationary states that form the initial and final states of the radiation process.

It will be the purpose of these remarks to show how, notwithstanding the fundamental departure from the ideas of the classical theories of mechanics and electrodynamics involved in these postulates, it has been possible to trace a connection between the radiation emitted by an atom and the motion of the particles which exhibits a far-reaching analogy to that claimed by the classical ideas of the origin of radiation.

Consider an atomic system of s degrees of freedom for which the motion of the particles is governed by the canonical equations

$$\dot{q}_i = \frac{\delta E}{\delta p_i}, \quad \dot{p}_i = \frac{\delta E}{\delta \dot{q}_i} \quad (i=1, \ldots s) \qquad (2)$$

where E is the total energy of the system considered as a function of the generalised co-ordinates $q_1 \ldots q_s$ and the conjugated momenta $p_1 \ldots p_s$. Now the selection of stationary states among the solutions of these equations claims that these solutions exhibit certain periodicity properties which involve that the displacement of each particle in any given direction can be represented as a function of the time by means of an expression of the form

$$\xi = \Sigma C_{\tau_1 \ldots \tau_r} \cdot \cos\,[2\pi(\tau_1\omega_1 + \ldots + \tau_r\omega_r)t + \gamma_{\tau_1 \ldots \tau_r}] \qquad (3)$$

where $\tau_1 \ldots \tau_r$ are positive or negative integers and $\omega_1 \ldots \omega_r$ represent the so-called fundamental frequencies of the motion. The number of these frequencies, the degree of periodicity, is fixed by the condition that no relations exist of the form $m_1\omega_1 + \ldots + m_r\,\omega_r = 0$ where $m_1 \ldots m_r$ are positive or negative integers. In general the summation in (3) is to be extended to all positive and negative values of the integers $\tau_1 \ldots \tau_r$.

The stationary states of such an r-double periodic system are now determined by a set of r quantum relations of the form

$$J_k = n_k h \qquad (k=1 \ldots r) \qquad (4)$$

where h is again Planck's constant and $n_1 \ldots n_r$ are integers, the so-called quantum numbers, while $J_1 \ldots J_r$ is a set of quantities which characterize certain mechanical properties of the motion, and which fulfil the relation

$$\delta E = \sum_k \omega_k \delta J_k \qquad (5)$$

where the symbol of differentiation δ refers to two neighbouring solutions of the equations (2). By this relation the quantities J are fixed apart from arbitrary additive constants. These constants, however, are fixed by the further condition

$$\sum_k \omega_k J_k = \overline{\sum_i p_i \dot{q}_i} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

where the member of the right side represents the mean value of the expression under the horizontal line taken over a time interval long compared with the fundamental periods of the motion.

According to the quantum relations (1) and (4) we get now for the frequency of the radiation emitted by a transition between two stationary states characterized by the quantum numbers $n'_1 \ . \ . \ . \ n'_r$ and $n''_1 \ . \ . \ . \ n''_r$ respectively

$$\nu = \frac{1}{h}(E' - E'') = \frac{1}{h}\int_{''}^{'} \sum \omega_k dJ_k = \overline{\sum (n'_k - n''_k)\omega_k} \quad . \quad . \quad . \qquad (7)$$

where the mean value of the last expression is to be taken over such solutions of the equations (2) which in the r-dimensional J-space are represented by a straight line connecting the points $(J'_1 \ . \ . \ . \ J'_r)$ and $(J''_1 \ . \ . \ . \ J''_r)$ indicating the two stationary states involved in the process.

In the limit where the values of the quantum numbers are large compared with their differences $n'_k - n''_k$, we may consider the frequencies ω_k as constants in the mean value in equation (7), and get the asymptotical relation

$$\nu \sim \sum_k \omega_k (n'_k - n''_k). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

In this limit the frequency of the radiation will accordingly coincide asymptotically with the frequency of that harmonic component in the motion represented by (3) for which the relations

$$\tau_k = n'_k - n''_k \qquad (k = 1 \ . \ . \ . \ r) \quad . \quad . \quad . \quad . \qquad (9)$$

are fulfilled.

This result opens a possibility in the limit of large quantum numbers to obtain a connection between the statistical results of the quantum theory and the classical theory of radiation. It must be emphasised, however, that here we have by no means to do with a gradual disappearance in this limit of the fundamental difference between the quantum theory and the classical theory. In fact, according to the latter theory the radiation from the atom will take place continuously and consists of the simultaneous emission of a multitude of wave systems with different frequencies, each corresponding to one of the harmonic components in the motion, while on the quantum theory each train of waves is emitted by an independent process of transition between stationary states, the relative occurrence of the different processes being governed by laws of probability. Just this circumstance leads us to consider the connection between the harmonic components of the motion and the various processes of transition traced in the region of large quantum numbers, as evidence of a general law holding for all quantum numbers. According to this law, the so-called "correspondence principle," every transition process between two stationary states given by (4) can be co-ordinated with a corresponding harmonic component in the motion defined by (9). This co-ordination involves that the probability of occurrence of the transition depends on the amplitude of the corresponding harmonic component in a way analogous to that in which, according to the classical theory, the intensity of the radiation emitted from a particle performing a harmonic oscillation would depend on its amplitude. At the same time, the state of polarisation of the radiation emitted during the transition is assumed to depend on the shape and orientation of the corresponding harmonic oscillation in a way analogous to that in which, on the classical theory, the polarisation of the radiation would depend on the orbit of the emitting particle.

In this discourse it was shown by examples from the investigation of the spectra of the elements and of the effects of electric and magnetic fields on spectral lines, how this correspondence principle has been supported to an extent that seems to justify us in using it as a guide also in more complicated cases, which we meet in the theory of atomic constitution, and where it has not yet been possible to fix the stationary states in an unambiguous way by use of symbols borrowed from classical mechanics.

16. Prof. P. Ehrenfest.—*Remarks on Quantisation.* (See p. 508.)

17. Prof. P. Langevin.—*The Structure of Atoms and their Magnetic Properties.* (See p. 510.)

18. Prof. R. W. Wood, For. Mem. R.S., and Dr. A. Ellett.—*The Effects of Weak Magnetic Fields on the Polarisation of Resonance Radiation.*

The resonance radiation of mercury vapour in vacuo, at a pressure of about 0.0001 mm., excited by polarised 2536 radiation, is polarised to the extent of 90 per cent. This polarisation is completely destroyed by a magnetic field of 1 or 2 gauss, directed towards the observer. The magnetic field of the earth reduces the percentage of polarisation to less than fifty. Other orientations of field produce polarisation of the radiation in directions in which it is normally absent, *e.g.* in the direction of the electric vector of the exciting light. Sodium vapour, similarly excited by D_1D_2 radiation, exhibits less than 10 per cent. of polarisation in the absence of any magnetic field. This small trace of polarisation is destroyed under circumstances similar to those which obtain with mercury vapour, except that a field of about 100 gauss is required. With the field oriented in other directions the percentage of polarisation is increased to thirty or more.

With the exciting light (electric vector perpendicular to the plane of paper) and the magnetic field parallel and in the plane of the paper, we have strong polarisation in directions perpendicular to the plane of the paper. In the absence of magnetic field no polarisation would be exhibited in this direction. If the field is rotated through 90°, remaining in the plane of the paper, the plane of polarisation turns with the field, the electric vector of the resonance radiation being horizontal when the field is vertical. If, however, the electric vector of the exciting light is in the plane of the paper (*i.e.* vertical) the polarisation diminishes as the magnetic field is rotated, becoming zero with the field at 45°, and rising to a maximum again when the field is vertical. These relations are difficult to describe without the aid of a diagram. It seems quite evident that we are dealing with an orientation of the molecules in the magnetic field.

19. Mr. I. O. Griffith.—*Note on the Measurement of Very High Temperature.*

The high temperature is obtained by means of an arc burning in a gas at high pressure, and is determined by measuring the ratio of the intensities of the light at two wave-lengths. Under a pressure of 80 atmospheres the temperature is found to be approximately 8600° absolute. Owing to difficulty in keeping the arc constant at high pressure this is probably a minimum value, and there are indications on some of the plates of the existence of a higher temperature.

Tuesday, September 18.

20. Discussion on *The Spectra of the Lighter Elements.*

Professor McLennan referred briefly to some theoretical and experimental aspects of the ultra-violet and X-ray spectra of the lighter elements, and attention was drawn to fundamental differences in the origin of these spectra.

The merits of the photo-electric and absorption methods of determining the wave-lengths of soft X-rays were discussed, and the advantages possessed by the ruled and crystal grating methods were emphasised.

An analysis was made of the experimental results obtained by the different methods with the object of showing that the radiations which atoms of the lighter elements can be made to emit are such as one would expect to obtain with the scheme of electronic orbits provided by Bohr for the neutral atoms of the elements.

Professor Bohr discussed certain problems connected with the bearing of spectroscopic evidence of an atomic constitution.

Professor Millikan forwarded a summary of the results obtained to date by various investigations on the extreme ultra-violet spectra of the elements.

Professor Fowler dealt with optical spectra. Alternation of doublet and triplet series in the spectra of elements of successive groups in the periodic classification. General relations between the spectra of the elements of the same group, and departure from these relations in the case of some of the lighter elements. Remarks on the spectra of the lighter elements for which series have not yet been traced. The spectra of ionised elements; the displacement law. The spectra of certain elements, including silicon, at successively higher stages of ionisation. General accordance of the phenomena with Bohr's theory.

21. Dr. D. Coster.—*On High Frequency Spectra and the Theory of Atomic Structure.*

Moseley showed that the characteristic X-ray spectra have a very simple structure. The square root of the frequency of a given X-ray line is a linear function of the atomic number. The great changes in physical and chemical properties, which mostly occur when proceeding from one element to the next one in the periodic table, are not expressed in the X-ray spectrum.

Recent researches have revealed that some peculiarities of the periodic table find expression in the X-ray spectrum. If we plot Moseley curves not for the lines themselves but for the spectral terms,[1] we observe at different stages sudden changes in the slope of these curves. These irregularities correspond with regions of the periodic table where, according to Bohr, an inner group of electrons is being completed—*i.e.* in the neighbourhood of the iron group, the palladium group, the platinum group, and in the case of the rare earth metals.

Recently X-ray spectroscopy has led also in a more direct way to a confirmation of the Bohr theory. According to Bohr, the element of atomic number 72 should not belong to the rare earth metals, but must be a homologue of zirconium. This conclusion of the theory was verified by the discovery of hafnium.

22. Dr. F. W. Aston, F.R.S.—*Further Determinations of the Constitution of the Elements by the method of Accelerated Anode Rays.*

23. Mr. R. W. Roberts.—*The Magnetic Rotary Dispersion in certain Paramagnetic Liquids.*

It is well known that the presence of iron salts in aqueous solution will cause a diminution of the magnetic rotation of the solvent. It was found by Richardson, Roberts, and Smith that the same is true for cobalt salts at ultra-violet frequencies, but not for nickel salts. As the effect shown by cobalt salts might be a dispersive one, the ordinary dispersion of aqueous solutions of several cobalt salts in the visible and ultra-violet portions of the spectrum has been investigated. The results obtained show that the depression in the magnetic rotation exhibited by aqueous solutions of cobalt salts is a true paramagnetic one superimposed on the usual positive rotation explained by the Hall effect.

24. Mr. R. Ablett.—*The Angle of Contact—Variation with Relative Motion of Solid and Liquid.*

When a cylinder with its axis horizontal is partially immersed in a liquid to such a depth that the liquid surface is horizontal right up to the cylindrical surface, then the tangent at the line of contact makes an angle with the horizontal equal to the angle of contact θ. This has been found to be $104°34' \pm 5'$ for paraffin wax and water at 10° C. On rotating the cylinder uniformly the angle on the side emerging decreases towards a minimum value

[1] Every line frequency may be represented by the difference of two terms, each of which corresponds with the energy of the atom in one of its stationary states.

θ_2, whereas that on the other side increases towards a maximum θ_1. At every speed $\frac{1}{2}(\theta_1+\theta_2)=\theta$. Beyond the critical speed of 0.44 mm. per second θ_1 is constant (113° 10′) and also θ_2 (96° 20′).

Drops of water sessile on a plane wax surface have been photographed, and the plates obtained projected through a lantern, and the angles of contact measured. For a fresh horizontal surface $\theta = 104° 40'$; for the surface inclined until the drop just slips $\theta_1 = 113° 00'$ and $\theta_2 = 96° 00'$.

These results clearly account for the hitherto unexplained discrepancy in the values of θ obtained by different methods—some obviously giving values between θ and θ_1 and others between θ and θ_2, according to the type of experiment involved.

25. *Report of the Seismology Committee.* (See p. 283.)

SECTION B.—CHEMISTRY.

(For references to the publication elsewhere of communications entered in the following list of transactions, see p. 504.)

Thursday, September 13.

1. Joint Discussion with Sections A and G on *Cohesion and Molecular Forces*, opened by Sir WILLIAM H. BRAGG, F.R.S.

2. Prof. SVEN ODÉN.—*The Formation of Precipitates.*

3. Prof. G. S. WHITBY.—*The Nature and Significance of the Resin of Hevea Rubber.*

The resin of raw rubber, which constitutes about 3 per cent. of the material, has been found to contain liquid unsaturated acids, a new solid fatty acid (Heveïc acid), a phytosterol glucoside, a phytosterol ester, a free phytosterol, quebrachitol, and *d*-valine. The acids have a marked influence on the vulcanisation of rubber in the presence of catalysts. The introduction into the rubber of strong bases has a striking effect in increasing the rate of vulcanisation with catalysts and in enhancing the tensile strength of the product. This effect is not due merely or mostly to the elimination, by neutralisation, of the retarding influence of acids, but is due largely to the dispersing action on the caoutchouc of the soaps produced. The total resin-acid-content of different samples of raw rubber varies greatly. Such variation is probably an important factor in vulcanisation by rubber samples. The ability of the resin constituents and of certain related substances to act as emulsifying agents has been studied. The ability of a wide range of organic substances to swell rubber has been studied in relation to the question of the mode of occurrence of the resin constituents in latex and in rubber.

Friday, September 14.

4. Presidential Address by Prof. F. G. DONNAN, F.R.S., on *The Physical Chemistry of Interfaces.* (See p. 59.)

5. Prof. G. N. LEWIS.—*The Quantum Theory in Chemistry.*

6. Dr. N. V. SIDGWICK, F.R.S.—*The Bohr Atom and the Periodic Law.*

7. Dr. G. HEVESY.—*The Chemistry of Hafnium.*

Though hafnium is to be placed in the periodic table between zirconium and thorium where formerly cerium happened to be placed, its chemical properties are not intermediate between those of zirconium and thorium, but much nearer to the former element.

While the fluorides and double fluorides of thorium are practically insoluble, the corresponding zirconium compounds, and still more the hafnium compounds, are fairly soluble in cold, very soluble in hot water. By this method zirconium can easily be separated from hafnium. The mineral is melted with KFHF, and by crystallising the potassium double fluorides the hafnium concentrates in the mother-liquor. Most of the preparations exhibited have been obtained by this method.

Hafnium oxalate is, like zirconium oxalate, soluble in an excess of oxalic acid. The oxychloride of hafnium is less soluble than zirconium oxychloride. When crystallising compounds of zirconium sulphuric acid like $(NH_4)_4[Zr(SO_4)_4]$; $(NH_4)_4[Zr_4(OH)_8(SO_4)_6]$ hafnium concentrates in the mother-liquor. Hafnium is more basic than zirconium; accordingly the latter is more easily precipitated by ammonia, sodium thiosulphate, &c.; and while zirconium sulphate begins to decompose above 400°, the temperature at which hafnium sulphate undergoes a marked decomposition lies about 100° higher. Thorium phosphate is easily dissolved by strong mineral acids, zirconium phosphate much less, whereas hafnium phosphate is found to be still less soluble.

The close relationship of zirconium and hafnium is also clearly exhibited by the fact that zirconium extracted from different minerals always contains ½-30 per cent. hafnium, while in none of the typical thorium minerals could hafnium be detected. We must conclude that 'zirconium,' hitherto thought to be an element, is a mixture of two elements, of zirconium and hafnium.

8. **Joint Discussion** with Section I on *The Physical Chemistry of Membranes in Relation to Physiological Science*, opened by Prof. H. E. Roaf.

9. Dr. E. B. R. Prideaux.—*Membrane Potentials considered as Diffusion Potentials.*

Through most ordinary membranes, such as vegetable and animal parchment, &c., a slow diffusion of electrolyte takes place, and the membrane potentials at these are not due to the impermeability, but to the selective permeability, of either anion or kation. These potentials are generally higher than the corresponding diffusion potentials, and may be considered as diffusion potentials in which the transport numbers or the relative mobilities of one ion are modified by the membrane. A suitable case already investigated was that of sodium benzoate. The investigation has now been extended to potassium benzoate and salicylate. A comparison of the mobility of the anion determined by conductivity with the present measurements of diffusion potentials, viscosities, and membrane potentials, shows that the mobility of the benzoic anion has indeed been diminished by the parchment to a value which is apparently definite both for potassium and for sodium salts. The mobility of the salicylic ion has been diminished in a higher ratio.

10. Miss Edith H. Usherwood.—*The Activation of Hydrogen in Organic Compounds.*

In the first part of this paper it is shown that a great variety of organic chemical phenomena depends upon one and the same molecular condition. This condition is then defined in terms of molecular structure, and the result follows that tendency to undergo reactions of many different kinds is referred to certain definite and easily recognised structural features. Thus, without instituting any proposal as to the root cause of organic reactions, and with a minimum of tacit hypothesis, a collation of diverse data is obtained, and, in addition, an instrument for the prediction of new phenomena.

The usefulness of the view in this latter connection is illustrated by reference to certain phenomena predicted from theory, and experimentally verified by the author within the last few months (*e.g.* the formation of rings with the aid of the nitroso group; the reversibility of the aldol reaction), and also by noting hitherto unverified consequences, on which the author hopes to obtain evidence in the immediate future.

Monday, September 17.

11. Dr. E. F. Armstrong, F.R.S.—*Enzymes.*

Enzymes are to be regarded as colloid catalysts. It is customary to think of them as definite chemical entities, but the activity associated with them is connected with certain aggregates of groups in a very much larger molecule. Probably the enzyme, as such, is incapable of existing, and the larger molecule may well be variable in its nature. Their activity in the main is hydrolytic—that is, they activate water molecules, and in special cases they also bring about synthetic action; there is also the class of oxidising and reducing enzymes which act again in activating water so as to give oxygen to one and hydrogen to another acceptor. The study of enzymes is thus intimately bound up with that of the behaviour of water in solutions.

Enzymes are obtained from animal and vegetable tissues in a concentrated, as opposed to a purified, condition; their outstanding and indeed remarkable property is their very highly specific character. In every instance their action is restricted to one or to a few substances very closely related in structure, and there is obviously the most intimate correlation between the structure of the substrate and of the enzyme complex.

Enzymes behave essentially as particulate colloids in an extremely fine state of division, and as such are naturally very unstable or, in other words, susceptible to outside influences. Their great activity as catalysts is due to this development of active surface, enzyme action taking place essentially at solid surfaces and not in solution; the older phrase 'soluble enzymes' is a misnomer.

Under ideal conditions, when the influence of secondary changes and of the products of action is eliminated, the rate of change conditioned by enzymes is such that equal amounts of substrate are changed in successive equal intervals of time.

Taking into consideration the intimate structural relationship between enzyme and substrate, there is every reason to assume that change is preceded by the formation of an unstable intermediate complex with the substrate at the surface of the colloid enzyme, the attractive force being chemical; the alternative theory pictures adsorption at the active surface, the layer being at most little more than one molecule thick and the attractive force being physical. The difference between the rival theories is practically only one of phraseology.

Subsequent action in which the activated water molecules take part results in the breakdown of the intermediate complex in all possible ways.

We have still to form a clear mental picture of how the energy necessary to effect this is derived. This problem, however, is primarily one for the student of the processes operative in solutions.

12. Dr. K. G. Falk.—*The Relation of Certain Enzyme Actions to Tissue Differentiation and Tumour Growth.*

The comparative lipase actions on a number of different esters and protease actions on several protein preparations, of different tissues and organs of rats as well as of the Flexner-Jobling rat carcinoma, were studied. Well-defined differences in the actions were found. A number of tumours of human origin and some normal human tissues were studied similarly. In general, the tumours showed the same comparative lipase actions on the different esters. These relative actions were similar to the relative actions found with the Flexner-Jobling rat carcinoma. A more complete study of the enzyme actions of fibromyoma of the uterus indicated in some cases enzyme actions similar to those of the rat carcinoma and other tumours, in other cases enzyme actions of the growths similar to those of uterus muscle, and in some cases both types of actions present in the material obtained from different parts of the same specimen. The enzyme results corresponded to the histological examinations of the same materials. The absolute amounts of the enzyme actions of the tumours of various origins were small in comparison with the enzyme actions of some of the tissues. The significant differences were found to be in the characters of the actions rather than in their magnitudes.

The materials for the enzyme tests were prepared by extraction with water after suitable grinding. The solid residues were also tested in a number of experiments. The enzyme actions were determined under comparable conditions.

13. Mr. W. G. Palmer.—*Catalytic Actions in the System Copper, Copper-Oxide, Oxygen, and Gaseous Reducing Agent.*

The rate of oxidation of a copper film about $\frac{1}{1000}$ mm. in thickness can readily be found from observations on the increasing electrical resistance; similarly the rate of reduction of oxide can be followed by observing the decrease of resistance. Such a film conducts electricity normally, but is sufficiently thin for the effects of gaseous diffusion to be absent.

Mixtures of reducing gas (such as carbon monoxide or hydrogen) with oxygen, when brought into contact with copper at 250° C., oxidise the metal more rapidly than does pure oxygen. This effect is very marked even when equal volumes of reducing gas and oxygen are used. The reduction of copper oxide by carbon monoxide or by hydrogen at low temperatures takes place only in the presence of copper, and the rate of reduction is simply proportional to the amount of metal present.

When hydrogen is used for reduction the water formed acts as a 'negative' catalyst, and the reduction is soon brought to a standstill unless the water is removed by exhaustion. Attempts to explain the effects described are greatly aided by the simplicity of the reactions concerned.

14. Prof. W. Vernadsky.—*Alumosilicates.*

We can distinguish in alumosilicates bodies of different chemical functions:

anhydrides: Al_2SiO_5 sillimanite
$Al_2Si_2O_7$ leverrierite
$Al_2SiO_4F_2$ topaz, &c.
acids: $H_2Al_2Si_2O_8 \cdot H_2O$—kaolinite
$H_2Al_2Si_4O_{12}$—pyrophyllite, &c.
salts: $K_2Al_2Si_6O_{16}$—orthoclase, &c.

All these bodies in the solid condition can give *addition products,*

e.g. zoisite $3CaAl_2Si_2O_8 \cdot Ca(OH)_2$
grossularite $CaAl_2Si_2O_8 \cdot Ca_2SiO_4$

where the alumosilicate group dominates the properties of the compound, the salts and their addition products can be divided into *three groups*:

1. *Sillimanite salts*—of acid $H_2Al_2SiO_6$ and their addition products: group of *chloritoids*.
2. *Leverrierite salts*—of acids $H_2Al_2Si_{2+n}O_{8+2n}$ $n=0, 2, 4, 6, 8$.
   p.e. $K_2Al_2Si_2O_8$—phacellite
   $K_2Al_2Si_4O_{12}$—leucite.

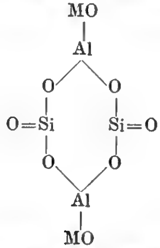
The addition products correspond to general formula

$pA\ qB$ where A—alumosilicate
B—group of elements of secondary importance.

$p=1 . 2. 3 \ldots.$
$q=1 . 2.$

These compounds have a chromogene constitution.

All these compounds contain a nucleus $M_2Al_2Si_2O_8$, give by weathering *clays* (kaolinite $H_2Al_2Si_2O_8 \cdot H_2O$), and are obtained by natural and synthetical reactions from kaolinite. The common nucleus can be expressed in cyclic form:



Zeolites, felspars, nephelines, garnets, epidote, scapolites, &c., belong to this group.

3. *Salts of polybasic acids* of anhydrides Al_2SiO_5, $Al_2Si_2O_7$, $Al_2Si_4O_9$ . . .

Chlorites $Al_2SiO_{5-n}(HO)_{2n}$ $Al_2Si_2O_{7-n}(HO)_{2n}$

Mostly hydrated Mg and Fe compounds.

Melilites, polygorsaites, &c., are products of addition $pA\ qB$

A—silicate
B—contains Al

and do not belong to the alumosilicates.

Tuesday, September 18.

15. Miss Elizabeth S. Semmens.—*The Biochemical Effect of Polarised Light.*

That plane polarised light has a distinct accelerating effect on the breaking up of starch grains in the presence of diastase can be shown under the microscope. At laboratory temperatures below 20° and with small concentration of diastase, starch grains exposed to light polarised by reflection or by a Nicol prism erode quickly and give crystals of sugar, controls in ordinary light or in the dark remaining almost intact. If the diastase is concentrated, the starch grains exposed to ordinary light also undergo hydrolysis. Above 25° erosion takes place in the controls kept in the dark.

16. Dr. R. G. Fargher.—*Cotton Wax.*

The term 'cotton wax' has been applied by different writers to the extracts obtained from cotton by means of organic solvents, and even to the material removed by boiling the cotton with dilute sodium hydroxide. Generally, it includes fat, wax, and the more readily soluble portion of the resin present in the cotton, the proportion of fat being relatively small. This material interests the spinner and manufacturer, as it probably lubricates the hairs during spinning and the preceding processes, and to some extent cements them in the spun yarn; whilst the bleacher and finisher consider that it must be efficiently removed if the maximum effect of certain finishing processes is to be attained.

Comparison of the extracts obtained with a number of organic solvents indicated that carbon tetrachloride removed the fat and wax and left the major portion of the resin undissolved; whilst chloroform, using a 'hot' soxhlet, dissolved fat wax and resin. The characteristics of the crude wax obtained from three cottons—American Upland, an almost pure strain American cotton grown in the Mississippi Delta, and Egyptian Sakellaridis—are given.

Special analytical methods have been devised for dealing with very small quantities of material.

The character of cotton wax indicates that emulsification must play a considerable part in its removal during scouring; this has been shown to be the case by large-scale trials.

17. Dr. D. A. Clibbens.—*The Absorption of Methylene Blue by Cotton.*

A quantitative investigation of the conditions which determine the absorption of methylene blue by bleached cotton from neutral solutions of methylene blue hydrochloride. The object of the work has been to provide a method for determining the efficiency of cotton-bleaching processes with respect to their production of pure cotton cellulose. The bleaching of raw cotton involves two distinct series of operations: (*a*) 'scouring,' which consists of a treatment, or series of treatments, with hot dilute alkalis, and which effects the removal of the greater part of the non-cellulose impurities, and (*b*) the bleaching process proper, in which the scoured material is treated with dilute oxidising solutions. Measurements of the absorption of methylene blue at various stages of a bleaching process show:—

1. The absorption by raw cotton is high, and is a property not of the cellulose itself, but of certain acidic non-cellulose impurities.
2. The absorption diminishes progressively; it indicates and measures the

progressive purification of the cotton cellulose. A sufficiently energetic scouring process results in a minimum absorption which is not further diminished by more prolonged treatment, but if the scouring process is not efficient the bleached material still shows a high absorption. The minimum value referred to above is not, however, the same for all cottons, but is determined by the origin of the material, and is much higher in the case of Egyptian than in that of American cottons, the latter being characterised by a very low and constant 'minimum absorption.'

3. The absorption by scoured cotton is not further affected by normal bleaching, though excessive treatment with oxidising agents, so-called 'over-bleaching,' causes chemical attack of the cellulose itself and results in an increased absorption of the basic dye due to the presence of acidic oxidation products ('oxycellulose'). This fact has long formed the basis of qualitative dyeing tests for the presence of oxycellulose in bleached cotton, but it has not been generally realised that a positive result given by such tests may be due either to 'under-scouring' or to 'over-bleaching,' and that comparable results can only be expected from similar types of cotton.

18. Prof. H. E. Fierz.—*The Sulphonation and Nitration of Naphthalene.*

The author has investigated the interaction of naphthalene and sulphuric acid, and has been able to show that the rule established first by Armstrong and Wynne holds good in every case where the system naphthalene and sulphuric acid is involved.

The quantitative aspect of this reaction has been studied in detail, and the many errors of the scientific literature have been corrected.

Several of the free naphthalene-mono and disulphonic acids have been prepared and described. The crystals were measured and compared with the corresponding metal salts. Over 100 were investigated. It was found that the crystallographic shape is exclusively determined by the anion, and the free acids and the salts are very similar in all cases.

The nitration of the acids has also been studied, as well as the reduction of the nitro-sulphonic acids. It is shown the beta-naphthalene-mono-sulphonic acid is capable, under exactly defined conditions, of yielding quantitatively a new diazonium salt of technical interest. The other acids do not behave in the same way.

SECTION C.—GEOLOGY.

(For references to the publication elsewhere of communications entered in the following list of transactions, see p. 504.)

Thursday, September 13.

1. Prof. P. G. H. Boswell, O.B.E.—Lecture on *the Geology of the Liverpool District.*

2. Discussion on *The Geography of the Liverpool District from Pre-Glacial Times to the Present.* Opener, Sir Aubrey Strahan, F.R.S.

The estuaries of the Mersey and the Dee form the outstanding features of the Liverpool district. Indeed, the comparatively recent development of Liverpool as a port and business centre, and its outstripping of the ancient city of Chester, have been determined by the nature of the estuaries on which they are respectively situated; yet, for some reason not now obvious, the Dee attracted the Romans while the Mersey was ignored. It becomes of interest, therefore, to inquire whether there is any geological evidence of change in the character of the estuaries which will account for the shift of commercial centre.

That the estuary of the Dee has existed in approximately the same position since early Pleistocene times is highly probable, for borings have revealed the fact that Boulder Clay extends far below sea-level under parts of it. It appears, however, that the post-Glacial estuary does not exactly coincide with that which existed before the Glacial Period, and that the pre-Glacial course of the river after it left the Welsh hills was not recovered after the ice retreated. The changes in the upper reaches have been investigated by Mr. L. J. Wills (*Quart. Journ. Geol. Soc.*, vol. lxviii., 1912, p. 180). Lower down at Holt, Alford, and Chester, as shown in the *Geological Survey Memoir on Flint*, 1890, p. 161, the pre-Glacial course was so blanketed by Boulder Clay that the river cut a new course, partly in solid rock. A depressed area ranging through Pulford, Kinnerton, and Dodleston, presumably marks the site of the buried valley, and leads to a tract on the south side of the modern estuary, where Boulder Clay has been found to extend to a great depth below sea-level.

Similar changes seem to have been forced upon the Mersey as a result of glacial conditions. One diversion near Runcorn was made known by Mellard Reade, who showed that the pre-Glacial course ran north of Westbank under Ditton Marsh (*Proc. Liverpool Geol. Soc.*, 1871-2). He was led to anticipate that a pre-Glacial channel would be encountered in the Mersey Tunnel, as proved to be the case (*op. cit.*, vol. v., 1889, p. 74). In several other places also along the present course of the river great depths of Boulder Clay, sometimes far below sea-level, were recorded by him and others. It would not be safe, however, to assume that all the cases of deep drift are referable to the pre-Glacial channel of either the Mersey or the Dee. The soft Triassic rocks were deeply scored, and yielded vast quantities of the material which was carried southwards to form the glacial drift of Cheshire; shallow rock basins, as well as river channels, may lie buried beneath the glacial drift.

The changes which have taken place in post-Glacial times are of a different character, and due to a different cause. Evidence is furnished by buried land surfaces on the Lancashire, Cheshire, and North Wales coasts that the land has stood at a higher level in post-Glacial times than now. In South Wales the difference in altitude was ascertained to be not less than 55 feet (*Quart. Journ. Geol. Soc.*, vol. lii., 1896, p. 474), and the occurrence of polished flint-implements proved that one at least of the submerged surfaces was of Neolithic age. The deposits of this age lie in and below the present foreshore, and extend inland under the recent alluvial deposits of the valleys. Wherever exposed to the scour of the tide they are being rapidly swept away, and the assumption that they once extended far beyond their present limits is not only legitimate but supported by tradition, whatever that may be worth, concerning lost lands off the coast of North Wales. We may assume, therefore, that the coast was fringed by a low-lying forest-grown tract, and that the estuaries were bordered by similar uninviting ground. Sinking of the land and the submergence of these tracts were the first stages in the development of the estuaries as we see them. The admittance of the tide led to the further stages.

So far, however, we have found no good reason why the Dee was preferred to the Mersey by the early settlers. More than one hypothesis has been put forward to account for the preference. It has even been suggested that the Mersey estuary had no existence in Roman times, and that the river then formed a tributary of the Dee. The second-century maps of Ptolemy show what is without doubt the estuary of the Dee, but represent no estuary corresponding to that of the Mersey. Further support for the suggestion was found in the existence of a valley which runs near Stoke from one estuary to the other. That such a valley exists is true; it is, moreover, occupied by a continuous strip of alluvium which connects the alluvium of the Gowy, a tributary of the Mersey, with that of the Dee. The theory that it formed a free passage for the Mersey is founded on the continuity of the alluvium, on the occurrence of marine shells of recent species along it, and, lastly, on the authority of a map of the time of John Scott, eighth Earl of Chester, 1232-1237, in which it is represented as being occupied by water for its whole length from the Mersey to the Dee. These arguments, however, are worthless, for the alluvium, though continuous, forms a gentle slope rising to a height of 40 feet above the sea. A subsidence sufficient to submerge this slope would put under water many of the ancient roads of the district, and is known not to have taken place in post-Roman times. The marine shells occur as boulders in the Boulder Clay which forms the sides of the valley, and have no significance as regards its post-Glacial history. Lastly, in the same map Alford Brook is also represented as a continuous stream connecting the Dee and the Gowy by Tattenhall. Such a continuation of this brook can never have existed. There is, in fact, no geological evidence that the broad alluvial lands extending up to and beyond Warrington ever drained in post-Glacial times in any other direction than between Liverpool and Birkenhead.

The difficulty is not lessened by the fact that the navigation of the Dee estuary is intricate for small vessels and impossible for large. Notwithstanding this, the Irish packets sailed from Parkgate for many years, and it was not until the channel in its meanders through the shifting sands betook itself to the opposite side of the estuary that Parkgate ceased to be a port. Chester as a port had been abandoned in 1449. In 1700 an Act was passed to enable the Mayor and citizens to recover and preserve the navigation, and in 1833 a banked artificial channel had been made, and upwards of 7,000 acres reclaimed. About 1870 a bank was carried from Burton Point to Connah's Quay, but it was broken by a high tide, and the area enclosed by it was overflowed, and so remained for many years, until the Cheshire Lines branch railway was constructed. (Maps showing various stages in the reclamation of the estuary are reproduced in the *Geological Survey Memoir on Flint*, &c.)

In the meantime Liverpool was developing. In the twelfth century it was a small fishing village. In 1715 the first dock was built—that is, about the time when the Mayor and citizens of Chester were striving to recover their river. At the present day Liverpool is one of the great ports of the world. The problem, then, on which I wish to see light thrown by this discussion relates to the preference shown through several centuries for the estuary of the Dee, and the apparent neglect of the open tideway of the Mersey. It is no new question, for so long ago as 1849 Sir James Picton, in a paper on changes of level of the West Coast of England (*Proc. Lit. and Phil. Soc., Liverpool*, vol. v., p. 113) commented on the ignoring of the Mersey by the Romans, and speculated on the Mersey estuary having had no existence until after the Roman occupation.

For my own part I can only suggest that the land surfaces which were not submerged until the close of Neolithic time still extended so widely in the estuary and on the adjacent coasts as to create difficulties in navigation. There may, however, have been geographical and political reasons depending on other than geological considerations.

3. Mr. C. B. Travis.—*Recent Geological Changes on the Northern Shore of the Mersey Estuary.*

The area described forms part of the South Lancashire coast on the north-eastern side of Liverpool Bay, between Waterloo and Hightown.

This tract of coast, about four miles in length, consists superficially of Blown Sand, which in places rises in dunes to elevations of 30 to 50 feet. The sand lies on a platform of post-Glacial deposits, which are well exposed on the foreshore in a fine section about a mile in length and 50 yards in breadth. These deposits consist of the 'Upper Peat and Forest Bed,' underlain by Grey Sands and Silts, which rest in turn on unexposed Boulder Clay. The bed-rock which has not been exposed along the coast has been proved in borings to consist of an undulating surface of Keuper Marl, while inland at a short distance Keuper Sandstone outcrops. The River Alt breaks through the sand-hills at Hightown, and flows along the shore in a southerly direction, falling into the Victoria Channel at Crosby.

During the past ten years marine erosion has been very active along this coast, and the sandhills between Crosby and Hightown have suffered severely. This is due to tidal action and to changes in position of the River Alt on the foreshore, leading to a considerable lowering of the level of the beach. The Peat and Forest Beds and associated sediments are being rapidly fretted away, while the dunes have been cut back to a maximum distance of 85 yards within eight years This wasting of the coast has caused the destruction of valuable residential property, and has become a serious local menace. Owing to a landward swing of the Alt the wide expense of sandy shore formerly exposed at low tide is no longer available as a source of supply to the marginal dunes which have been strongly denuded and in places levelled during heavy gales. To the south, towards Waterloo, however, erosion diminishes with the recession of high-water mark from the margin of the land and the seaward bend of the Alt, and a marked accretion of sand is now taking place. A comparison of old maps and charts with the latest Ordnance Survey shows the changes which have taken place in the form of this part of the coast in the last three centuries, an important example of accretion being furnished by the development of the sand-dune salient of Formby Point, while in later times a broad tract of dune-land, forming the Altcar Rifle Range, has been built up by artificial means in less than a century.

4. Mr. T. A. Jones.—*The Middle Bunter Sandstones of the Liverpool District and their Pebbles.*

Of the various divisions of the Triassic sandstones, the middle series of the Bunter, generally known as the Pebble Beds, is most in evidence in the neighbourhood of Liverpool. They cover a large part of the Wirral Peninsula, where their thickness has been estimated at from 750 to 950 feet, and underlie the greater portion of the City of Liverpool and its suburbs, where the maximum thickness reaches 1,200 feet. They form hard, massive beds of a predominantly red or brown colour, varied by bands of grey, and have furnished the principal building stone of the district. Cross bedding is frequently seen, and marl bands several feet thick are of common but irregular occurrence.

In the almost complete absence of fossils from the Liverpool Trias, interest is largely confined to questions relating to the origin of the material constituting the sandstones and the methods of its transport and accumulation. On these points a study of the pebbles which occur in great number and variety in the Middle Bunter beds affords one of the most promising directions in which to seek for definite information. The pebbles are distributed in a very sporadic manner, and include in greatest number quartzites and grits of many kinds, with a small proportion of granites, felstones, and a very interesting group of metamorphic rocks characterised by the presence of tourmaline in many forms. The igneous rocks also are mostly schorlaceous, and in one granite pebble garnets were found in addition. The constant presence of tourmaline naturally suggests that the metamorphic rocks, together with the felstones, may all be related as contact rocks of the same intrusive mass, of which the schorlaceous granite pebbles may possibly be marginal samples. These pebbles resemble very closely those of the Bunter beds of the Midlands as described by Professor Bonney.

Fossiliferous pebbles are extremely rare, but one obscure specimen seems to indicate that the Ordovician quartzites found in the Midlands and at Budleigh Salterton may not be entirely absent. As these quartzites contain fossils which have never been found in the Ordovician sediments of the British Isles, but which occur abundantly in the Gres de May of Normandy, a southern origin of some portion at least of the Bunter deposits is suggested, notwithstanding that, following Professor Bonney, the majority of the quartzites are generally regarded as of northern origin. Support is lent to this view by the fact that the tourmaline-bearing pebbles, on the whole, seem to be most readily matched from outcrops still found in the south and south-west of England.

Whatever theory is adopted the great variety of the pebbles, no less than the enormous volume of the deposits, demands an extensive area of supply, and there is evidence of the existence at the dawn of the period of land masses extending on the west from north to south, where metamorphic rocks of the kind required, or conglomerates and breccias containing them, may have been exposed to denudation. From widely separated parts of this region torrents and rivers in flood may have carried down fragments and scattered them as pebbles over the sandy eastern plains.

In the afternoon an excursion took place to Hall Road and Crosby Shore to examine the sections described by Mr. C. B. Travis. (See No. 3 above.)

Friday, September 14th.

5. Presidential Address by Dr. GERTRUDE L. ELLES, M.B.E., on *Evolutional Palæontology in Relation to the Lower Palæozoic Rocks.* (See p. 83.)

6. Prof. P. F. KENDALL.—On *Quaternary Isostatic Readjustments in N.W. Europe.*

Jamieson's theory of Isostasy formulated to explain the raised beaches and submerged forest of Scotland has been applied in detail to Scandinavia and parts of North America, but some implications fully recognised by him have not been specifically adopted.

When an area is depressed by overloading a wave of sub-crust material must be generated which travels outward, producing a transient elevation. When the loaded area is again unloaded a return-wave travels inward. The latter alone has been recognised, *e.g.* by Upham, Gilbert, Brögger, and de Geer. In both movements there appears to be considerable lag.

The advance of the Scandinavian ice-sheet upon the Yorkshire coast was preceded by an uplift whereby the coast-line was deserted by the sea—perhaps for a prolonged period. Depression ensued at a later stage, represented by the Kirmington deposits and perhaps by the much disturbed Burstwick Gravels. Post-glacial movements have restored the land levels to their pre-glacial position.

In Scotland, though similar effects were most probably produced, they have been masked by the deformations due to native ice-loads. The isostatic recovery of Scotland deformed the strand-lines, though not to so marked a degree, nor in so clear a fashion as in Scandinavia, yet the effects are well seen, *e.g.* on the shores of the Forth.

Scandinavia furnishes a clear example of the lagging of the isostatic recovery and its wave-like progression. Brögger has shown that during the retreat of the ice-margin from the Outer to the Inner Ra depression was continuing, though the ice-load was diminishing. Simultaneously the wave of recovery was advancing across Denmark.

In Upham's monograph on Lake Agassiz it is shown that the recovery was delayed until the ice-margin had retired for a distance of 250 miles.

The movements in the North Sea Basin seem to lend no support to de la Mothe's speculations—they were diastrophic not eustatic—with the doubtful exception of that recorded in our submerged forests.

In the interpretation of the records it is necessary to take account of the effect of the closure of the North Sea by the ice-sheet, whereby a condition with regard to salinity would be produced comparable to that of the Baltic. This would explain the estuarine character of the faunas.

7. Prof. P. G. H. BOSWELL, O.B.E.—*The Structure and Succession of the Silurian Rocks in the Eastern Part of the Denbighshire Moors.*

Previous work on the area includes that of Ramsay, Professor Marr, McKenny Hughes, and Dr. Elles. This paper consists of a detailed description of the succession of the Ludlow deposits of the eastern part of the Denbighshire Moors. The rocks are mainly mudstones, siltstones, and fine sandstones, often flaggy and usually graptolite-bearing. They are of shallow-water character, and in places are slightly calcareous. Several of the graptolite zones of the Ludlow as worked out on the Welsh borders are present, and lithologically, the sequence most nearly resembles that recently described by Dr. L. J. Wills in the Llangollen district. The zone of *M. tumescens* is, however, developed in the Denbighshire Moors, where it lies above beds of Nant y bache type. Rolling siltstones and mudstones with abundant graptolites (the Nantglyn Flags, of nilssoni-zone, as described by Dr. Elles = the 'Slab' horizon of Dr. Wills) occupy a large part of the area.

Owing to the amount of faulting the thickness of the various divisions is difficult to estimate. The Nantglyn Flags consist of at least 1,000 feet of banded siltstones and mudstones containing abundant graptolites, which include *M. bohemicus*, *M. colonus*, *M. dubius*, *M. uncinatus* var. *orbatus*, *M. salweyi*, &c., belonging to the nilssoni-zone.

Succeeding these are 900 feet of cleaved, striped, and current-bedded sandy flags with bands of calcareous mudstones (=Nant y bache of Dr. Wills), and at the top, fine sandstones. Graptolites are not common, and are badly preserved, but are of *dubius* and *colonus* types. The sandstones occur as several thin bands, and are badly crumpled. The cleavage strikes approximately east-west, and dips north.

About 1,200 feet of flaggy beds and mudstones overlie these beds. Cleavage becomes less pronounced, and practically disappears in the mudstones. The uppermost beds are flaggy and contain *M. tumescens* and rarely *M. scanicus*. The mudstones contain *M. dubius*, *M. colonus*, *Dayia navicula*, *Rhynchonella nucula*, *Acidaspis hughesi*, &c. *M. leintwardensis* has not yet been found.

The country is broken into blocks by normal faulting. The dominant system courses approximately north-south, with usually the downthrow to the east. A similar series of fractures throws down the Carboniferous and Trias on the eastern margin of the area, and forms the western boundary of the Vale of Clwyd.

8. Prof. P. F. Kendall.—*The Formation of Inter-lake Deltas.*

In the afternoon an excursion took place to North Wirral and Storeton Quarries.

Saturday, September 15th.

In connection with the general excursion to Lake Vyrnwy a geological party, led by the President of Section C and Mr. W. B. R. King, visited sections in the Upper Ordovician and Lower Silurian rocks.

Sunday, September 16th.

A full-day excursion to Flintshire took place. (Holywell Shales, Carboniferous Limestones and Cherts, Glacial deposits, &c.)

Monday, September 17th.

9. Dr. R. L. Sherlock.—*The British Rock-salt Deposits.*

British rock-salt deposits are confined to the New Red rocks. Two areas are recognised: (1) a Western District containing the deposits of Cheshire, Lancashire, Isle of Man, North Ireland, Staffordshire, Worcestershire, and Somerset; (2) an Eastern District comprising Co. Durham and Yorkshire.

In the Western District the rock-salt is in the Keuper Marl; in the Eastern District its age has been a matter of controversy, and it is described by different authors as Keuper or Permian.

In the Western District there are frequently two beds of salt separated by a band of marl, as in Cheshire, Lancashire, North Ireland, Staffordshire, and Worcestershire. This leads to the conclusion that the two salt beds in these counties are contemporaneous, as probably are those of the Isle of Man and Somerset, where, however, the two beds have not been recognised.

The Cheshire deposits occur in a Top and Bottom Bed separated by from 20 to 45 feet of marl. The Top Bed is from about 30 to 90 feet thick, and the Bottom Bed from about 60 to 91 feet, the Top Bed being the more variable. This is in part owing to subsequent denudation. A recent investigation[1] indicates that the salt-field is much more extensive than had been supposed, covering an area of about 375 square miles.

[1] R. L. Sherlock. *Rock-salt and Brine.* Special Reports on the Mineral Resources of Great Britain, vol. xviii., *Mem. Geol. Surv.*, 1921.

In the Eastern District there are also two beds of salt, but both are present in only a few places. Comparing different borings it is apparent that the main (upper) salt-bed at Middlesbrough is in the 'Upper Permian Marl'[2] of Nottinghamshire, and the lower one in the 'Middle Permian Marl' of that county. It has, however, been shown that the so-called Permian of Nottinghamshire passes laterally into Trias northwards, and it is believed that there is no Permian System in Britain. The horizons of these salt-beds are lower than those of the Western District, and they have probably a different origin. The Eastern deposits are associated with gypsum, anhydrite, and dolomite, whereas in the Western District only secondary gypsum is known. It is inferred that, while the Eastern salts were deposited in the (Zechstein) sea, the Western salts originated in lakes in a desert, at a somewhat later period.

10. Miss M. Workman.—*The Permian Rocks of Skillaw Clough.*

Outcrops of Lower Permian rocks occur at Bispham, near Ormskirk, in Skillaw Clough, and also along Bentley Brook.

The Millstone Grit described for comparison is found in Skillaw Clough, and forming a ridge of hills behind Parbold; its junction with the Permian is probably unconformable.

In Skillaw Clough the Magnesian Limestone overlies purple-red fossiliferous marls resting on soft bright-red and hard brown sandstone; in Bentley Brook purple-red fine sandstone with shale bands is found above the Magnesian Limestone, which in turn overlies interbedded compact purple-red shales and sandstones. The cementing material is calcite with dark-red limonite.

The 'heavy' minerals include pyrite, magnetite, garnet, zircon, rutile, anatase, xenotime (?), tourmaline, ilmenite, hæmatite, hypersthene,[3] muscovite, epidote, chlorite, and monazite.

The shale sandstones and grits of the Millstone Grit series contain the following 'heavy' minerals: Pyrite, garnet, zircon, xenotime (?), rutile, tourmaline, ilmenite (and other iron ores), hypersthene,[3] topaz, muscovite, chlorite, and monazite. This assemblage is very similar to that found in the Millstone Grit of Leeds by Dr. Gilligan, as well as to that of the Lower Permian of West Lancashire. There is also a great similarity between the latter and other Permian, whether found east of the Pennines or in Devonshire.

As to derivation—the condition of the quartz, felspar, and garnets, and the presence of monazite indicate that the materials of the Permian came principally from the Millstone Grit which had a northern origin. Some basic or ultra-basic rocks, probably of the Highland complex, must have furnished the hypersthene, epidote, and chlorite. The rocks were apparently laid down in an arid climate on the shores of an inland sea which afterwards covered them.

11. Prof. G. Hickling.—*The Tectonics of the Lancashire Coalfield.*

The paper gives some conclusions resulting from a study of the South Lancashire Coalfield (excluding the Burnley basin) by means of a precise contoured plan showing the present configuration of the surface of one stratum, the Trencherbone coal-seam.

The Coal Measures attain a thickness of over 7,500 feet in the eastern part of the field, and show a striking westerly thinning to about 3,500 feet near Prescot. The greater part of this reduction is due to the dwindling of the Upper Coal Measures, in which both actual thinning of the measures (with loss of coal) and overlap by the Permian and Trias play a part. The Middle Coal Measures diminish from 3,500 feet on the east to 2,000 feet on the west. The coal-seams are brought nearer together by the reduction of the intervening strata, but little coal is lost. On the other hand, the area of Middle Coal Measures south of Bolton and Bury is remarkable for the failure of the lower seams (below the Cannel). The Lower Coal Measures are believed to be fairly constant, with a thickness of about 1,500 feet.

[2] R. L. Sherlock. *Relationship of the Permian to the Trias in Nottinghamshire. Q.J.G.S.*, vol. lxvii., 1911, pp. 75-117 and pl. V.

[3] The first record for this system.

The Coal Measures in this area are covered by

(3) Bunter Sandstones;

(2) Permian Marls with Limestones;

(1) Collyhurst (? Permian) Sandstones.

The Collyhurst Sandstones are mainly confined to the area around Manchester and Stockport, and their rapid and irregular variation in thickness (from 0 to 1,500 feet) within that area is only intelligible on the supposition that they are separated from the overlying Permian Marls by a strong unconformity. They appear to be separated from the Coal Measures below by a further unconformity. There is no definite evidence in this area of unconformity between the Bunter and the Permian Marls.

The Lancashire Coalfield occupies the N.E. angle of the rhomb-shaped 'Cheshire basin,' which may be regarded as bounded by the Ribble anticlines (N.E.-S.W.) on the north-west, the Audley anticline (N.E.-S.W.) on the south-east, the Pennine elevation on the east, and the Clwydian elevation on the west. The basin was probably subdivided in pre-Triassic by an E.-W. elevation passing a little south of Macclesfield and Chester, while the northern part of the basin is further subdivided by the Rossendale anticline (E.-W.), cutting off the Burnley basin, with the Knowsley anticline (N.E.-S.W.), which continues it to the south-west. A minor anticline of the N.E.-S.W. series modified the eastern side of the basin near Stockport.

The Lancashire Coalfield is probably separated from the Flint Coalfield by the N.-S. anticline which passes near Prescot, and which is probably continued under the Triassic cover to the south.

The partial basin with the limits just defined has a diameter of about thirty miles, and an area about three times that of the exposed coalfield.

This basin is further modified by two very pronounced troughs, due principally to faulting, which cross the exposed coalfield—the Irwell Valley trough and the Wigan trough. Both trend N.W.-S.E., and within each there is minor folding, which appears to be related to the faulting. In each case the depth of the trough increases towards the margin of the basin. A third trough between St. Helens and Prescot has exactly the same characters, except that its boundary faults trend N.-S.

The detailed study of the faulting of this area fully substantiates the recognition of two main groups N.W.-S.E. and E.-W. The former series includes all the largest faults. A third series trending nearly N.-S. is almost restricted to the eastern and western sides of the basin. While these directions are on the whole clear and distinct, and the dominance of the N.W.-S.E. series is very pronounced, there appears also some tendency to a convergence of these latter faults towards a point on the buried extension of the Ribble anticline about five miles south-west of Preston, suggesting a possible torsional strain.

The great majority of the faults are very regular planes, cases of apparent irregularity being due as a rule to combination of several faults. In the middle of the coalfield are several very instructive cases where displacement has attempted to follow a line midway between the N.W.-S.E. and the E.-W. fractures; the result being a zigzag fault following first one direction, then the other. Only one notable case of a fault following a curved course (turning through some 80°) has been met, the Bickershaw Lane fault.

The faulting is on a larger scale than in any other British coalfield. The 1,000 yards fault (Irwell Valley) is famous. There are seven or eight with throws exceeding 500 yards, and as many again nearly approaching that figure. One fault mapped may have a displacement of 1,500 yards or more.

The hade of the faults can be demonstrated only in a minority of cases. It is very variable in large and small faults alike. Several of the largest have a hade of 45° or more, while others are nearly vertical. The average hade is probably not far from 30°. Most of the E.-W. faults appear to be very steep, but with that exception there is no apparent relation between the trend or direction of throw and the hade.

A rough estimate of the lateral expansion of the area necessary to allow for the formation of the faults met with between the east and west ends of the coalfield gives a minimum increase of $2\frac{1}{4}$ miles in a present length of thirty miles. The folding along the same line cannot represent a contraction of more than one mile.

Many examples of astoundingly rapid variation in throw are found, the most extreme case proved being a change from over 700 yards to nil in a distance of $1\frac{1}{2}$ miles. Such cases are associated with the change of strike at the 'bends' in the rim of the basin.

A few cases of actual crossing of important faults have been found, but they are not common. There are several large-scale examples of reversal of throw along the same general line of fracture. No clear case of extensive lateral displacement along a fault-line has been found.

It is obvious that a large part of the folding and faulting was pre-Permian, and that it was continued through Permian and Triassic times.

The deepest part of the present basin lies nearer to its eastern side, a little south-west of Manchester. Both the Coal Measures and the Collyhurst Sandstone thicken towards this region, and thus suggest early movement roughly coincident with the later folding.

Certain cases of rapid changes of strata associated with faults suggest possible fault movements during Coal Measure deposition. There is no clear indication that any of the three fault-systems is older or younger than the others, though the marked dominance of the N.W.-S.E. series may indicate that it was first in the field.

The form of the coal basin indicates a large area of buried measures in which the coal should be at workable depth. The determining factor in actual development will be the thickness of the Permo-Triassic and Upper Coal Measure cover—not the depth of the coal-basin.

12. Mr. G. Slater.—*Observations on the Nordenskiöld and Neighbouring Glaciers of Spitsbergen*, 1921.

The Nordenskiöld Glacier.—As seen from Bruce City the gathering ground of this glacier is approximately marked by two great nunataks, Mts. Terrier and Ferrier. From these it passes downwards as a narrowing wedge-shaped mass deflected seawards by a long frontal moraine, the result of which is the formation of a compressed zone of ice in the south-western corner.

The front of the glacier stretches two miles across the deep waters of Adolf Bay, forming partly submerged cliffs of ice, from which bergs are wrenched off at frequent intervals.

The floor of the glacier has a fairly steep gradient, and consists of hard rocks of the pre-Devonian basement series associated with igneous rocks, whilst across the more central part is a buried ridge of highly metamorphosed rocks. These rocks form the englacial moraine layers of the lower part of the ice, while the softer Permo-Carboniferous rocks from the surrounding mountains furnish material for the surface moraines.

The glacier may be divided into two main zones according to the distribution of tension and pressure. The central portion consists of an amphitheatre of broken ice dissected by two sets of crevasses into rectangular blocks, while towards the sides the ice assumes a rounded form.

Directed concentrated pressure is indicated in the south-western portion by a zone of hummocky surface neve ice associated with thrust-planes, which passes into smooth, finely-corrugated uncrevassed ice dissected by inclined longitudinal fissures running parallel with the englacial bands and associated with ribbon-structure. Here the ice becomes increasingly stagnant towards the periphery, not one of the six surface moraines of this area reaching the sea.

The ice in the central area moved 51.1 feet per day as determined in August by Mr. Mathieson with a theodolite.

The englacial rim of ice adjoining the frontal moraine was apparently stationary.

Measurement of the overhanging ice-cliffs of the south-western compressed area showed irregular differential slide over the lower dirt-filled ice associated with marginal crevasses. The upper hummocky ice moved by thrust-planes towards the lower compressed area.

The glacier is in a retreating phase, and the average retreat of the ice adjoining the moraine is estimated at about 13 feet per year, and this is supported by a comparison of the position of the ice on the top of the frontal moraine in 1910 with its position eleven years later.

Ebba Glacier.—This is fed from the same gathering ground as the Nordenskiöld.

Its special feature is the upper 'neck,' where the ice is nipped in by and passes over a ridge of pre-Devonian rocks, afterwards fanning out as a rounded dome-shaped glacier with radiating crevasses.

Sections at the neck showed bands of crevassed and contorted ice filled with englacial material. This section compares well with the model of ice action described by Professor Sollas.

A side section of the glacier near its termination showed banded ice with masses of included gravel, and the frontal face showed an exceptional amount of banded englacial material.

A smooth, rounded *roche moutonnée* occurs in front of the glacier, and is evidently the cause of the inclination of the englacial bands.

The Sven Glacier forms part of the Horbye Glacier. Its upper part rests on a highly inclined ridge of Devonian rock exposed through the ice in places. Over this the neve ice passes, and is traversed by innumerable thrust-planes resembling strain-slip cleavage.

The effect of exceptional pressure of neve ice is seen in a side section of the glacier: masses of contorted ice curve upwards along thrust-planes over a lower zone of ice filled with morainic matter. The upper surface of the ice is much wrinkled, and contains scattered mounds of morainic material composed of angular fragments.

13. Mr. K. W. Earle.—*Preliminary Report on the Geology of the Windward and Leeward Islands.*

The Windward and Leeward Islands, with the exception of the Virgin Islands on the extreme north, are composed entirely of Tertiary and Recent rocks. The basement beds consist of Hypersthene- and Augite-Andesites of ? Eocene age, and are overlain spasmodically by sedimentary tuffs and limestones of Eocene and Oligocene age. These are covered and incorporated with later eruptive rocks—chiefly of the pyroclastic type, but varied by basaltic lava-flows—ejected at all periods from Middle Tertiary to Recent times (*e.g.* Mt. Pelee and St. Vincent).

While such islands as Anguilla show little but the sedimentary deposits unobscured by later eruptives, the majority are extremely mountainous, and the sedimentary deposits are largely denuded or obscured by the later ash and boulder deposits. The occurrence of marine limestones in almost every island, sometimes at a height of 800 to 1,000 feet, indicates extensive oscillations in the chain, and that the old distinction between the volcanic and purely sedimentary islands must be abandoned.

With the exception of the Virgin Islands the chain bears no resemblance either to the Cuba-Porto Rico belt of islands or to Barbados and Trinidad, which latter island is essentially South American in type. There is, however, evidence in Grenada that the islands have in part been subjected to the same earth movements as Trinidad.

The writer is of opinion that the old Continental theory of the origin of the Lesser Antilles must be abandoned and the islands recognised as the denuded cones of submarine volcanoes operating at various foci from earliest Tertiary times.

In the afternoon an excursion took place to Scarth Hill, near Ormskirk, and Skillaw Clough, near Parbod.

Tuesday, September 18.

14. Mr. C. P. Chatwin.—*A New Gasteropod Fauna from the Chalk.*

This communication dealt with a collection of numerous small gasteropods found in the mucronata zone of Norwich.

15. Discussion on *Metamorphism*. Opener, Dr. J. S. Flett, O.B.E., F.R.S.

In the afternoon an excursion took place to Green Collieries and Brick Pits in Coal Measures.

SECTION D.—ZOOLOGY.

(For references to the publication elsewhere of communications entered in the following list of transactions, see p. 504.)

Thursday, September 13.

1. Presidential Address by Prof. J. H. Ashworth, F.R.S., on *Modern Zoology: Some of its Developments and its Bearings on Human Welfare.* (See p. 108.)

2. Prof. E. B. Poulton, F.R.S.—*The Meaning of the Transparent Under-surface of the Wings in Certain Butterflies.*

Mr. W. J. Kaye has recently shown that the dead-leaf-like under-surface of the Neotropical butterfly *Protogonius* is transparent, so that the upper surface alone is seen when the insect is sailing overhead. Although these butterflies have been known for 150 years, no one until the last few months has thought of holding a specimen up to the light! When the species, or more probably geographical races, of this genus are studied from various parts of tropical America, they are always found to resemble dead leaves on the under, and the dominant association of distasteful butterflies found in their locality on the upper surface. Everywhere this latter pattern is the one seen during flight and the leaf pattern only at rest with the wings closed. Mr. Kaye's important discovery has suggested a new point of view in the study of insect patterns which has already led to many interesting and surprising results.

3. Reports of Committees. (See pp. 318 *seq.*)

4. Mr. J. T. Cunningham.—*Origin of Adaptations: Present Position of the Question in relation to Recent Research.*

The novelty and interest of many recent discoveries have so absorbed the attention of biologists that the problems and the phenomena which occupied the minds of a former generation are in danger of being neglected and forgotten. The younger generation are apt to think that most, if not all, of the habits and ideals of the Victorian era were merely the outward and visible signs of an earlier and less advanced stage of evolution. But just as from time to time the present generation finds it has to deal with the same problems of human life and society as had its parents and grandparents, so it is important for biologists to consider how far the new facts recently discovered help to explain the old phenomena and solve the old problems.

Prof. Poulton, at a meeting of the Eugenics Society in July, described and showed lantern slides of some very extraordinary cases recently investigated of secondary sexual characters in male moths and caddis-flies. He described facts which in his opinion showed that sexual selection actually occurs. Prof. Poulton was not in this case following any of the new doctrines, but upholding, as he thought, the original Darwinian theory. Yet he was forgetting the fact that the essential point in secondary sexual characters was their limitation in inheritance (not in heredity) to one sex, and that Darwin himself pointed out, in his volume on 'Sexual Selection,' that the selection would not bring about the difference between the sexes unless the variations selected were already limited in heredity to the sex in which they occurred ('Descent of Man, &c.,'

2nd edit., Chap. XV.). The problem to be explained is the sexual limitation of inheritance, and that we know now is due to the action of the sexual hormones.

At the meeting of the Association last year Mr. J. S. Huxley discussed the question of time-relations in amphibian metamorphosis, especially with regard to the discovery that the metamorphosis is to a great degree influenced by the internal secretion of the thyroid. Administration of thyroid hastens metamorphosis in the frog, causes it in the Axolotl, but fails to produce it in Perennibranchiates such as Necturus. The question to be considered is the relation of these facts to the old problem of metamorphosis as a recapitulation of successive stages of evolution. It is this problem which is being overlooked and forgotten.

On the other hand, we have the discoveries of the geneticists, especially the occurrence and nature of mutations. These are of quite a different character from the changes indicated by recapitulation, and a careful comparison will show that mutations like those observed could never, for example, have resulted in the evolution of terrestrial from aquatic vertebrates.

None of the recent discoveries throws any new light on the question of the origin of adaptations, except one—namely, that the sexual limitation of inheritance is due to the influence of the sexual hormones.

5. Mr. H. R. Hewer.—*Colour Changes in the Common Frog.*

1. A hormone from the posterior lobe of the pituitary (*pars intermedia*) has been established as the chief factor (central control) of colour change in the common frog.

2. The effects of environmental stimuli have been determined to a certain extent.

Low temperatures, moisture, and black background tend to produce darkening of the skin.

Medium to high temperatures, dry surroundings, and white background tend to produce pallor.

The effect of light and darkness is obscured by the effects of background, but it would seem that the former tends to produce pallor and the latter darkening of the skin.

3. The receptors of these stimuli are discussed. The only ones definitely known are those for background—namely, eyes and some kind of receptor in the skin.

4. Evidence has been brought forward to show that the stimuli transmitted from the eyes to the pituitary are inhibitory in nature, and probably pass by way of the parasympathetic nervous system.

5. It is stated that the weight of the evidence goes to show that the dermal melanophores 'expand' and 'contract' by means of movements of the granules alone.

6. No evidence has been brought forward to show how the pituitary hormone brings this about.

6. Mr. Julian S. Huxley.—Lecture on *The Physiology of Development in the Frog.*

Friday, September 14.

7. Prof. James Johnstone.—*Rhythmic Change in the Plankton.*

This paper is an account of the results of a series of plankton hauls made by Sir William Herdman in Port Erin Bay during the years 1907-1920. The catches have been worked through by Mr. Andrew Scott and the numbers of the larger organisms have been estimated in each example. These quantitative results are tabulated and means for the series of fourteen years are calculated. There is a very clear seasonal change in the case of each organism, and this repeats itself from year to year throughout its period. The time of occurrence of the maximum of abundance may vary, throughout the series, by a month or more, and there is also a variation in the actual quantities of each organism taken. There may be no similarity, even in the case of closely related species, in these variations of absolute abundance and time of culmination of the invasion, and each species appears to be affected differently by the environmental conditions. The factor influencing actual abundance appears to be a statistical one—a chance association of sub-factors, and not at all any single physical event, or even a few main physical events, in the sea.

8. Mr. B. Storrow.—*Age, Growth, and Maturity of Herrings.*

The 1918 year-class of the North Sea in 1920-21 divided into two sections; one migrated north, the other south. The northern section grew rapidly in 1921-22. The area of greatest growth was west of the passage between the Orkneys and Shetlands. Growth is influenced more by environment than heredity. Atlantic water activity is followed by a prolonged spawning season, formation of new spawning grounds, more extensive or more obvious migrations, and a mixing of shoals. The formation of races in the North Sea is a physical impossibility. Spring spawners of the Forth come from northern waters, and so do the East Anglian shoals. Whilst the conditions of the year preceding hatching are held to be of the most importance in the production of good year-classes, those occurring in the herring's third year may modify the yield from the fishery.

9. Dr. Marie Lebour.—*The Feeding of some Plankton Organisms.*

Living plankton organisms, consisting chiefly of Cœlenterates, were kept alive in the laboratory in plunger jars, in order to study their food and methods of feeding. Others were examined fresh from the tow-nets. It was found that a large number of species of Medusæ were able to capture and digest small larval and post-larval fishes; this applied also to Pleurobrachia, Sagitta, and Tomopteris. Aurelia, from the scyphistoma and the smallest ephyra up to a breadth of at least an inch and a quarter, was able to feed largely on fishes; other Medusæ, beginning at less than a millimetre across, were eating young herrings, sprats, and sand-eels. It is thus shown that many of these plankton organisms are true enemies of the little fishes, although most of them, practically omnivorous, are able to eat a variety of other food.

10. Mr. A. C. Hardy.—*Plankton in Relation to the Food of the Herring.*

As part of the general scheme of investigations at present being carried out by the Ministry of Agriculture and Fisheries into the natural history of the North Sea herring, a study has been made of its food at all ages, and that of the mature fish at different seasons of the year. Plankton samples have been taken simultaneously with the catch of fish, and selection of food in the plankton is shown to take place by both young and adult fish. The change of food during the period of growth and throughout the year is described and such points as the following discussed : the apparent dependence of the young post-larval herring on the copepod *Pseudocalanus elongatus*; the suspension of feeding in the spawning season; the preference for small fish, notably sand-eels, rather than copepods in the spring; the importance of Oikopleura; the distribution of the principal food forms and, briefly, the relation of the herring to the plankton in general.

11. Mr. J. N. Carruthers.—*North Sea Currents in Relation to Fisheries.*

In view of the fact that the economics of a fishery are bound up in the fate of the passively floating eggs, larvæ, and planktonic food materials, many investigations into the nature of the currents of such an important fishing area as the North Sea have been made.

Valuable work by Fulton, some twenty-five years ago, threw light upon the source of the plaice stock of the Scottish coastal areas.

The Ministry of Agriculture and Fisheries embarked, in 1920, upon an extensive experiment designed to elucidate the non-tidal movements of both surface and bottom water in the southern North Sea. Drift bottles, both of the surface-floating and bottom-trailing types, were put out from each of seven light-vessels in this area. Twenty-five of each kind were liberated each week at each ship. The resulting information from this experiment shows very suggestive relationships with fishery-research problems.

12. Mr. H. C. Chadwick.—*Exhibit of Microscope Slides and Lantern Slides of Plankton Organisms.*

This exhibit consisted of forty to fifty lantern slides and a few microscope slides of plankton organisms. Amongst these were some little-known forms.

13. Dr. P. L. Kramp.—*Medusæ in relation to Hydrographic Conditions.*

Planktologists have frequently called attention to the importance of pelagic organisms as indicators of sea-currents, but actually very little advantage has been taken of the fact. Mere lists of species, or enumerations of individuals, are insufficient. The first condition for drawing general conclusions from the occurrence of the organisms is knowledge of the biological habits of each species : distribution, breeding, growth, requirements of hydrographic conditions, &c. The Danish species of Hydromedusæ have been studied from this point of view. Faunistically the Danish seas are particularly interesting, because they connect an extensive brackish-water area (the Baltic) with the ocean, and receive inflows of water of very different origin. If we take into constant consideration the life-history, &c., of the species, the Medusan fauna becomes a great help in tracing the origin of the different bodies of water. The cruise of the 'Dana' in April-May 1923 serves to illustrate this statement.

14. Dr. Th. Mortensen.—*Observations from the Danish Expedition to the Kei Islands, Malay Archipelago,* 1922.

The expedition was undertaken in order to find the best place for the establishment of a marine biological laboratory for the study of deep-sea organisms. Previous researches ('Challenger,' 'Siboga') suggested the Kei Islands as offering unusual advantages, and this was fully confirmed through the investigations of the expedition. The sea-bottom round these islands was found to form a regular plateau, *ca.* 2-400 m., affording excellent dredging-ground, with a rich, genuine abyssal fauna distributed all over it. The relatively small depths and the rather high bottom-temperature (10-12° C.) make access to the living deep-sea animals exceptionally easy. The shallow-water fauna being likewise very rich, health conditions good, communications good and regular, the place seems ideal for such a laboratory, which would naturally become a central institution for biological investigation of the eastern part of the Malay Archipelago (Banda Sea, Arafura Sea, Moluccas, New Guinea). Cost of establishing such a laboratory and annual expenses would be relatively small.

15. Prof. W. J. Dakin.—*The Food of Aquatic Organisms, with special reference to the Theory of Pütter.*

16. Dr. Johs. Schmidt.—*The Dana Expeditions and their work on the Life-History of the Eel.* Popular lecture, illustrated by lantern slides and cinematograph film.

Saturday, September 15.

By the kindness of the Lancashire and Western Sea Fisheries Committee there was a whole-day dredging trip on their steamer the 'James Fletcher.'

Monday, September 17.

17. Prof. F. J. Cole.—*The Vascular System of Myxine.*

Three features which are of unique interest in the vascular system of Myxinoids are the presence of a heart on the portal vein driving blood to the liver, the existence of a pair of hearts in the tail operated by extrinsic musculature connecting up the blood and lymphatic vascular systems, and the occurrence throughout the body generally of large 'lymphatic' sinuses, trunks, and vessels which always contain a percentage of red blood. Although it is often asserted that the presence of red blood in the lymphatics is due to accidental extravasation, it can be demonstrated beyond question that its occurrence there is a normal phenomenon. This being so, it is obvious that there must be a regular circulation in the lymphatics, and it should be possible to show how red blood enters and leaves the so-called lymphatic system. As regards the latter point there are four definite places where the contents of the lymphatic spaces are directed by valved openings into veins : (1) the contents of the large subcutaneous sinus are drained by the caudal hearts and pumped into the caudal vein, whither they pass into the paired posterior cardinal veins; (2) the last or sixth pair of peribranchial sinuses discharge into the venous anastomosis between the right and left anterior cardinal veins immediately in front of the heart; (3) the lingual sinus discharges posteriorly into the inferior jugular vein; (4) each anterior cardinal vein is constituted in front by the union of a superficial and a deep factor; the former originates in the brain, but the latter arises directly and without the intervention of capillaries from the hypophysio-velar lymph sinus.

In addition to these veno-lymphatics, however, a true lymphatic system, arising as blind capillaries and discharging into the venous system, can be established in Myxine. An undoubted lymphatic capillary plexus is found on the gall-bladder and everywhere in the wall of the gut. In the latter case it forms a typical and beautiful plexus of almost microscopic vessels lying superficially to the blood capillaries and discharging into a longitudinal lymphatic duct which accompanies the portal vein. At its two extremities and at intervals along its length this duct communicates with the sub-chordal lymphatic trunk, from which the lymph can enter the blood-stream by three routes via the caudal hearts. There is another elaborate plexus of, however, coarse lymphatic capillaries on the surface of the ventricle of the heart. This plexus discharges into the lymph sinus which surrounds the ventral aorta, from which the lymph reaches the anterior cardinal veins via the peribranchial sinuses. A further coarse plexus is associated with the fin rays of the caudal fin. This opens into the subcutaneous sinus, and thus communicates with the caudal vein as already described.

In addition to the system of lymphatic sinuses and ducts, there occurs also in Myxine a series of segmental lymphatic units which originate largely from capillaries in the somatic musculature. They differ from the segmental arteries and veins in that they course in contiguous pairs, which occur sometimes in most segments of the body and sometimes in alternate segments. They empty into a paired sub-chordal trunk which passes almost from one end of the body to the other. Each segmental lymphatic has a special connection with the extensive subcutaneous sinus, and its contents may reach the venous system by several routes.

18. Prof. J. H. Ashworth, F.R.S.—*The Life-history and Affinities of Rhinosporidium.*

Rhinosporidium seeberi causes proliferation of the connective tissue and overlying epithelium, producing growths in the nose, conjunctiva, &c. Recorded from Argentina, India, and U.S.A.

Earliest stages about 6μ in diameter, spheroidal, with chitinoid envelope, vacuolated cytoplasm, and vesicular nucleus the chromatin of which is contained in the karyosome. Chiefly between or among connective-tissue cells. Granules of protein and fat globules soon begin to appear in cytoplasm, and increase until cell reaches a diameter of about 60μ, when chromatin issues from karyosome, four chromosomes are formed, and a spindle with centrosome at each pole, and mitosis takes place. Succeeding nuclear divisions result in formation of 4, 8, 16, 32, and 64 nuclei. At each division the nuclei undergo synchronous mitosis. About the time of the seventh nuclear division (128 nuclei) the envelope becomes much thickened by deposition of material indistinguishable from cellulose on its inner surface, except at one point where the future pore will be formed for escape of the spores. In sporangia with about 2,000 nuclei the cytoplasm begins to condense around the nuclei, and by the time the next nuclear division is completed the cytoplasmic division is also complete; thus are formed about 4,000 rounded cells from which, by two further divisions, some 16,000 young spores are produced. The central spores begin to enlarge, their cytoplasm becomes vacuolated, and refringent spherules appear, each lying in a vacuole, until ten to sixteen are present. The spherules have been previously mistaken for sporules, as many of them exhibit, in iron-hæmatoxylin preparations, a more deeply staining central portion of denser material or of different composition, which, however, is not a nucleus. The thin film over the pore of the sporangium ruptures, and the ripe spores issue; the majority of them escape in the nasal secretion, but others become distributed in the tissue, where the stages of transformation from spore to trophic phase have been met with.

It is suggested that the nearest relatives of Rhinosporidium are not the Sporozoa, but the lower fungi (Phycomycetes), such as the Chytridineæ.

19. Dr. J. W. Heslop Harrison.—*Polyhedral Disease in the Vapourer Moths of the Genus Orgyia.*

Certain Lepidoptera, in particular the Liparidæ, are subject to diseases known as polyhedral diseases, not up to the present recorded from the British Islands. However, an epidemic, quite typical in its symptoms, broke out in a series of cultures of *Orgyia antiqua* reared for genetical research from wild Aberdeenshire ova. In these batches the larvæ attacked succumbed for the most part just before reaching full growth, but others managed to pupate before doing so. Only rarely were imagines reared from diseased broods. Affected caterpillars, immediately after death, disintegrated into a brownish liquid having a faint, nutty, and not unpleasant smell. Microscopical examination showed this to be crowded with bodies roughly polyhedral or crystalline in appearance, which originated within the nuclei of blood, fat, tracheal and other cells.

Attempts made to infect the larvæ of Gipsy and other moths met with but little success, although many Orgyiæ forms proved very susceptible, and from them passage infections were carried out. Clearly, unless the Italian race of *Liparis dispar* employed is immune, the disease is not identical with that attacking the Gipsy Moth.

In the successful experiments certain hybrids and races were more resistive than others, and the males more so than the females. This immunity of the male is more apparent than real, and depends on the fact that the male Orgyia larva has one less instar than the female.

Evidence was secured proving that the disease could be transmitted through the egg.

20. Mr. A. D. Peacock.—*Parthenogenesis in Sawflies.*

Revised list of parthenogenetic species; recent additions to list. Parthenogenetic condition within the group and the problems arising therefrom—*e.g.* thelyotoky and arrhenotoky within the same genus, deuterotoky. New observations on the breeding habits and their significance in relation to sex-ratio; dechandry and adechandry, impotence. Sex-change experiments (1) by dieting larvæ with chemically treated food; (2) by X-ray, electrical, and chemical treatment of eggs. Species used : *Pteronidea ribesii*, facultatively arrhenotokous, occasionally deuterotokous; *Pristiphora pallipes* (in which the male is excessively rare), thelyotokous; *Atlantis pallipes*, obligatory thelyotokous. Brief reference to gametogenesis.

21. Mr. E. R. Speyer.—*The Evolution of Aphids with Complex Life-cycles.*

Researches upon the Larch Chermes (*Cnaphalodes strobilobius* Kalt) have brought to light certain processes of development relating to regular increase of one type of individual over another in successive generations, independently of environmental conditions, and to a regular alternation of form controlled by an internal mechanism. From these principles it is possible to arrange the existing species of Chermesinæ in an evolutional series, starting from the earliest period at which parthenogenesis correlated with apterism resulted in a simple alternating cycle. Subsequent stages in evolution comprise complete loss of sexuality, migration, and morphological changes through natural selection in a second environment, evolution of a return migrant, and recent acquirement of long-lost sexuality through individuals with few characters in common with other individuals of the cycle, and a final recapitulation of the original cycle on the definite host-plant.

22. Dr. H. A. Baylis.—*Some Considerations on the Host-range of Parasitic Nematodes.*

The nematodes parasitic in vertebrates show great variety in the extent to which they are limited to particular hosts. A review of a considerable number of genera shows that they may be divided broadly into a section with more or less strict 'specificity' and a section with members occurring in various hosts, often of quite distantly related groups.

Many of the genera with wide ranges have an intermediate host (commonly an invertebrate) during their earlier phases, and it is suggested that these forms, being introduced into the final host at a more advanced stage than those which have a direct development, are better able to withstand violent changes of environment, and thus better able to adapt themselves to a variety of final hosts.

Since 'specificity' can only be rightly considered in its relation to evolution, it is suggested that among forms with a direct development those which show the strictest specificity are the most specialised, this being often correlated with specialisation, in habits or otherwise, of the hosts, while those which have a wide range have retained a primitive adaptability.

23. Discussion on *The Systematic Position of the Nematoda*, opened by Prof. S. J. Hickson, F.R.S.

24. Prof. B. Blacklock.—*The Tumbu Fly, Cordylobia anthropophaga* Grünberg, *and the Congo Floor Maggot, Auchmeromyia luteola* Fabricius, *in Sierra Leone.*

The Tumbu Fly is a troublesome fly in tropical regions of Africa on account of the habits of its larvæ. These enter the skin of animals and proceed to grow and develop there until the larvæ are full-grown and ready to pupate, when they leave the skin and continue their development on the ground. Man and many animals are affected by them, and suffer from painful boils as a result of the presence of the larvæ in the skin. Young animals are very heavily infected and frequently die as the result of the disease. It has been possible to obtain large numbers of wild and laboratory-bred flies, and as a result a study of the various stages from egg to adult has been possible. Many new facts on the morphology of the stages and on the bionomics have been observed, and it has been determined that wild rats are an important factor in the preservation and spread of the infection.

The Congo Floor Maggot is a parasite which has a totally different life-history. This maggot's unique habit of sucking blood from human beings lying asleep on the floor of their huts was discovered by Dutton, Todd, and Christy in 1904 while on an expedition of the Liverpool School of Tropical Medicine to the Belgian Congo. This larva is incapable of penetrating the skin, but it has a special arrangement of the mouth apparatus by which it is enabled to adhere firmly to the skin while sucking blood.

The adult flies of the two larvæ are similar in appearance and belong to the same sub-family Calliphorinæ of the Muscidæ. A comparative study of myiasis due to these and other larvæ is outlined.

25. Mr. H. Graham Cannon.—*On the Post-naupliar Development of an Estherid Crustacean.*

The post-naupliar development of an Estherid Crustacean from Baghdad has been worked out. The larva hatches as a true nauplius. The mesoderm of the post-naupliar region forms a continuous sheet around the gut. This very early splits along the mid-dorsal line, thus forming the cardiac cavity. Ventrally the mesoderm separates from the gut forming the perivisceral cavity. The ventral mesoderm shows a transitory segmentation that soon becomes obliterated by growth. A little later the dorsal parts of the mesoderm develop a series of seven pairs of pouches. From these pouches the heart tube is formed exactly as in Peripatus. The pouches ultimately dwindle in size, their cavities disappearing and their collapsed walls forming the pericardial floor. The cavities in no way open into the general body cavity. In the maxillary segment the ventral mesoderm remains in connection with the dorsal pouch, and in this ventral portion a cavity appears which becomes the end sac of the maxillary gland.

Tuesday, September 18.

26. Dr. F. A. E. Crew.—*Sex-reversal in the Domestic Fowl.*

Eight cases are described which form a consistent series illustrating the process by which the female of the domestic fowl undergoes a sex-transformation and comes to possess the sex-organisation of the male. One bird in the series having functioned for three years as a female ultimately became the father of chickens. It appears that it is the presence of growing oocytes which prevents the assumption of the male characters by the female, and that if this inhibiting physiological influence is removed through disease the internal environment may become such as encourages the differentiation into spermatic tissue of the sex-cords which periodically invade the sex-gland. It can be anticipted that in all hens in which growth of oocytes has ceased spermatic tissue in some form will be found. The phenomenon is interpreted in terms of Goldschmidt's hypothesis.

27. Dr. J. W. Heslop Harrison.—*Sex in the Salicaceæ and its Modification by Eriophyid Mites and other Influences.*

The members of the Natural Order *Salicaceæ* are typically diœcious, although ocasional plants are encountered in the genus *Salix* departing from this condition.

These are of two types : (1) the so-called androgynous form restricted to hybrids, in which the catkins bear varying proportions of male and female flowers, and (2) the *metamorphosans* variety, in which plants, primarily male, produce catkins with the flowers forming a chain of intergrades between maleness and femaleness.

Regarding sex-determination in diœcious plants as proceeding on the same fundamental basis as in animals, it is suggested that the explanation of the androgynous form lies in environmental influences temporarily affecting the general metabolism of male plants, necessarily regulated by chromosomes derived from different species, and therefore in a state of unstable equilibrium.

Irregularities of the *metamorphosans* type are peculiar to male plants of the section Capreæ, and affected catkins are invariably infested with Eriophyid mites. Cytological examination of such catkins always shows that their tissues, whether in male, female, or transitional areas, are built up of cells uniformly endowed with the chromosome complement proper to the species and intrinsically of male potentialities. Thus the development of the intersexes cannot depend on non-disjunction or other mitotic irregularities postulated to account for gynandromorphs, but rather upon a metabolism modified locally by external stimuli toward the level typical of the opposite sex; agents affording such stimuli are seen in the parasitic Eriophyidæ.

In diploid Salices a census of the sexes made in the field reveals practical equality in numbers, but in tetraploid and hexaploid species a great preponderance of females is noted. To account for the latter observation two explanations are advanced. Firstly, the evolution of the tetraploid and hexaploid species almost necessarily implies a duplication of the sex chromosomes in their micro- and megaspores, so that disturbance in the sex ratios of later generations, favouring the female, are to be anticipated; and, secondly, the polyploid species are facultatively apomictical, and the progeny so produced in *Salix* is always female.

28. Prof. W. J. Dakin and Mr. S. T. Burfield.—*An Attempt to Influence the Sex of the Fœtus by means of Antibodies.*

29. Mr. JULIAN S. HUXLEY and Prof. A. M. CARR-SAUNDERS.—*Failure of Attempts to induce Eye-defects by Antibodies.*

Thirty female rabbits have been treated, some more than once, in an attempt to influence their embryos *in utero* by means of antibodies against lens substance. The number of treatments was forty. The treatments were varied as follows: (1) The most usual treatment was injection of serum from fowls treated with rabbit-lens; (2) injection of serum from fowls treated with ox-lens; (3) direct injection of rabbit lens; (4) direct injection of ox-lens. No fowl serum was used unless it gave precipitation reactions with rabbit-lens *in vitro.* Over sixty young from treated females were examined, but none showed any abnormality of eye or lens. If the animals died very young the lenses were dissected out; otherwise an ophthalmoscope was employed.

Guyer and Smith report having produced eye-abnormalities by method (1) above in about 6 per cent. of the offspring from treated parents. The above negative results show at least that this considerable percentage cannot always be expected. Reinvestigation on a large scale is necessary to discover the extent to which the effect is really operative.

30. Mr. JOHN R. BAKER.—*Genetic Intersexuality in Pigs.*

Intersexual pigs occur commonly in the New Hebrides. The individual examined differs from the usual intersexes in pigs and goats in that there is no sign of uterus or of vagina, while there is a vulva, clitoris, and urinogenital sinus just like that of a female. A tendency to intersexuality is inherited. The hypothesis is suggested that these intersexes are virtual males carrying a sex-chromosome which differs in potency from the ordinary sex-chromosome. The effect of this sex-chromosome is to make the various organs less easily affected by the interstitial hormone, so that they develop past the point at which they can be affected before they have changed completely to the male condition. They thus remain permanently in an intermediate or intersexual condition.

31. Dr. A. S. PARKES.—*The Value of the Sex-ratio at Birth as Evidence regarding Sex Determination in Mammals.*

In mammals the ratio between the sexes is only readily obtainable at birth, and therefore the ratio at this time has to be used in discussing sex determination in mammals. This is unsound in so far as the ratio at birth may not be the same as that at the time when sex is determined. In the absence of complete sex reversal the only way in which the sex-ratio can be changed during gestation is by pre-natal mortality having an unequal sex incidence.

All the available evidence goes to show that both abortion and reabsorption of embryos are processes which fall preponderatingly upon the males. As the amount of fœtal elimination may be very considerable, the sex-ratio at birth is often very different from that at the time when sex is first determined, and is therefore not good evidence upon which to discuss theories of sex determination.

In the afternoon an excursion took place to Delamere Forest. Leader, Prof. R. NEWSTEAD, F.R.S.

Wednesday, September 19.

32. Prof. W. C. MCINTOSH, F.R.S.—*On Two Remarkable Polychaet Tubes (probably of Polyodontes) from the Cape and Cuba; and on the Discharge of the Ova in Thalepus.*

(1) The tube from South Africa has a diameter of about two inches, and the anterior region consists of silky fibres, chiefly longitudinal, and arranged at intervals in transverse rows, loosely felted externally and smoothly and finely felted internally, the thickness of the whole being about 3 to 4 mm. The posterior region is firmer, transversely wrinkled, and devoid of the silky aspect of that in front. The Cuban tube is 4 feet 6 inches long and $1\frac{3}{8}$ inches in

diameter in front, rounded and firm for fully a foot anteriorly, flaccid posteriorly. It is composed of similar fine fibres secreted by the annelid, the exterior larger (1 mm. thick) being denser, the interior (2.5 mm. thick) softer. The structure of both tubes is unique.

(2) The discharge of the ova in *Thalepus* takes place apparently by two comparatively large and neatly finished elliptical apertures between the sixth and seventh setigerous processes (one on each side). No such apertures have hitherto been found in the group. The ova are large.

33. Dr. Stanley Kemp.—*Notes on the Fauna of the Siju Cave, Garo Hills, Assam.*

The Siju Cave is situated in the southern part of the Garo Hills, Assam, on the right bank of the Someswari River. The cave is in nummulitic limestone of Middle Eocene formation, is about three-quarters of a mile in length, with a stream flowing through it, and has no opening other than the entrance. The fauna comprises about 100 species, of which only twenty-two occur in the inner parts at distances exceeding 500 yards from the entrance. The vast majority of the fauna consists of species which are found, or might be expected to be found, outdoors, and only five or six show definite adaptation to cavernicolous existence. Of the latter the most interesting are a fresh-water prawn (*Palæmon*) with eyes well pigmented but less than half the normal size, and a small gastropod (*Opeas*) in which the retinal pigment is completely absent in 6 per cent. of the individuals collected.

34. Dr. A. J. Grove.—*Some New Observations on the Sexual Congress of the Earthworm, Lumbricus terrestris.*

The accounts of this process in the text-books in common use show a surprising lack of unanimity, particularly with regard to the nature of the exchanges. Direct observations have confirmed the account by Hering (1857), that, after the approximation of the two worms in the usual 'head to tail' position, and adhesion by their clitella, seminal fluid issues from the apertures of the vasa deferentia of each worm and travels backwards along a groove or furrow, which has been termed the seminal groove and extends from segment 15 to the clitellum. On reaching the clitellum the seminal fluid collects as a white mass between it and the adposed ventro-lateral surfaces of the 9th-11th segments of the co-operating worm. Later the spermatozoa become aggregated into two masses lying in the grooves between segments 9 and 10 and 10 and 11, and thence pass into the spermathecæ.

The nature of the seminal groove has been much in dispute, probably owing to its temporary character. It is brought into existence and operation by a special musculature which extends from segment 14 to the end of the clitellum.

The adhesion of the two worms is largely effected by the clitella, the apposition of the ventral portion of this region of one worm to the ventral portion of segments 9-11 of the other being very close. The setæ in this region are also instrumental in maintaining the connection. The structure of the ventral portion of the clitellum differs from that of the lateral and dorsal portions.

The pores of the ventral setal sacs in the clitellar region, and also in certain other segments of the body which show tissue of a similar character on the ventral surface, have simple glandular diverticula in connection with them, which are not present in other parts of the body. The secretion of these glands is not mucin, such as is secreted by the goblet cells of the epidermis.

35. Miss M. S. G. Breeze.—*Invasion of the Tissues of the Higher Plants by Protozoan Parasites.*

Recent work on the pathological condition of sterile and otherwise diseased tissues points to the presence of protozoan or protistan parasites in plant tissues.

The research falls under three headings :—

(i) The discovery of various species of Leptomonas and other protozoa in the latex of many plant families. These organisms were first demonstrated in 1909 by Lafont, and his results have been confirmed by many other medical research workers, including Laveran, Mesnil, França, and Franchini.

(ii) The discovery by Matz in sugar-cane, by Knakel in corn, and by Palm in tobacco of less well-defined organisms, some of which are amœboid in structure and are found in plant tissues affected by mosaic disease.

(iii) The demonstration of protistan organisms causing widespread sterility in a large percentage of the anthers and ovaries of cultivated plants.

The above investigations lead to the suggestion that some of the unexplained virus diseases of plants may be due to the attack of protistan organisms having phases in their life-history which hitherto have eluded observation.

SECTION E.—GEOGRAPHY.

(For references to the publication elsewhere of communications entered in the following list of transactions, see p. 505.)

Thursday, September 13.

1. Presidential Address by Dr. VAUGHAN CORNISH *on The Geographical Position of the British Empire.* (See p. 126.)

2. *The Region around the Mersey and Dee Estuaries.*

Three papers dealing with the area which is being studied by the Liverpool and District Regional Survey Association, having Liverpool as its centre, and extending nearly to Southport on the north, Wigan and Warrington on the east, and including the western portion of Cheshire and the northern slopes of the Flintshire range of hills beyond the estuary of the Dee.

(*a*) Mr. W. HEWITT.—*Physiographical Features.*

The sandstone ridges; low-lying coastal plains and alluvial areas; sand-dune belt; ancient inland mossland, and meres; influence on site of early settlements; contrasted features and history of the two estuaries; tidal inlets on the Mersey and their utilisation; isolation of south-west Lancashire.

(*b*) Mr. H. KING.—*Distribution of Population.*

Method of representation; consideration of distribution in 1801 in relation to (i) the coalfield and other industries, (ii) the port of Liverpool, (iii) the agricultural areas, (iv) means of communication. Evolution of the present distribution in relation to (i) expansion of industries and trade, (ii) development of railway system and extension of residential districts. The effect of institutions on the relative density. Desirability of retaining existing thinly populated areas between the industrial districts and the coastal towns.

(*c*) Mr. R. C. MOORE.—*The Industrial Geography.*

No single dominating industry but many of importance. Liverpool itself more a centre of commerce than of industry, but has long association with alkali, sugar-refining. milling, engineering, &c. Well-defined industrial areas within region. Problems in connection with origin and growth of industries, and the situation in relation to communications and supply of raw materials.

In the afternoon an excursion to the Docks took place.

3. *Report of Committee on Geography Teaching.* (See p. 321.)

Friday, September 14.

4. Prof. J. L. MYRES, O.B.E.—*The Marmora Region.*

Low-lying but mainly land-locked, between Continental plateau of Asia Minor and 'Balkan' highlands of Europa Minor, permits intercommunication between them; but as their convergent drainages skirt instead of intersect it, such intercourse is inevitably subject to local controls, especially as the basin itself sinks so low as to be traversed by an open sea-way from the Bosphorus to the Dardanelles. This makes the Marmora also a region of transition and traffic between the Ægean Archipelago and the Black Sea even more strongly contrasted in physique and products than are the Continental areas of Europe and Asia. Yet this sea-way does not result from the main structure of the region, but interrupts it, giving to the shores exceptional control over the channel, while the channel penetrates a district otherwise not maritime. Consequently, while its place in history mainly results from events in the four larger regions interacting through it, the peculiarities of the Marmora itself modify this interaction, sometimes profoundly. Seldom populous or productive enough for political independence, it has repeatedly offered exceptional facilities for imperial administration over adjacent and even distant provinces; and for mercantile exploitation of wide areas. Possession of it has been, and is, contested by States which experience its geographical control; but hitherto its political, no less than its economic, relations have been so varied as to be irreconcilable. It is the site for a great capital without commensurate provinces.

5. Joint Discussion with Section H on *The Place of Man and his Environment in the Study of the Social Sciences.* Opened by Prof. J. L. Myres.

Doubts on this matter arise partly from defective nomenclature of these branches of knowledge, partly from accidents of personality and convenience in the growth of existing organisations for the study of them. Recent conferences between sociologists and representatives of kindred studies went far to define the frontiers, but left it uncertain whether social science itself as it actually exists is a pure science, tracing biological development in human behaviour; an applied science, employing criteria of value to select modes of behaviour for imitation in practice; or a branch of philosophy, standing in the same relation to Anthropology, Psychology, and History as Metaphysics to Physics or Astronomy. As a branch of natural science, sociology would appear to merge in the 'social' or 'cultural' aspect of Anthropology; as a study in correlations between men's behaviour and their environment it overlaps the human department of Geography; as an aspect of Philosophy, it is difficult to distinguish from what was formerly called the 'Philosophy of History.'

In the afternoon an excursion to the Wirral Peninsula took place.

Monday, September 17.

6. Mr. O. H. T. Rishbeth.—*Australian Railway Development: a Study in Political Geography.*

The great continental new-lands offer striking human contrasts with the more individualised home-lands of Western civilisation. Australian railway development symbolises Dominion as contrasted with European social and political life. North-Western Europe, owing to physical and racial characters and history, intensely individualised; progress of social and economic synthesis slow and painful: railway development reflects this. Australia, starting with European traditions but with more homogeneous physical and human conditions, is rapidly discarding its essentially artificial political and social conditions; railway development reflects rapid growth of *spirit* of Commonwealth. Outline forecast of future of Australian railway system.

7. Mr. R. R. Walls.—*The High Plateau of Brazil.*

Geological structure. The evolution of the plateau. Physical features. Climate. Resources. Inhabitants and social conditions. Development and future.

8. Prof. J. W. Gregory, F.R.S.—*To the Alps of Chinese Tibet.*

Problems of the mountain system of South-eastern Asia. The plateau of Yunnan. The three views of Chinese Tibet. The Alps of Chinese Tibet and the glaciers past and present.

9. Rev. W. Weston.—*The Influence of Environment on the Characters of the Japanese.*

Japan's position as advanced frontier of East Asia; influence of that contiguity on national character, religion, art, and history. Three-quarters of

Japan mountainous and uncultivated. Geological formations very varied. Mountains have tended to mould religious ideas, to preserve local characteristics, and to shape course of much internal history. Soil only moderately fertile conduces to industrious habits, ingenious methods, &c., of people. More than half population are 'on the land.' Every type of climate found in Japan. Widespread natural beauty has refining influence on tastes and customs of all classes. Abundance of water modifies surface and responsible for rich vegetation, and for periodical inundations which on one hand destroy much property, and on the other have led to skill in riparian work.

10. Joint Discussion with Section L on *Geography as a Basis for a General Science Course.* Opened by Sir R. A. Gregory.

Tuesday, September 18.

11. Mr. J. A. Steers.—*Orfordness.*

General description of the spit. Action of the sea. Evolution of the beach. Historical changes.

12. Mr. H. A. Matthews.—*Mediterranean Climates of Eurasia and the Americas.*

Similarities and differences. In Mediterranean the enclosure of a warm branch of the Atlantic results in typically marine phenomena such as autumn rain from low-pressure centres over warmer sea. In California and Chile relief and exposure to a cold sea result in (i) abnormally low coastal temperature in summer and high temperature gradient between coast and inland stations, while (ii) autumn rainfall is of far less importance than spring rainfall.

13. Mr. J. N. L. Baker.—*Some Geographical Factors in the Development of Irrigated Lands.*

The development of irrigated lands regulated partly by local conditions, including general climatic influences, the nature of the soil, and the type of the crop grown, and partly by external factors, the chief of which are availability of markets, costs of production, facilities for transport, and presence of labour supply. The factors operate in different ways in the old world and in the new, resulting in contrasted production, but in both cases the development of irrigated lands may be regarded as an attempt to solve local problems.

14. Mr. W. H. H. Arden-Wood, C.I.E.—*Changes in the Courses of Rivers in the Alluvial Plains of India in their Relation to Man and his Activities.*

SECTION F.
ECONOMIC SCIENCE AND STATISTICS.

(For references to the publication elsewhere of communications entered in the following list of transactions, see p. 505.)

Thursday, September 13.

1. Mr. C. E. R. Sherrington.—*A Comparison of the Probable Economic Results of the United States Transportation Act,* 1920, *and the British Railways Act,* 1921.

This paper described shortly the conditions which led up to the passing into law of the Transportation Act, 1920, in the United States, and the British Railways Act, 1921, in Great Britain.

The provisions of each Act, and the probable economic effects, were dealt with in each case. These may be divided into—

(1) The relation of employee and employer in railway service.

(2) The financial effects which may be expected from the advised amalgamation in one case and the compulsory amalgamation in the other.

(3) The effect on the traffic working and methods of operation.

(4) The effect on the relationship of the Government and railways.

(5) The economic results caused by changes in the services rendered by the carriers as between one area and another.

(6) General economic effects on the countries concerned, which may be subheaded into (a) the result of possible lower rates, with the consequent widening of the market; (b) the result of a greater degree of co-operation amongst the transport facilities offered.

The paper ended with a comparison between these probable economic consequences in the two countries concerned.

2. Joint Discussion with Section J on *The Inter-connections between Economics and Psychology in Industry.* Opened by Mr. Eric Farmer.

The fundamental concepts of economics cannot be fully understood without paying attention to their psychological aspects. Economic laws do not work in a pure field, but in a field in which psychological factors are also operative, and the work of the industrial psychologist is to endeavour to measure the effect of these factors. Although this branch of psychology is comparatively new, yet sufficient progress has been made to throw considerable light upon such problems as the most economic spell of work and type of movement; and there is little doubt that as the work continues a definite body of laws will be established which will tend to make our knowledge of the factors governing production more accurate than at present.

In the afternoon an excursion to the Docks took place.

Friday, September 14.

3. Prof. Henry Clay.—*The Post-War Wages Problems.*

The settlement of wages before the War was facilitated by the existence of well-understood and stable relations between wages in different occupations, kept in close correspondence with commercial exigencies by continual small modifications. The effect of the War was to dislocate these relations, interrupt this modification, and bring wages into correspondence with War-time economic needs instead of normal commercial needs.

The post-War problem is to restore the stability in the relations of wages and the close correspondence with commercial possibilities that existed before the War. This involves changes from pre-War relations, and the recognition as lasting of changes that are still regarded as temporary, in order to allow for certain important changes since 1914 in the factors underlying wages. The chief of these are changes in the distribution of workers among different occupations; changes in the organisation of wage-earners; changes in the character of work required; and changes in the markets of British industries.

It is difficult to ascertain whether the general level of real wages has risen or fallen, and impossible to forecast its level in the future; so far, however, as a general level has to be assumed for the purpose of settling particular rates, it will prove necessary to take the average level of wages in export industries as the norm, rather than continue the present custom of taking the pre-War level of money wages, and raising it to compensate for the increased cost of living.

4. Joint Discussion with Section M on *The Economic Outlook for British Agriculture.* (See p. 501.)

Monday, September 17.

5. Mr. H. D. Henderson.—*Stability in the Standard of Value.*

The assumption of stability in the purchasing-power of money fundamental to our economic life, based on the exchange of commodities and services, and the undertaking of future obligations in terms of money. The degree to which this assumption was realised before the War, with gold standards generally adopted. The great disturbance in the purchasing-power of gold arising from the abandonment of gold standards during the War. The possibility of a similar disturbance in the event of a general return to gold standards. The peculiar monetary position of the United States. The evolution of the idea of attempting to ' control ' the purchasing-power of gold so as to secure stability.

The connection of trade fluctuations with changes in the price-level, and the possibilities of diminishing these fluctuations by securing a stable standard of value. The far-reaching social consequences of trade fluctuations, and the immense social advantages which would result from their removal.

The present monetary policy of Great Britain. The advantages—real and sentimental—of a return to the old gold standard. The uncertainty of future monetary policy in the United States. The respective advantages of exchange stability and price stability. The desirability of combining both if we can do so; the greater advantages of the latter if we have to choose between them.

6. Presidential Address by Sir W. H. Beveridge, K.C.B., on *Population and Unemployment.* (See p. 138.)

In the afternoon the Liverpool Cotton Association, St. George's Hall, was visited.

Tuesday, September 18.

7. Dr. P. Sargant Florence.—*Individual Variations in Efficiency and the Analysis of the Work-Curve.*

Evidence of unanalysed work-curves published and unpublished: the effect on efficiency of long spells of continuous work, of overtime and the long working day, of deliberate restriction of output, and of the type of work engaged in. Typical curves for work on furnaces, on power-driven lathes, on automatic looms, and for dexterous and muscular handwork.

Practical and scientific value of work-curves: The best distribution of hours of work: the industrial manifestation of practice, spurt, incitement and fatigue; distinction between cyclical and cumulative fatigue.

Need for further analysis (1) of the behaviour of the individual leading him to produce a given work-curve, (2) of the degree to which individual work-curves conform to the average work-curve.

(1) The work-curve as the combined effect of variations in small voluntary pauses and in the speed of work. Recent American observations of lathe-work. The attainment of rhythm in sporadic runs of high speed. Conflicting conceptions of rhythm in industry.

(2) Variations in individuals' daily and hourly outputs; recent American evidence as to form of distribution. Variations in individuals' work-curves; evidence of approximation of a squad of individuals at similar work to one type of curve.

8. Prof. F. Y. Edgeworth.—*Women's Wages in Relation to Economic Welfare.*

The Presidential Address to Section F, 1922, dealt with the question: What relation between the wages of men and women is most productive of wealth? In this sequel the inquiry is directed to a higher aim—welfare. The satisfactions which constitute economic welfare depend on Distribution as well as Production. If the wealth of a community is increased or diminished, the gain or loss of satisfactions depends not only on the amount added or subtracted, but also on the proportions in which the benefit or burden is shared.

It is now a recognised principle of taxation that the burden is to be adjusted so that the aggregate sacrifice incurred may be a minimum. If the taxation exacted by the State consisted of services instead of money, presumably 'more would be expected from the powerful man' (Stamp, *Principles of Taxation*). But in general it would be unsafe to proportion the remuneration of labour to fatigue suffered rather than to work done. It would be inconsistent with the action of competition. However, competition is not a finely graduated instrument. It determines the integers, so to speak; but leaves the decimals to be settled by collective bargaining (Address, § 10). So within narrow limits some differentiation in favour of weaker workers is consistent with Competition. Even within those limits it might be unsafe to favour any class if the numbers of the class could be increased through an inflow attracted by the favours. But this objection does not apply to discrimination (within limits) in favour of the weaker sex. To make some distinction in favour of the sex would be the more practicable because in keeping with the manners of Christendom. Loss of wealth to the community is not to be apprehended from a slight infraction of competition; in virtue of the principle that a *slight* variation in the conditions determining a maximum is generally attended with a *very slight* diminution of the quantity maximised (*loc. cit.*, § 8). The relaxation of competition now proposed is not, like that before advocated, based on the requirements of family life, nor limited to mothers of young children. The claims before made on their behalf on the score of wealth (including an efficient progeny among products) (*loc. cit.*, § 21) are now strengthened by considerations of welfare. But there is no weakening of the objections to the sustentation of families—normally and on a large scale—by the State (*loc. cit.*, § 20). Whether proposed on the ground of wealth or welfare or some other, non-economic, ground—the various and serious economic evils attending such schemes are not to be ignored.

9. Mr. J. A. Bowie.—*The British Coal Agreement of* 1921.

Over 60 per cent. of the cost of production of coal is spent on wages, hence the necessity of their rapid adaptation to the varying prosperity of the industry. The report of a Committee of the Mining Association in 1916 and the evidence of Lord Gainford and of Professor Cannan before the Coal Commission foreshadowed the 1921 Agreement.

The Details of the Agreement considered under the following headings: The district basis, wage-regulation clauses, National and District Boards, standard wages and profit, the surplus profit and the recoupment clause. The Agreement is a notable industrial charter; it means measurement and publicity, the co-relation of wages and profits, and it is democratically administered. Yet it was hurriedly drafted, and calls for amendment in certain details.

Wednesday, September 19.

10. Mr. J. J. Clarke.—*Some Factors Relating to the Re-housing of Slum-dwellers.*

Importance of the subject as one of the consequences of the War. The treatment in three main divisions—*viz.* (1) Pre-War re-housing; (2) immediate post-War re-housing; (3) the future.

Re-housing before the War.—The function of the private builder. Some reasons which prevent the continuance of his operations. Re-housing by Local Authorities. Their powers and duties. The example of Liverpool and comparisons with other towns. General and Vital Statistics.

Re-housing after the War.—The difficulties presented by the cessation of building during the War. The problem of overcrowding and its relation to slums. The conditions as represented in certain typical towns in this neighbourhood. Liverpool — Birkenhead — Bootle — St. Helens — Wallasey—Warrington. The Assisted Housing Schemes as one solution of the problem. Why it has failed to reach the slum-dweller. Building rings. Economic rents. The example of Birkenhead. The effect on character.

The Re-housing of the Slum Dweller in the Future.—Two main considerations of this problem—*viz.* (1) The industrial town, (2) the large city.

Wallasey a difficult example. Bootle, St. Helens, and Warrington as industrial towns capable of expansion. London and Liverpool as examples of the large city. Why we re-house on the slum area. The difficulties of transport.

Suggestions for the Future.—The tenement or the flat? Social Institutes. Progress by means of the linking up of tramways and railways. A proposal for the Liverpool area. Encouragement of house-purchase by means of Municipal Banks. The Unemployment Problem may be solved by a National Housing Scheme.

SECTION G.—ENGINEERING.

(For references to the publication elsewhere of communications entered in the following list of transactions, see p. 505.)

Thursday, September 13.

1. Joint Discussion with Sections A and B on *Cohesion and Molecular Forces.*

2. Joint Discussion with Section J on *Vocational Tests for Engineering Trades.* (See p. 482.)

Friday, September 14.

3. Presidential Address by Sir Henry Fowler, K.B.E., on *Transport and its Indebtedness to Science.* (See p. 162.)

4. Mr. A. E. Berriman.—*Road Transport.*

Introduction.—Essential to consider the engineering side against a background representing the broader political and commercial aspects of inland transport as a whole. Businesses most dependent on distribution can least afford to ignore any mode of conveyance that offers economic advantages.

(1) *Freight Transport by Road versus Rail.*—Railway freight charges and revenue. Causes of diversion of freight from rail to road. Comparison of direct cost by rail and by road. Importance of a high load factor. The Railway Bill for road transport powers. Fundamental technical advantages of rail traction. Need for increasing freight mobility on railways. Could more use be made of the container principle?

(2) *Types of Commercial Vehicles and their Suitability for Different Purposes.*—Petrol, steam, petrol-electric, electric. Producer gas. 'Semi-Diesel' engines. Throttled efficiency. Six-wheeled vehicles and track machines.

(3) *Passenger Vehicles, Private and Public.*—Private vehicles and private incomes. Motor-cycle with side-car. Front-wheel brakes. The high-speed engine. Influence of racing. Mean effective pressure and piston speed. The London 'bus. Railed traffic on road surfaces. The trolley 'bus. Private hire services. The side-car taxi. The pneumatic tyre.

(4) *Roads Improvement and Traffic Control.*—Mileage and classification. Cost of maintenance and the contribution from motor taxation. The rating controversy. Vehicle classification. Automatic traffic control by warning signs. Can this be improved by adopting the principle of a right of way on the primary road at crossings? Traffic congestion in America.

5. Col. E. O'Brien, D.S.O.—*The Future of Railway Transportation.*

The probability of future progress must be viewed in the light of the past. The introduction of railway transportation has had a profound influence on the mode of life of the human race; its further development may produce even more striking changes, more especially as the railway penetration of Asia and Africa progresses. The engineering development has been rather in improvements in detail and material—with consequent possible increase in weight and speed of trains—than in the introduction of any radically new principle; in principle the steam locomotive is unchanged since its introduction. The one radical change has been the introduction of electric traction; the application of this new system of transport has been very limited in Great Britain, but extensive in America. The cost of electric power delivered for use in locomotives is practically as great as that of coal delivered for the same purpose, except where coal is very dear and water-power available, a fact which retards development of the system. In conclusion, it is evident that the general use of steam locomotives will persist for many years to come, but that there is a great future for electric traction for suburban traffic and busy main-lines in Great Britain and elsewhere.

6. Major-General Sir SEFTON BRANCKER, K.C.B.—*Air Transport.*

Development of British Empire transport system one of to-day's outstanding problems. The world's history a history of transport development. Empire adminstration and Empire trade dependent on communications. Solution of problems of maintenance of Empire bonds depends on efficiency and rapidity of its communications. Air transport, properly handled and steadily developed, an antidote to some of these difficulties and may prove to be the most important factor in preservation of the Empire.

Air transport has the same problems and the same basic factors as other means of transport; but the exact rules which govern established means of transport must be modified in dealing with the new element.

Financial failure of air transport in the past. Lack of State encouragement sufficient to attract solid capital and solid business organisations. Delay in provision of State financial support towards development; subsequent lack of fixed policy or guarantee of security of tenure.

Operational success considerable. Government considering definite long-dated policy.

Certain facts established. Bad visibility the only deterrent to completely reliable operation of air transport. Air transport safe with highly efficient administration. British operating services proved that that administration can be achieved. No fatalities to passengers in services of last two years.

Services to Paris, Brussels, and Amsterdam, experiments by which these facts have been proved. These routes too short to show material time-saving. Extensions to Manchester, Cologne, and Berlin give very material saving in time, and more constant traffic should be obtained. Present international situation a temporary handicap.

Cost per ton-mile with existing equipment achieving a speed of 100 miles per hour varies from 3*s*. 6*d*. to 5*s*.

Making due allowance for possible head-winds, 100 miles an hour the economic speed for cross-Channel air transport.

With substantial traffic available, cost per passenger-mile at 50 per cent. load is 8½*d*.; maximum fare to be expected is 6*d*. With established traffic increase in load factor can be anticipated; technical development will reduce running costs.

Value of newspaper, mail, and goods traffic on long routes; with short routes ground delays in handling render time-saving in transit of little value.

Bad visibility and high costs the present weak points in air transport.

Wireless a corrective of bad visibility. Dependable communication with machines in the air achieved. Pilots kept informed of meteorological conditions along the route and at terminals. By means of direction-finding stations pilots given, on request, their exact position. Perfection of this system will entirely eliminate danger of pilots losing themselves and enable them to select clear landing-grounds. In addition, definite progress being made towards greater stability in aircraft. Probable early elimination of loss of control of machines in fog or cloud. Possible future ability to land in fog, though even without this no reason why air transport should not become as reliable as other forms of transport in bad visibility.

Heavy traffic will reduce high costs considerably; insurance costs already falling, and with maintenance of efficiency will fall still lower. New aircraft being developed which will carry greater paying load per horse-power and be less costly to maintain. Use of heavy oil will effect enormous reduction in fuel and engine maintenance costs.

Basic problem unsolved—the education of the public. Public support dependent on realisation of safety and reasonable fares. Duty of the Government to give financial assistance to enable such fares to be charged until increased traffic and improved aircraft make air transport commercially self-supporting.

Operational problems being studied; present experience points to 2,000 hours' flying per machine per annum as practicable and desirable, and to a 200 per cent. engine reserve per machine; 600 hours' flying per annum not an undue strain on pilots.

Passenger comfort being studied and improved. Experiments being carried out in heating, ventilation, silencing and general comfort. Silencing the greatest difficulty, but progress being made.

Air-sickness not nearly so prevalent as alleged; most uncommon in open aircraft; in closed machines limited to a small proportion on rough days; causes being investigated; improvements in heating, ventilation, and silencing will do much to eliminate.

Rival merits of airships and aeroplanes; conflicting claims of large and small aeroplanes.

Airships and aeroplanes not rivals; the airship the instrument of sustained flight; latest designs permit twelve days' continuous cruising with day and night flying; rates for commercial loads lower by airship than aeroplane. Little practical experience of transport work by big rigid airships; estimates therefore largely theoretical. Large capital expenditure involved in airship organisation; destruction of an airship fleet unit a serious financial loss.

Aeroplane operational costs now estimated on bases of practical experience; measure of reliability similarly capable of estimate; the aeroplane easily and cheaply handled and able to land frequently and to deal with local traffic; the aeroplane more adaptable to frequency of service.

Broadly, the economic airship stage is never less than 1,000 miles; the economic aeroplane stage rarely more than 300 miles. The two should grow up together, and one will help the other.

Design expert opinion calls for an airship of not less than 3½ million cubic feet to provide an economic service, and is satisfied that ships of such size can be constructed easily and handled efficiently; the scheme now under consideration by the Government caters for a bi-weekly service to India with an eventual extension to Australia.

Present difficulties of night-flying by aeroplane; due to lack of visibility coupled with lack of inherent stability; when stability is secured night-flying completely practical for aeroplanes; in these circumstances the aeroplane will achieve speed superiority over airships on long-distance routes, but the airship will still provide greater degree of comfort.

Large aeroplanes, carrying 100 passengers, will come, but the first step is to develop the efficient small aeroplane and utilise on new services; the small aircraft more easily handled; gives a greater load percentage and the advantages of frequency of service.

Standardisation of operational methods on every route impossible. Cross-Channel air services require high speed to compete with established transport, frequent services, absolute regularity in spite of adverse weather conditions; on a route such as Cairo-Baghdad these considerations do not apply. Each route must be taken on its own merits, bearing, however, in mind the economic value of standardisation on connecting routes; reduction in fleets and stores which would result from standardisation on routes now radiating from London, but unsuitability of employing the same type of equipment between Cairo and India.

Three types of aircraft called for by the Air Ministry: one for short-distance work in civilised countries; another for Eastern routes; the third for long-distance, non-stop flights.

Desirability of transport experts taking part in development of air transport.

New trade routes available to air transport; utilising the shape of the globe; the North-East passage to the Pacific; weather conditions in the Arctic Circle probably more friendly to air transport than those of London; cold but fine and eminently suited to the airship; even in future a possible practicability for aeroplanes.

Conclusion. Air transport safe and reasonably reliable. Costs still high; capable of reduction. Government assistance necessary in early stages. Air transport an Empire necessity. The necessity of educating the public to utilise, support, and demand the development of British air transport. The nation's debt of gratitude to pioneers who have placed British air transport in the premier position it holds.

7. Mr. A. T. Wall, O.B.E.—*A Broad Outlook on the Future of Transport and its Past Obligations to Science. Transport by Sea.*

Use of iron and steel. Armour. James Watt and steam propulsion. Turbines and internal-combustion engines. William Froude and resistance of ships. Shipyard machines. Early mathematical work on stability. Loss of H.M.S. 'Captain.' Magnetic and gyroscopic compass. Gyroscopic gun control.

Problems awaiting solution. Factor of ignorance. Need for research work. Difficulties to be overcome. Early possibilities. High elastic-limit mild steel. Electric welding. Improved metals.

Necessity for training. Importance of experience and practice. Antagonism between theory and practice. Need for co-ordination. Engineering becoming more complicated. Level of engineers' knowledge must be raised. Need for the scientific practical man. Value of pure theory. Science applied to experience. Absolute and comparative science. Science becomes practice. Finance, practice, and science.

In the afternoon Messrs. Cammell Laird's Shipyard, Birkenhead, was visited.

Monday, September 17.

8. Mr. J. Parry.—*Conservation and Control of Water Resources.*

(1) The need long felt for more effective control over the appropriation and distribution of our sources of water supply.

(2) The various sources to be dealt with: (*a*) Upland catchment areas; (*b*) direct river supplies; (*c*) underground supplies.

(3) Claimants for upland areas: (*a*) Town supplies; (*b*) rural supplies; (*c*) power schemes.

(4) Principles on which allocation of sources should be based.

(5) Distinction to be drawn between a survey and administration.

(6) Recommendations of Water Power Resources Committee. Objections to same. Alternatives.

(7) Desirability of inquiry by a Royal Commission. Questions requiring investigation.

9. Capt. J. A. Slee, C.B.E.—*Recent Developments in the Application of Wireless Telegraphy to the Mercantile Marine.*

The chief improvements which have been effected during the last eighteen months are as follows:—

(1) The introduction of high-speed automatic transmitters and receivers in the largest transatlantic ships. Speeds up to ninety words per minute can be used at distances up to about 700 miles.

(2) Improvements in protective tuning in receivers for continuous-wave telegraphy, avoiding almost all of the serious interference which was experienced due to the larger number of powerful continuous-wave stations now in use.

(3) The use of directed 'beams' of very short wave-length, which can be employed to inform ships of the bearings of the transmitter. This form of apparatus is entirely independent of the ordinary wireless outfit, and the receiver can be operated by the navigator.

(4) Steady progress in the accuracy of direction-finders fitted on board ship.

(5) Experimental work on the subject of extending to ships the facilities

of the land-telephone service. In England a modest beginning has been made, and in the United States much more ambitious results are being attempted.

10. Mr. W. Barnes.—*The Development of the Single Bucket Excavator* (with cinematograph illustrations of machines at work).

Early history illustrating an old under-water excavator of the sixteenth century. The first steam navvy, the Otis, in 1839. The Dunbar and Ruston in 1875. Mechanical features involved in these and the latest 'power shovels.' The first crane or full-circle navvy in 1887. The latest machine of this type on caterpillar tracks, illustrating recent striking developments. The Dragline excavator; its fundamental principles and uses. The latest Dragline, weighing 300 tons, and destined for India to do the work of approximately 1,000 coolies. Interesting applications of excavators to various classes of work. Their economic value in developing a country.

11. Mr. J. B. C. Kershaw.—*Smoke Abatement and the New Bill.*

The author first summarised the provisions of the Bill introduced into the House of Lords this year, with the object of consolidating and strengthening the various laws and enactments relating to the excessive emission of black smoke by works and factories of the United Kingdom, and then discussed the educational and voluntary methods which have been found most useful in combating the evils arising from industrial smoke.

The work of the 'Verein für Rauchbekampfung,' of Hamburg, was described, and figures showing the remarkable development of this voluntary organisation of steam-users were given.

The paper closed with a plea for the wider application in this country of similar voluntary methods of improving the efficiency of combustion, and for minimising the evils resulting from black smoke.

12. Dr. Hubert Mawson.—*Analytical and Experimental Investigations relating to Water Turbines.*

The first part of the paper deals with an analytical method of predicting the form of the characteristic laws for a water turbine, the experimental verification of these and their application to the design, and the prediction of the laws for similar turbines.

The second part gives analytical methods of estimating the rise of pressure in the pipe lines, and the rise of speed of the turbine when the load is removed and the motion of the controlling vanes is known. The results are checked by experiments in which use is made of a timing device consisting of a vibrating tuning-fork and pendulum-controlled pens to obtain the variation in the above quantities after the load is removed.

13. Mr. W. J. Kearton.—*The Strength of Forked Connecting Rods.*

There are two distinct types of forked connecting rod; one has the gudgeon pin attached to the crosshead, and the other has the gudgeon pin integral with the fork. Both are statically indeterminate structures, and the formulæ given in text-books for calculating the stresses in the fork are based on erroneous assumptions. The paper shows how the stresses in a forked connecting rod in which the gudgeon pin is integral with the fork may be calculated. The stresses for an actual rod are worked out in full, and an account is given of experiments which verify the calculated results.

In the afternoon the Helsby Works of the British Insulated and Helsby Cable Company were visited.

Tuesday, September 18.

14. Joint Discussion with Section L on *The Teaching of Dynamics.* Opened by Sir J. B. Henderson, K.B.E.

15. Mr. T. M. Newall.—*Description of Work in progress at Gladstone Dock.*

16. Report of Committee on *Complex Stress Distributions in Engineering Materials.* (See p. 345.)

17. Prof. E. G. Coker, F.R.S.—*A Comparison of Experimental Methods for obtaining the Stress at a Point in a Plate by Optical and Mechanical Methods.*

In the afternoon the new Gladstone Dock Works of the Mersey Docks and Harbour Board were visited.

Wednesday, September 19.

18. Prof. E. W. Marchant and Mr. T. H. Turney.—*On a Method of Improving the Shape of the Voltage Wave of Alternators by External Means.*

This paper describes an arrangement of shunts which can be used, especially on three-phase generators, when it is necessary to correct the wave shape of an alternator without rebuilding it. The essential features of the device are, first, shunts adjusted to have zero reactance for the ripples which it is desired to get rid of, and, second, a limiting inductance arranged in the neutral of the three-phase supply, through which the shunt current produced by the ripple flows. The shunt circuit consists of an air-core inductance and condensers arranged in series, the condensers being of fairly large capacity in order to reduce the voltage on them as much as possible. The limiting reactance in the neutral may be an iron-core inductance. Curves are shown in which the method has been used on four machines with bad wave shapes. A demonstration of the device was given at the meeting.

19. Prof. E. W. Marchant.—*On the Currents Flowing between the Earth Neutral of an Alternator and the Earth Sheath of the Cable System.*

In some modern power-stations it is found that there is a considerable current flowing through the earth lead from the neutral point of the alternator, even when only one machine is earthed. It has been found that the current so flowing is of three times (or a multiple of three times) the fundamental frequency. This current is due to a ripple in the pressure curve of the alternator between each phase and the neutral point. If such a ripple exists, a current corresponding with it will flow from each core of the three-phase cable network to the sheath, and the currents so passing, if they are of three times (or a multiple of three times) the fundamental frequency, add up and do not cancel each other, as do the three-phase capacity currents of fundamental frequency. Oscillograms of currents observed in the earth circuits of the neutrals of alternators in two large power-stations are given in the paper.

20. Mr. F. H. Clough, C.B.E.—*Electric Ship Propulsion.*

Consideration of power and speed of screws. Propelling machinery—reciprocating steam engines, steam turbines, Diesel engines. Reasons for adopting steam turbines; need for speed-reduction mechanism. Single and double reduction gearing. Tooth pressures, lubrication, increased stresses due to acceleration and faulty alignment.

Electric transmission of power—alternating and direct current. Comparison of size and weights of electric motors and gear wheels. Description of operation of electric generators and motors—magnetic forces; revolving fields. Model showing action of forces and speed-reduction features. Control. Operation of excitation and reversing switches. Analogy with motor-car control. Model to show operation of control.

Further considerations of electric transmission—efficiency, reliability, repairs, ventilation.

Effect of electric transmission on turbines and propellers, superheated steam, reversing blades. Use of double-ratio transmission for naval vessels.

Electric transmission for Diesel-engine ships. Simplicity of starting, subdivision of engines; use of most suitable speeds.

Examples of electric ships and experience obtained with them.

21. Mr. R. L. Morrison.—*Conversion from Alternating Current to Direct Current by means of Mercury Arc Rectifiers.*

The need for a simple stationary converter that can be compared with the static transformer. Valve action of the mercury arc, with fundamental considerations underlying it. The efficiency of this form of converter, high for high-pressure D.C. conditions, thus making it eminently suited to main-line electrification. Single and polyphase rectifiers with wave forms. Special transformer enabling both halves of alternating wave to be utilised. Construction of large rectifiers. Sealing against atmosphere. Anode material and its effect on the continuous operation of the plant. Main auxiliaries—*i.e.* vacuum pump, ignition converter, &c. Sizes at present manufactured. Operation in conjunction with other types of converter. Overloading. Rectifiers specially for high-tension D.C. work, with details of those at work on the Midi line of France. Upkeep. Automatic control. Advantages and general information.

22. Dr. T. F. Wall.—*Squirrel-cage Induction Motor with High Starting Torque and Low Starting Current in the Line.*

The rotor conductors are built up as composite bars as follows: A central copper rod is surrounded by a steel sheath, and the outside of the steel sheath is copper-plated to a suitable thickness.

Each rotor conductor is thus in effect a simple form of transformer, the central copper rod being the primary winding, the steel sheath being the magnetic core, and the outer copper-plating the secondary winding.

In accordance with a well-known result in the theory of transformers, the desired result is obtained that the resistance of the rotor winding is automatically increased at starting, whilst when normally running it has the same value as for a standard type of squirrel-cage motor.

23. Prof. W. M. Thornton.—*The Mechanism of Gas Ignition.*

The two modes of spark ignition used in engineering are by disruptive discharge at high voltages and by the arc formed at the point where a circuit is broken. The former is a well-known case of ionisation by collision, but ignition does not depend solely upon the sparking voltage. There is for each inflammable mixture a certain intensity of spark necessary for ignition. Below this it is possible to pass sparks indefinitely without explosion resulting. A certain rate of production of ions is necessary, which bears little or no relation to the total energy dissipated in the spark. Ignition occurs when a critical rate of electrical activation of the combining gases is reached.

The case of the momentary arc at break is less simple. That it is mostly ionic and not thermal has been shown by a long series of observations, in which wide but regular differences between the ignitions of various gases under varied electrical conditions have been found. Recent observations on the ignition of hydrogen-air mixtures give more direct evidence of its nature. Working with alternating currents at a frequency of 250 a second and a circuit voltage of 85, the following results were regularly obtained: After breaking a 10-ampere circuit fifty times in air alone, iron poles being used, ignition of a 35 per cent. hydrogen-in-air mixture occurred with a circuit current of 0.4 ampere. After sparking freshly cleaned poles the same number of times in pure hydrogen, ignition of the 35 per cent. mixture could not be obtained with less than 6.0 amperes, giving a large thick arc. It is clear that this kind of ignition also does not depend upon the energy of the arc, which is 225 times greater in the latter case. Heating the metal in hydrogen to arc temperature destroys that which causes ignition of a subsequent explosive mixture. The direct and only chemical effect of heating iron in pure hydrogen is to reduce an oxide film or to burn out oxygen absorbed in the surface. In cooling, hydrogen may be absorbed; if so, its presence greatly retards ignition, though it facilitates electron discharge.

The evidence is that ignition does not depend upon the heat energy of the arc, nor upon the total electron discharge, which is greater since the current is so much larger, but upon the emission of that which is suppressed by the hydrogen. This can only consist of oxygen normally absorbed or absorbed by the poles in contact with air and activated by the combined effect of the thermionic discharge and strong electric field at break.

24. Prof. W. M. Thornton.—*A Safe Method of Lighting Coal Mines.*

The remarkable increase in the number of cases of nystagmus amongst coal-miners, known to be produced by imperfect lighting at the coal-face, calls for improved methods of illumination. The direction in which this has been hitherto sought is by the use of more powerful portable low-voltage electric lamps. The maximum voltage permitted at the face for signalling purposes is 25, direct or alternating, and with this unarmoured cab-tyre flexible cables may be used. An evident method of improving illumination is to use 25 volts with fixed or portable lamps. The objections raised to any such scheme are solely those of ignition, since shock is impossible at such voltages and the circuits are non-inductive.

Recent observations on the influence of frequency on the ignition of methane (fire-damp) show that by the use of much higher frequencies than those now employed for power purposes a higher factor of safety can be obtained. For example, ignition of the most explosive mixture of fire-damp in air—9.5 per cent.—by the break of a 200-volt direct-current circuit occurs at 0.5 amperes. At a frequency of 50 the least igniting current is 6.5 amperes, while at 160 it rises to 23 amperes. At a voltage of 20 and a frequency of 160 it is impossible to ignite this mixture with a clean break of less than 150 amperes. Now the currents taken by 15-watt gas-filled lamps suitable for use at the face do not exceed 1 ampere. There is, therefore, a wide margin of safety possible.

A system now being tested consists of a 160 frequency supply at 15 volts, each circuit having about twenty portable lamps. These have double filaments; the shorter of the two, connected to the battery contained in the lamp, gives 2 candle-power, by which the miner travels. The larger one carries 15 volts, by which, when connected to a plug housed in a heavy movable block, the illumination at the working face can be raised to 15 or more candle-power, the shorter filament being then cut out. In the case of failure of supply, work can be continued on the lamp battery. Each plug has a special interlocking contact by which a break of circuit is prevented until the lamp is switched over on to the portable cell. There is, therefore, no risk of open sparking. The plug-box also contains a fuse, by which, in the event of a short circuit in a lamp, that alone is cut out. The less likely case of a short circuit on the main heavily cab-tyre flexible cable which runs through all the plugs is provided for by a choking coil permanently in circuit, which limits the current to less than that which could cause ignition of a 9.5 per cent. mixture if broken in the open. The system is therefore protected by all the usual devices against excess current, but its chief safety is in the use of currents of such frequencies that, without any other change, the factor of safety is raised to a high value.

25. Mr. J. Scott-Taggart.—*Developments in Wireless Reception.*

Particulars are given of various developments in wireless reception, these being of an original character. The application of the methods to the reception of continuous waves, spark signals, and telephony is discussed, and circuits particularly suitable for the reception of broadcasting are described. Attention is given to the provision of stable and reliable dual amplification circuits for wireless reception.

SECTION H.—ANTHROPOLOGY.

(For references to the publication elsewhere of communications entered in the following list of transactions, see p. 506.)

Thursday, September 13.

1. Dr. Alb. C. Kruyt.—*The Stone-using People of Central Celebes.*

Among the immigrants who came to Celebes was a people who made large pots in stone and earthenware. In the first they kept the corpses of their dead; in the earthen pots they preserved the bones of the deceased. The name of these pots means 'vessel'; it was their intention to send back the deceased members of their family to their native home on the other side of the sea.

They erected menhirs and statues in memory of their dead. In making these objects they used bronze axes, and it is certain that they did not know iron. It is probable that they cultivated grain, for many stone mortars for pounding grain are found. If they grew rice it was planted in dry and not in irrigated fields.

The contact of this stone-using people with the aborigines whom they found in the country must have been peaceful; but they fought strenuously with another immigrating people, the Betel people, who came after them, and introduced iron. Owing to the influence of these various peoples the culture of the present inhabitants of the Toradjas is of a very composite character.

2. Mr. W. E. Armstrong.—*The Inhabitants of Rossel Island.*

Rossel Island is the most easterly island of the Louisiade Archipelago, which lies to the east of New Guinea. Its culture differs fundamentally from that of the Massim peoples who occupy all the islands between it and the mainland. The religion is elaborate. There are numerous gods, one of whom is supreme; most of these partake of the nature of snakes and human beings. Connected with these gods are numerous places rigidly taboo. Cannibalism of a peculiar kind occurred until recently, the death of a chief necessitating the ceremonial consumption of one or more persons. Polygamy is common, and there is a supplementary form of pseudo-marriage, according to which one woman may be owned for sexual purposes by a number of men; she is also let out on hire on festive occasions. A remarkable currency occurs, all but a few low values of which are believed to have been made in the beginning by God. These coins are so denominated as to simplify the calculation of interest-charges.

3. Mr. E. Torday.—*Native Traders in Central Africa.*

Commerce has played an important *rôle* in the opening of Africa; it might be said that without its stimulating influence it would probably still be rightly called the 'Dark Continent.' To the white men and Arabs we owe a great debt for our knowledge of its ethnology, and there are good reasons to believe that the native traders, who long before them travelled widely over the continent, have considerably influenced its history and the customs of its various tribes.

Usually trade is limited to the village and the tribe and its immediate neighbours, but there are to-day people, like the Bamputu, the Badjokwe, and the Bateke, who embark on long expeditions, and spread their activity over hundreds or thousands of miles. This we know as historical fact of the Bateke, whose very name means 'those who sell'; the Bushongo traditions of expeditions, and circumstantial evidence, such as the rapidity with which useful plants, insect pests, and diseases have overrun the continent, or, again, the finding of implements and currency, whose source can be traced to very distant tribes, show that before the advent of the white man there was a certain amount of commercial communication spread over large areas. Some of the old trade routes are known, but it would be of the greatest interest to trace others; they might serve to explain many problems which have baffled ethnologists.

4. Mr. W. Bonser.—*The Magic Practices of the Finns in Relation to those of other Arctic Peoples.*

Primitive Arctic culture survived owing to its isolation, but was modified and complicated in Finland owing to its contact there with Christianity. The Shaman derived his powers from the supreme god, who was himself, therefore, the greatest sorcerer. The powers, together with the familiars, were hereditary. The Lapps, being the original inhabitants, were reputed greater magicians than the Finns. The sorcerer was baptised, usually by his mother, both for initiatory and protective purposes. It was usual to remove the clothing for practising magic, but to put on extra clothing as a protection against the magic of others. The efficacy of magic was increased by the neighbourhood of rocks and stones, especially those of a variegated nature. The dead Shaman was more potent than the living one: wherefore the underworld was a storehouse of Shamanic wisdom.

5. Prof. C. A. Brodie Brockwell.—*The Evolution of Arithmetic as Exemplified in Plato's Millennium Cycle, erroneously styled his Geometrical Number.*

Ancient statements show that pre-Christian Mediterraneans used arithmetical processes without analogy in modern arithmetic. Western treatises on arithmetic of the fifteenth and sixteenth centuries show that our arithmetic tables had not been invented at the beginning of the sixteenth century. Modern scholars, through ignorance of these things, have misinterpreted almost all ancient numbers, have obscured the meaning of most ancient time-determinations, have failed to discriminate between cause and effect, and so to unfold the evolution of ancient Mediterranean social and cultural institutions.

Plato's dynastic abacus is a typical exemplification of Mediterranean arithmetic worked by processes belonging to different stages of social evolution. The apparent contradictions of ancient dates and longevity numbers, &c., have arisen from the custom of transmitting one and the same date, or number, in the styles of different stages of arithmetical evolution.

6. Mrs. Scoresby Routledge. — *Mangarevan Folk-lore: Some Results of an Expedition to the Austral Islands and Mangareva.*

While there exist numerous megalithic remains in the Austral Islands, and interesting *maraes* on even the neighbouring island of Temoe, there have never been on Mangareva any stoneworks of importance.

Mangareva is, however, rich in folk-lore, and is possibly unique among Pacific islands in possessing written history in the native tongue. This dates from about the middle of last century, the work being instigated by the early R.C. missionaries; it appears to be a genuine record of events for about the two hundred years preceding, and comprises yet earlier legends. Interesting additions to the written histories are still recounted verbally.

A large number of folk-tales, more purely domestic or mythical in character, have been transmitted orally and are well known.

The number of songs is enormous. A large collection has been made in writing by a Mangarevan recently deceased. They refer frequently to the folk-tales, but many cannot be explained. There are interesting points of contact with the Easter Island script.

The general knowledge of folk-lore has been kept alive through dances or dramatic representations, when the best-known stories are depicted with stage properties and accompanied by songs.

7. Capt. A. G. Pape.—*Is there a New Race Type?*

Friday, September 14.

8. Prof. E. Ekwall.—*The Early History of Lancashire in the Light of Place-names.*

Introductory remarks : The chief subject is the history of Lancashire, but by way of illustration some remarks will be offered on adjoining counties—the value and limitations of place-names as evidence. Place-names should be used in connection with other evidence (archæological, historical, &c.).

1. Britons in Lancashire.

There are no unequivocal traces in place-names of a pre-British population. Notes on British place-names in England generally. Various types of names and their distribution. Place-names point to the survival of a fairly considerable British element in parts of Lancashire, and of a strong British element in parts of Cumberland.

2. Anglians in Lancashire.

Time of invasion. Districts first colonised. Menians and Northumbrians in Lancashire.

3. Scandinavians in Lancashire.

Remarks on the interpretation of the evidence. Distribution of Scandinavian names. Danish colonies. Norse colonies.

4. Irish-Gaelic elements in the Lancashire place-nomenclature. These are bound up with Norse elements and need not indicate a considerable Irish-Gaelic immigration.

9. Joint Discussion with Section E on *The Place of Man and his Environment in the Study of the Social Sciences.* (See p. 458.)

10. Prof. H. J. Fleure.—*The Prehistory of Wales.*

Archæology in Wales has special difficulties of dating finds. Flint is absent save on the beaches; metal apparently was rare in prehistoric times; so, apart from polished stonework, Wales is at a disadvantage. Probably in earlier times, as now, agriculture was subordinate to stock-raising following hunting, so settlement was less developed in Wales, and ancient pottery is rare. As pottery is most valuable for dating, workers in Wales have a special difficulty. Again, for the last 2,000 years, Wales has been a centre of preservation of old phases of life; probably this characteristic has marked it from still earlier times. Finds which are related in type to those of known periods elsewhere may thus be later in Wales. On the other hand, Wales shows interesting developments in megalithic monuments and in polished stonework.

A very short sketch of the phases of human activity in Wales, so far as they can be inferred, through prehistoric time was attempted.

11. Dr. R. E. Mortimer Wheeler.—*Hill-Forts in North Wales: Their Historical Background.*

Several contour-camps or 'hill-forts' which have been partially excavated in North Wales are of various types, but have yielded homogeneous results indicating occupation during (though apparently not before) the Roman period. Certain features suggest that these hill-forts may in part be a result of new social or political tendencies, which, during the first centuries B.C. and A.D., found expression in the great native oppida of Gaul and southern Britain. If, as the evidence suggests, this series of Welsh hill-forts was not built before the end of the first century A.D., the gradual north-westward diffusion of these new tendencies is logical both in time and in space. The survival of native hill-towns or 'hill-forts' in Wales throughout the Roman occupation is explained by the very incomplete Romanisation of this rugged frontier district, and it is even possible that under the later Empire, when the coasts were increasingly harassed by Irish and other invaders, the building or rebuilding of strongly fortified native settlements such as Dinorben may incidentally have assisted the Roman frontier organisation in the defence of the coast-line.

21. Mr. I. T. HUGHES.—*Field-Notes on the Earthworks of North Cardiganshire.*

This is part of a survey scheme, based on principles laid down by the Board of Celtic Studies, to interpret the earthworks of Wales by means of large-scale plans and contours at 25 feet intervals, thus supplementing any omissions of the O.S. sheets. The 28 hill-top camps between the River Dyfi and the Upper Teifi-Wyre line form one of the well-defined groups of Wales. Different types occur here, all lying within the limit of present-day cultivation. They well show their landward and seaward strategic value, and are found to be definitely related to important valley routes, to metalliferous areas, and to ridgeways, which branch from the old hillside road from the Dovey Estuary to Lledrod. *Gwyddel* place-names, together with flint and bronze implements of Irish design, are associated with this region, the former being noticed about the 'Dinas,' and near the best landing-places. The 'Dinas' is larger than the 'Caer' or 'Castell,' and seems to stand in some relation to ancient territorial divisions. So far, these camps may be considered as first or second century Brythonic constructions, on the forest edge or forest clearings, wherein some military chief lorded over the cultivable lands—conditions closely analogous to those of the Achæans of Pre-Classical Greece.

Monday, September 17.

13. Presidential Address by Prof. P. E. NEWBERRY, O.B.E., on *Egypt as a Field for Anthropological Research.* (See p. 175.)

14. Capt. L. W. G. MALCOLM.—*Plurality of Souls in Egypt and in the Western Parts of Africa.*

15. Dr. J. SAMPSON.—*The Origin and Early Migrations of the Gypsies.*

In default of historical data the origin of the Gypsies must be sought in their language. An analysis of the recently collected specimens of Syrian Romani, and a comparison of this dialect with those of Armenia and Europe, throw new light upon the speech of the original Gypsies and their wanderings. Romani resolves itself into two main branches, which may be termed respectively the speech of the *Ben* and *Phen* Gypsies. As neither dialect is derivable from the other, both must have originated in the Indian tongue spoken by the Gypsies who entered Persia about the ninth century. On the separation of the two bands, about a century later, the *Ben* Gypsies travelling southwards to Syria became the ancestors of the present Nawar of Palestine, the Karaci of Persia and Transcaucasia, and the Helebis of Egypt; while the *Phen* Gypsies, after settling for a time in Armenia, migrated westwards through Kurdistan and Byzantine Greece, reaching the Peloponnesus before the end of eleventh century, whence (*c.* 1440) they overspread Europe.

16. Mr. T. H. WALKER.—*The Races of the Middle East.*

17. Discussion on *The Origin of Domesticated Animals and Plants.* Opened by Prof. PERCY E. NEWBERRY.

During the past twenty years many important discoveries have been made relating to the early history of cultivated plants and domesticated animals, but botanists and zoologists have paid little attention to these subjects. Anthropologists need their help and co-operation. That the cultivation of a plant began in the country where that plant was found growing wild is obvious, yet how little is really known about the native habitats of many of our common cultivated plants. Where, for example, was the original home of flax, or of the date-palm, or of the vine? A subject of great interest to the anthropologist would be the study of weeds. Schweinfurth, when in Central Africa, noted the preponderating Indian origin of the common weeds of the wide stretch of country between Tondy and the Dyoor, and he pointed out that a better acquaintance with the geographical facts connected with them would probably be as trustworthy an indication of the various migrations of an uncivilised people who have no history as either their dialect or their physical development. Cornfield weeds are most important evidence for the original home of wheat and barley. There are many questions relating to domesticated animals that have as yet received no satisfactory answer. From whence came the domesticated sheep and goat? From whence the ass, the horse, and the camel? Notwithstanding the work of Rolleston and others we know hardly anything about the origin of the domesticated breeds of swine. And where was the ox first brought under domestication? These are some of the many questions that can only be answered satisfactorily by botanists and zoologists working in co-operation with anthropologists; the answers to them must necessarily throw considerable light on the early migrations of man.

Tuesday, September 18.

18. Prof. W. J. Sollas.—*Miocene Man.*

The late Mr. A. Westlake, of Fordingbridge, Hants, spent six months in 1905 digging out so-called eoliths from the Upper Miocene gravels of Aurignac. He amassed a magnificent collection of some 4,000 or 5,000 specimens.

During his life he entrusted a number of these to the author for description, who has subsequently had renewed facilities for continuing his investigation.

The universal absence of incipient cones on the broken faces of the flints excludes any appeal to the action of torrents in explanation of their form, which resembles in a remarkable manner that of instruments made by design.

Movements of the soil, accomplished under pressure, have in many cases produced such remarkable simulacra of genuine implements that considerable hesitation may well be felt before arriving at conclusions based solely on the form of supposed implements.

In the present state of our knowledge it cannot be understood how the eoliths in question can have been formed by natural agencies. They seem to bear cogent evidence of design.

19. Mr. Stanley Casson.—*The North Ægean Coast in the Bronze Age.*

Little or nothing is yet known of this region in the periods preceding the Early Iron Age. In view of the probability of future excavation and research all available scraps of evidence are of interest. In the western half of this area, from the Haliacmon to the Strymon, a homogeneous culture with incised pottery belonging to the full Bronze Age has been revealed, partly by chance finds on tumuli and partly by the excavation of a stratified site near the Vardar valley. With the remains of this culture must be associated traces of Mycenæan culture from the south which are found along the coast, and Mycenæan weapons imported into the interior.

From the Strymon to the Maritsa are numerous traces of the Chalkolithic Moldavian culture, with painted pottery, but neither the Macedonian Bronze Age nor the Mycenæan period seems to be represented. East of the Maritsa neither the Moldavian nor the Macedonian cultures are represented, as far as is known.

20. Mr. Stanley Casson.—*Prehistoric Sites in the Dardanelles and Bosporus.*

The recent identification of two prehistoric sites of the Neolithic or early Chalkolithic period, one at the western extremity of the Gallipoli peninsula, the other opposite Constantinople at Kadikeui, has made it possible to establish the extent of habitation and the interrelation of sites in the Straits. Troy I. and its companion sites in the Troad thus acquire a greater importance than has hitherto been attributed to them. The shores of the Straits except at these points seem to have been but sparsely inhabited.

21. Baron F. Nopsca.—*House-building and House Implements in Northern Albania.*

22. Miss E. H. McLean.—*Survey Maps of Humberstone and Scraptoft Lordships.*

23. Mr. E. Torday.—*Hungarian Folk-Music.* (With instrumental and vocal illustrations.)

The study of folk-music, and particularly of folk-songs, is a perfect treasure-mine for the ethnologist, and yet, as far as civilised people are concerned, it has not received sufficient attention. Take the case of the Magyars. Of their early culture we have none but foreign records, and many of their customs, especially those connected with their religious rites, must have escaped the observation of these chroniclers. In old songs, the few that have survived, we find, however, indications of practices they knew nothing of. None of the chroniclers speaks of human sacrifices, yet the various songs connected with the festivities of St. Ivan show us that they existed, and were made to the fire-god; other songs show us that the usage of sprinkling on Easter Monday is a survival of the drowning of human beings in honour of the water-god.

From the point of view of antiquity the songs of St. Ivan are the oldest documents we possess; they are characteristic of the pagan period when songs brought from the old home were still in vogue. Then followed the advent of Christianity, and with it the influence of the Church. The third stage was reached with the arrival of the Gypsies, who soon, in the sixteenth century, became the executants of the popular airs. The idea, originated by Liszt, that Gypsies were the creators of the modern form of Hungarian music has been duly discredited; that it is a fallacy can be proved by the various versions of the same tune as produced in Magyar, Roumanian, or Ruthenian regions, and by giving the form in which the Gypsies play it. But it would be equally unreasonable to say that the Gypsies, who for centuries were its interpreters, have not left their mark on Hungarian songs; by comparing music of the three periods we find that, though they have brought no new elements into it, they have been responsible for the emphasising of those characteristics which distinguish Magyar music from that of other nations.

24. Prof. J. Sebelien.—*On the Composition of Early Bronzes.*

25. Sir Arthur J. Evans.—*Crete as a Stepping-Stone of Early Culture: some new lights.*

The geographical position of Crete, lying almost midway between Europe, Asia, and Africa, marked it as the point where the primitive culture of our Continent was first affected by that of the older civilisations of Egypt and the East. Its original affinities were rather with Anatolia—answering to late geological conditions. Neolithic affinities point that way. New light is thrown on this by discovery of a Late Neolithic house at Knossos, showing fixed hearths. The rise of 'Minoan' Culture in Early Metal Age coincides with cultural impact from the Nile Valley and the possibility of actual immigration of members of the Old Race in Egypt at the time of the dynastic conquest must be considered. Evidence of continuous relations exists throughout Early and Middle Kingdom. Knossos is a principal goal. Traces of an important transit route thither across the island from havens near Phæstos on the Libyan Sea have been found. Middle Minoan and Ægean influences extend to Malta. Minoans were intermediaries in trade in vitreous beads with the Iberic West and Early Bronze Age Britain. New discoveries illustrate an intensive influence from the Nile Valley and the opposite Libyan Coast at the opening of the Late Minoan Age (16th century B.C.), as is indicated by wall paintings of Soudan Monkeys and Negro mercenaries found at Knossos. From the beginning of the Age of Palaces in Crete (MML., c. 2200 B.C.) a growing influence is perceptible from the Syrian and Babylonian side. Cylinders found of Hammurabi's time. Cult customs and costumes were affected. Horses and chariots were introduced. Cretan civilisation became cosmopolitan. The diffusion of Minoan elements in Central Ægean islands was followed by widespread conquest in Mainland Greece. Later a 'Mycenæan' culture fusion of Minoan and other Ægean elements with native 'Helladic' took place. Colonial expansion from Sicily to Cyprus. The Adriatic amber trade connected with Minoan survivals at Glasinatz, &c. There was a great set-back of civilisation in Crete and Greece owing to the Achæan and Dorian invasions, but there was a return-wave later from the Ionian side, where Minoan tradition had a strong hold.

Wednesday, September 19.

26. Mr. de Barri Crawshay.—*An Outline of the Life and Work of Benjamin Harrison, of Ightham, Kent, including an Account of the Original Discovery of Eoliths.*

Born December 14, 1837; at fifteen studied the deposition of gravel high above present river levels; discovered Neolithic Dwelling Sites at Rose Wood in 1856; Palæoliths at 300 O.D. and 500 O.D. in 1863.

In 1866 he observed ochreous flint drift upon the surface of the Chalk Plateau at 520 O.D. which contained Eoliths and Palæoliths.

In 1871 he found Palæoliths east of Oldbury, which proved to be related to the Rock Shelters under which he excavated in 1891.

In 1889 and 1891 Prestwich introduced Harrison's discoveries at Geological Society and Anthropological Institute.

In 1894 he proved the drift beds of the Plateau near South Ash, finding Eoliths *in situ*, exhibiting them at British Association Meetings, Edinburgh 1892, Oxford 1894; Royal Society 1895, and many times since.

In 1895 the Geological Society conferred a moiety of the Lyell Fund upon him.

He gave great numbers of specimens away; afterwards countless Museums and private individuals acquired collections.

He lived for his home and science, dying on September 30, 1921, in full possession of his faculties to the last.

27. Mr. de Barri Crawshay.—*Eoliths from the South Ash (Kent) Pit*, 1921.

This was sunk upon the position where Benjamin Harrison in 1866 first observed ochreous flint drift which contained Eoliths.

A seam of flint gravel at 2 feet deep, resting at 4 feet deep on clays and sands, contained Eoliths; there was ample evidence of ice movement by the festooning of the gravel into the overlying loamy clay; numerous stones standing on their sharper ends, some being striated.

Separated from the above seam by horizontally bedded clays is a second seam of larger flint gravel, also containing Eoliths, and presenting the same characters *except* the festooning, the largest stones invariably standing on their ends.

At 7 feet 6 inches clean clay appeared mixed with a few flints.

Tertiary Pebbles were very rare; no Palæolithic implement was found; and the chalk was not reached by probing a couple of feet deeper.

28. Mr. Roger Thomas and Mr. Evan Dudlyke.—*A Prehistoric Flint Factory at Aberystwyth.*

Situation :—

Just south of Aberystwyth at the foot of Pen Dinas hill, and above the shore and rivers Ystwyth and Rheidol.

Soil Formation :—

(*d*) Upper 18 inches disturbed by cultivation, and contained flint chips, clay-pipe stems, modern pottery, and lead; mixed together.

(*c*) Sterile loam layer 24 inches thick, near the hill.

(*b*) Layer with flints immediately upon :—

(*a*) Boulder clay.

Finds :—

Numerous microliths, mainly acute triangular, also cores, scrapers, flakes, knife-blades and limpet scoops. Flint derived from the sea-beach on which it has accumulated from boulder clay brought down the Irish Sea. The finds from this station may be compared with those from numerous others, especially those of Western Europe, *e.g.* Svaerdborg and Mullerup. It is suggested that the microliths are related in type to those usually allowed to be of late Tardenoisian age, though in date we cannot decide whether they may not be later. Animal remains, which would help in dating, are absent.

SECTION I.—PHYSIOLOGY.

(For references to the publication elsewhere of communications entered in the following list of transactions, see p. 506.)

Thursday, September 13.

1. Prof. H. E. Roaf.—*The Analytical Mechanism of the Cochlea.*

2. Mr. T. C. Angus.—*A Recording Katathermometer.*

This instrument is an adaptation of Prof. Leonard Hill's well-known katathermometer by which the ventilation conditions of buildings can be measured.

The *cooling-power of the air*, depending on its temperature and movement, is found by the rate of cooling of a large bulb thermometer of known thermal capacity and dimensions.

In this instrument the lengths of a succession of cooling periods are recorded side by side on a moving paper, and a curve is thus drawn whose height at any time gives the cooling power of the air in millicalories per sq. centimetre per second.

3. Presidential Address by Prof. G. H. F. Nuttall, F.R.S., on *Symbiosis in Animals and Plants.* (See p. 197.)

4. Prof. H. Zwaardemaker.—*Bio-radioactivity and Humoral Environment.*

(1) Normal bio-radioactivity depends on the normal potassium content of the cells. (2) An important part of this content is the potassium in the superficial layers of cells. (3) The ionic balance is itself a condition. A heart perfused with Noyons' glucose solution shows the balance at its lowest level. When the balance has been brought to a higher or lower level than the normal, there is, respectively, an increase or decrease of radioactivity. (4) The sensitivity of the tissues to radioactivity is regulated by the blood hormones, so that a normal activity is guaranteed under very different conditions.

5. Prof. R. Magnus.—*Carbon Dioxide and Adrenaline as Regulating Factors for the Musculature of the Bronchi and Pulmonary Vessels.*

Experiments by Löhr and De Lind van Wijngaarden on surviving perfused cat's lungs in the author's laboratory have showed that the bronchio-spasm produced by defibrinated or hirudinised blood, &c., is relaxed by the addition of from 1.4 to 30 per cent. of CO_2 to the air respired. Carbon dioxide in concentrations from 1.4 per cent. upwards causes in most cases constriction of the lung vessels, but when adrenaline is present in the blood in amounts over 1 per milliard the effect of CO_2 is to cause dilatation. Alteration in the concentrations of oxygen and nitrogen in the blood are without influence on the bronchial or vascular tone.

It is concluded, therefore, that carbon dioxide in physiological concentrations helps to keep the air-way patent, and, in presence of physiological amounts of adrenaline, to facilitate the pulmonary circulation. An increased alveolar CO_2 tension may, under pathological conditions, also have some important regulating influence.

6. Prof. J. M. Beattie.—*The Action of Finely-divided Particles of Slate, &c., on Toxins.*

Friday, September 14.

7. Mr. J. R. Bruce and Prof. W. Ramsden.—*Irreversible Coagulation of Albumin at Free Surfaces.*

8. Mr. J. Brooks and Prof. W. Ramsden.—*Factors Determining which of two Liquids forms the Droplets of an Emulsion.*

9. Prof. H. E. Roaf.—*The Oxygen Content of Methæmoglobin.*

10. Dr. S. Monckton Copeman, F.R.S.—*Diet and Cancer.*

This investigation was undertaken with the object of determining the ultimate effect, in the adult, of a dietary deficient in the fat-soluble A. vitamin.

Work on the normal individual having shown that the requirements of the human adult are extremely small, patients suffering from cancer were placed on a diet from which foodstuffs of animal origin containing the fat-soluble vitamin were excluded, in the hope of obtaining some differential effect on the growing tumour.

Treatment on these lines, in suitable cases, has been found capable of affording increased expectation of life, together with freedom from pain, which may be so complete as to obviate entirely previous need for anodynes.

11. Joint Discussion with Section B on *The Physical Chemistry of Membranes in Relation to Physiological Science.*

12. Dr. S. C. Brooks.—*The Electrolytic Conductance of Micro-Organisms.*

Monday, September 17.

13. Dr. W. W. Waller.—*Red Blood Corpuscles under the Microscope.*

Fallacy due to glass.—Alkali causes a characteristic series of microscopic changes in the corpuscles. Glass slides act as alkaline surfaces. Once this fallacy is recognised and eliminated, it is seen that the corpuscles keep their shape in a wide range of salt concentrations (in the absence of serum).

Corpuscular Membrane.—Acid reverses the normal negative charge, but we cannot yet explain the ionic interchanges in terms of Membrane Equilibrium. Hæmolysis by alkali shows marked contrast microscopically with acid hæmolysis, and in the latter case the corpuscles remain visible. The normal shape may be explained teleologically as enabling the corpuscle to change volume without alteration of surface area, as does the box of an aneroid barometer.

14. Prof. C. Lovatt Evans.—*Experiments on the Contraction of Plain Muscle.*

Experiments on plain muscle from various sources have shown that the oxygen usage is practically independent of the state of tonus of the muscle. The lactic acid content is also under all circumstances considerably lower than that of striated muscle. The amount of glycogen in plain muscle is so small that it seems doubtful whether it can be regarded as the source of the lactic acid. Since the usual effect of increased H-ion concentration of the muscle is to cause relaxation (as experiments carried out in conjunction with Dr. S. W. F. Underhill have shown), change of reaction of the muscle appears not to provide an explanation of the phenomenon of contraction. A more feasible explanation seems to be that some potent metabolite is responsible for the contraction, that the circulation in the contracted tissue is greatly reduced, with the result that lactic acid and carbon dioxide accumulate, so causing relaxation.

15. Prof. H. E. Roaf.—*Measurement of Colour Blindness in terms of Wave-lengths.*

16. Dr. F. W. Edridge-Green, C.B.E.—*The Effect of the Blood in the Retina on Colour Equations.*

Whilst the effect of the pigment of the yellow spot has been frequently discussed, that due to the absorption by the blood in the retina has been generally overlooked. It is known that the phenomena attributed to the visual purple of the rods gradually diminish in the rod-free portion of the retina. Curves constructed by Hecht show that the rod-free portion behaves as if there were dilute visual purple in this region; this would naturally follow if the visual purple has to flow into the liquid surrounding the cones of the fovea. Numerous equations are valid both for the fovea and the peripheral portion of the retina, but if an equation be made of red λ $650\mu\mu$ (corresponding to an absorption band of hæmoglobin) and green λ $553.8\mu\mu$ to match the white light of the tungsten arc, it will be found that more green is required in the equation when the image falls on the retina 15° from the centre of the fovea, in which there are no blood-vessels.

17. Dr. M. C. Grabham.—*Dental Caries at Porto Santo.*

The object of this paper is to stimulate inquiry and to suggest that the mineral waters of the island possess some influence in resisting the development of caries. Porto Santo is a small island of the Madeira Archipelago, and its water-springs are highly mineralised with chlorides, carbonates, and sulphates, in contrast to the sweet waters of the principal island. The outstanding features of the people's diet are that the food is taken cold, no green vegetables or milk are included, and there is nothing to require grinding mastication. The people drink moderately. Consumption is frequently present, while there is no scurvy, no alimentary disorders, and no malignant disease as far as the author can ascertain. But the teeth of the district are characterised by a thin yellow line across the upper incisors, which in after-life spreads and stains the teeth generally. The stain is unknown in Madeira. The writer states with confidence that the yellow stain on the incisors is a sure indication of a sound set of teeth, and its regular occurrence is believed to furnish conclusive evidence of the permeation of the blood fluids in the interstices of the columnar enamel, and is certainly due to some constituent in the local and highly mineralised water.

18. Prof. J. J. R. Macleod, F.R.S.—Lecture on '*Insulin and its Value in Medicine*, followed by discussion.

19. Mr. J. C. Waller.—*Conditions which Determine the Direction of the Photo-Electric Current in Green Leaves.*

A. D. Waller showed that the electric effect of illumination upon the green leaves of Iris, Begonia, and Nicotiana is negativity of the illuminated part; in the green leaves of Mathiola and Tropæolum the effect is positivity of the illuminated part.

Photographic records of the two types have been obtained, using Geranium (which belongs to the Iris type) and Tropæolum.

The type of response in Geranium can be brought to resemble that of Tropæolum by keeping the plant for long periods in darkness.

The type of response of Tropæolum resembles that of Geranium under certain conditions not yet defined, but apparently connected with the previous action of sun and wind.

Tuesday, September 18.

20. Prof. J. S. Macdonald, F.R.S.—*Cycling at a Constantly Maintained Speed with Varied Brake.* (Carried out with the help of the late Mr. A. Wallis.)

These experiments form a continuation of experiments previously made by direct calorimetrical methods (*Proc. Roy. Soc.*, B., vol. 89, 1916, p. 394, &c.). They were carried out by indirect calorimetry (Douglas Bag and Haldane's Gas Analysis method) over the greater range made possible by this change. The results confirm those already reported.

21. Prof. J. S. Macdonald, F.R.S.—*Variation of Length of Step in Walking.*

Previous observations have been made on the length of step by the Webers, by Marey, and by others. These new experimental data are in agreement in showing a definite relationship between step and velocity, which is departed from notably at a certain higher range of velocity. At this maximum the step-length fails to undergo any further increase : below it the relationship in each case is approximately $\frac{s^2}{v} = k$ when k is constant in each individual case and has a definite relationship to the height of the individual in different individual cases.

22. Miss Margaret S. Macdonald and Prof. J. S. Macdonald, F.R.S.—*The Cost of Walking.*

Experiments have been made on a number of subjects—male and female, adult and young. The results are generally capable of being plotted out best in relation to v^3. Utilising the observation that $\frac{s^2}{v}$ is almost a constant, attempts have been made to analyse these results in the general form

$$k + y\left(\frac{s^2}{v}\right)^m + z\,\frac{v^3}{s}\left(\frac{s^2}{v}\right)^n$$

and a general formula developed in which it has been found possible to insert 'pendular characteristics of length of time,' involving the length of the leg and its square root. In this general formula the area of the surface of the body is inserted in unconventional fashion (*a*) as determining a cooling factor which reduces the sum due to basal metabolism and to vertical movement, and (*b*) as the measure of 'wind resistance' impeding progression and increasing the sum due to movement. This procedure follows the line suggested by the cycling experiments.

23. Dr. T. W. Wadsworth, Prof. J. S. Macdonald, F.R.S., and Mr. Geo. Macdonald.—*Variation in Character of Step.*

Observations have been made on the pressure exerted by the heel in walking, and on the time occupied by heel-pressure, also in cruder fashion on the lift of the body at each step.

24. Dr. F. A. Duffield.—*Cycling at Varied Rate and Work.*

Experiments have been made with a modified 'rope brake' ergometer, devised so as to ensure maintenance of the load as exactly as possible, and the simultaneous operation of taps on the Douglas-bag apparatus. Two subjects have been utilised. In one case the results are such as to justify the statement that each rate of movement determines a base line of metabolism upon which the value of the brake erects a directly proportional increment. In the other case the statement of results is evidently not so simple, and experiments are being continued to study the significance of the requisite modification in statement.

(Laboratory Demonstrations.)

25 Dr. F. A. Duffield.—*Demonstration of the Method used for the Measurement of the Cost of Cycling at Varied Rates and Work.*

26. Prof. Charles E. Walker and Miss F. M. Tozer.—*Cytological Demonstration.*

27. Prof. W. Ramsden.—*Adsorption Films.*

28. Mr. R. Watson Jones.—*The Metabolism of the Frog at Different Temperatures.*

Two series of six-hourly experiments were conducted with frogs, at temperatures varying between zero and 35° C., using a slightly modified Haldane-Pembrey apparatus. The CO_2 production was estimated, and found not to increase regularly with every rise of temperature, it being quite constant between 15° and 20° C. This confirms some experiments by Pembrey, where the range of temperature was 9° to 19° C.

At temperatures which are normal for the frog—0° to 20° C.—the animal has some control over its metabolism, so that the increased CO_2 output, associated with a unit rise of temperature, becomes smaller as the temperature is raised. Between 20° and 35° C. (abnormal temperatures for the frog) there is no control, and the frog behaves simply as a chemical mass, the CO_2 output increasing two or three times for every 10° C. rise of temperature.

The CO_2 production in frogs at 37° C. is—per kilogram of body weight—the same as in a resting man.

SECTION J.—PSYCHOLOGY.

(For references to the publication elsewhere of communications entered in the following list of transactions, see p. 506.)

Thursday, September 13.

1. Prof. T. H. Pear.—*Imagery and Mentality.*

Importance of realising that the thinking processes in different persons may employ different vehicles and proceed along different routes. The importance of various kinds of imagery and of imageless thought in the mental life of the individual. Abilities and disabilities accompanying the predominance in an individual of a particular kind of imagery. The influence upon psychology itself of writers whose mentality is strongly coloured by a certain imagery type.

2. Joint Discussion with Section F on *The Inter-connections between Economics and Psychology in Industry.*

3. Joint Discussion with Section G on *Vocational Tests for Engineering Trades.*

The importance of vocational tests in the selection of employees, and in the guidance of juveniles to future careers.

The general principles of selection. General intelligence, specific abilities, temperament and physique as factors in the choice of workmen. The difficulties of vocational testing in the engineering trades owing to the variety of types of work, and the different types of machine used. The four general methods of arriving at the type of vocational tests. Vocational testing in engineering on the Continent and in America. The use of group tests and individual tests in vocational selection. Analysis of engineering trades according to specific abilities and temperamental factors required. How such an analysis may be arrived at. Special abilities common to most engineering trades. A consideration on some of these abilities, with specific examples in vocational testing.

4. Dr. G. H. Miles.—Lecture on *Vocational Guidance.*

Friday, September 14.

5. Dr. G. H. Miles.—*Effects of Glare in Industrial Lighting.*

6. Mr. W. Piercy.—*The Relations of Psychology and Economics.*

7. Presidential Address by Dr. C. Burt on *The Mental Differences between Individuals.* (See p. 215.)

8. Miss Evelyn Fox.—*Mental Deficiency.*

9. Mr. H. Banister.—*The Relation of Phase and Pitch in the Localisation of Tones.*

Triode oscillators were used to produce the tones used. Each observer, who was seated by himself in the sound-proof room, noted the deviation caused in the apparent position of the sound by varying the phase difference of the two notes from 0° to 90°. Two observers reported constant amounts of deviation (90° and 45°) for all frequencies; two others gave constant deviations of 45° for all but low frequencies, for which larger deviations were obtained; other observers gave reports showing individual differences. The results are compared with those obtained by other experimenters.

10. Mr. J. H. Kenneth.—*Mental Reactions to Olfactory Stimuli.*

Experiments were made on fifty persons, with a view to investigating mental reactions to smells, particularly in order to determine the effects and associations induced by certain odorous substances.

While variations in the effect produced by a given odour are noted, a standard effect can be determined, and marked deviations from this effect can be explained in some cases. Sexual differences in the effect can be observed in the case of certain stimuli—*e.g.* musk. Metabolic causes can be ascribed to alteration of the effect in female subjects.

Associations were given in the majority of cases, and their classification presents difficulties. Certain associations are more common than others, however; individual associations cannot be foretold. Word associations to smells can be investigated and utilised in a similar manner as those to words.

Owing to the vivid and extensive character of the associations, a carefully selected series of odours can be used as an adjunct to the usual psycho-analytic methods. Conversion phenomena (particularly psycho-galvanic reactions), delayed reaction time, and other complex indicators have been noted, and some amnesiæ have been revealed. Certain odorous substances produce a greater variety of associations than others, and further experiments on a large scale are required in order to determine which osmyls are most valuable in this respect.

11. Dr. Marguerite E. Bickersteth.—*Psychograms: An Experimental Investigation of the Genesis and Development of Number Forms.*

12. Mr. Eric Farmer.—Lecture on *A Psychological Inquiry into Coal-mining.*

A new method of using the pick, in which greater attention was paid to the natural rhythm of the body, was taught to certain groups of miners by means of a metronome. The miners themselves approved of the change, and said they went home feeling less tired than when they employed the usual method; their output also increased.

Laboratory experiments were carried out to determine the relative efficiency of different methods of lighting, by measuring the number and duration of the after-sensations caused. These experiments showed that a diffused light was less painful than the ordinary type, and that although a 28 per cent. loss in intensity was caused by using an opaque cylinder, yet its efficiency, as measured by visual acuity, was equal to that of the ordinary lamp. These new lamps met with the miners' approval and are being generally adopted in the pit.

Monday, September 17.

13. Joint Discussion with Section L on *The Delinquent Child.* (See p. 497.)

14. Dr. J. Drever.—*Colour Preference: Some Experimental Results.*

15. Dr. R. H. Thouless.—*Theories of the Soul.*

Short Lectures.

16. Mr. R. C. Moore.—*Educational Tests.*

17. Mr. T. P. Tomlinson.—*A Mental Scale for School Surveys.*

18. Dr. Ll. Wynn Jones.—*Galvanometric Tests of Emotion.*

Tuesday, September 18.

19. Mr. J. A. Fraser.—*Methods of Selection and Training of Operatives for the Weaving Industry.*

(1) The relative importance of training and selection in the weaving industry.
(2) Existing methods of selection of operatives.
  (*a*) Consideration of methods used in different factories.
  (*b*) Some defects of these methods.
  (*c*) Suggested lines of improvement.
(3) Existing methods of training operatives.
  (*a*) Consideration of methods used in different factories.
  (*b*) Some defects of these methods.
  (*c*) Suggested lines of improvement.
(4) Conclusions and problems for further research.

20. Dr. S. Dawson.—*Variations in the Mental Efficiency of Children during School Hours.*

The mental efficiency of 1,200 children was tested by giving them ten-minute spells of arithmetical work at different hours during the school day, and it was found that children over nine years of age worked equally well at 9.30, 10.30, 11.30 a.m., 1.30 and 2.30 p.m.; that children below that age showed signs of a falling-off in efficiency at the last of these periods; that the effect of a small amount of practice was comparatively large; and, finally, that the best work was done in the hour at which the children had been accustomed to have their arithmetic lesson.

21. Mr. J. C. Flügel.—*Fatigue Curves with School Children.*

22. Prof. E. P. Cathcart.—*A new Type of Pursuitmeter.*

23. Miss W. Spielman.—*Vocational Tests for Dressmakers' Apprentices.*

Tests for dressmakers' apprentices are desirable both for vocational guidance and for vocational selection. An analysis was therefore made of the factors determining efficiency in this trade, and tests were devised to measure these factors. The tests are not sample needlework tests, but aim at measuring the factors directly, thus finding aptitude rather than present skill. The diagnostic value of the tests is indicated by the results obtained.

24. Mr. S. Wyatt.—*Monotony.*

25. Miss Isabel Burnett.—*An Experimental Investigation of Repetitive Work.*

(1) The problem of monotony, and the aims of this line of research. The question of individual differences.

(2) Disposition of experiment.
- (*a*) Subjects. Method of selection.
- (*b*) Nature of work, material, and conduct of experiments.
- (*c*) Distribution of rest pauses.

(3) Results obtained.
- (*a*) Comparison of intelligence ranking with output ranking, illustrated by output curves and statistics.
- (*b*) Discussion of individual output under different conditions of work. Curves obtained from each individual on each different day.
- (*c*) Capacity to do a specific task is not necessarily correlated with the

(4) General conclusions and suggested line of further research.

26. Miss Alice G. Ikin.—*An Inquiry into the Qualities Desirable in a Foreman.*

(1) (*a*) Importance of a foreman in relation to the management and workmen.
- (*b*) Inadequacy of many existing methods of selecting foremen, and comparative lack of adequate training.
- (*c*) Capacity to do a specific task is not necessarily correlated with the capacity to instruct or lead others.

(2) Methods of obtaining data concerning qualities required.
- (*a*) A comparative examination of opinions obtained from
  - (i) Managers;
  - (ii) Foremen.
- (*b*) Inquiry into and observation of foremen's duties.

(3) Need for vocational tests for and improved methods of training foremen.

SECTION K.—BOTANY.

(For references to the publication elsewhere of communications entered in the following list of transactions, see p. 507.)

Thursday, September 13.

1. Presidential Address by Mr. A. G. Tansley, F.R.S., on *The Present Position of Botany.* (See p. 240.)

2. Miss E. R. Saunders.—*Evolution and Reversion in the Rhœadales.*

Certain structural characters and relationships exhibited by the carpels in a large number of spermophyte families, notably among those included in the Rhœadales, are difficult to explain on the accepted view of the composition of the gynœcium.

There is abundant evidence that in the course of evolution of existing types of flowering plants the gynœcium has undergone varying degrees of reduction, consolidation, and sterilisation.

The manner in which these processes have taken effect can be traced in many families both of Monocotyledons and Dicotyledons, while in some few cases they can be observed actually in progress, either habitually or occasionally, under specially favourable circumstances.

As a result we are able to account for certain of these apparent morphological anomalies and to discard others as fictions, as *e.g.*, the *commissural* stigma.

3. Prof. H. H. Dixon, F.R.S., and Mr. Nigel G. Ball.—*The Extraction of Sap from Living Leaves by means of Compressed Air.*

Branches of *Tilia americana* and *Sambucus nigra* were enclosed in a strong cylinder in such a way that their cut ends protruded. Compressed air at pressures up to 20 atmospheres was admitted into the cylinder, and the liquid which exuded from the cut end of the branch was collected. This liquid was found to be completely, or almost completely, free from sugars. Experiments carried out in early and late summer gave similar results. After the leaf-cells had been made permeable by means of toluene vapour the sugar in the expressed sap amounted to about 5 per cent.

4. Prof. W. Neilson Jones.—*Regeneration of Roots and Shoots in Cuttings of Seakale.*

Experiments on the regeneration of roots and shoots in root-cuttings of seakale point to the following conclusions :—

(1) The end of the cutting nearest the original root apex shows a marked capacity for producing roots. There is only a slight tendency for this capacity to extend any distance from this end, and none of the methods tried has been successful in appreciably lengthening this distance.

(2) The end of the cutting nearest the original stem apex shows a marked capacity for shoot production. There is a strong tendency for this capacity to spread along the cutting. Various means accentuate this tendency.

(3) Short pieces of root when they regenerate always produce shoots from both ends. Any roots that are produced arise from one end only.

(4) Repeated attempts have been made to correlate this 'regeneration gradient' with a gradient of electrical potential or hydrogen-ion concentration, but without conclusive results.

5. Dr. M. C. Rayner.—*Contributions to the Biology of Mycorrhiza in the Ericaceæ.*

(1) 'Digestion' stages in roots.

The root mycorrhiza of *Calluna vulgaris* exhibits digestion stages resembling those found in the root-cells of orchids. It is believed that the relations between root-cells and fungus show seasonal periodicity, the digestion of mycelium reaching a maximum during the autumn months.

(2) Formation of mycorrhiza in 'cuttings' of Calluna.

The roots of shoot cuttings, struck under controlled conditions in sterilised sand, show infection of the same type as that exhibited by other young roots. The observations recorded by Christoph have not been confirmed.

6. Dr. F. G. Gregory.—*The Interrelation of Light and Temperature in Growth and Assimilation.*

(1) Growth of leaf-area and increase of dry weight in the greenhouse. The method of studying growth in leaf-area and the errors of the method. Growth of leaf-area during summer and winter. The compound-interest law of leaf-growth and its modifications when light intensity is comparatively low.

(2) Growth under continuous illumination at different constant temperatures. The effect of temperature on the growth of single leaves and of the total leaf-surface. The effect on the net assimilation rate. Total assimilation is dependent primarily on leaf-surface growth. Growth at supra-optimal temperatures. The law of the optimum and the law of limiting factors. Growth and assimilation conditioned by light intensity and temperature under all conditions.

(3) The energy-efficiency of plants. Variation of efficiency with temperature. The hypothesis of shifting optima and the law of limiting factors.

7. Mr. C. Hunter and Miss E. M. Rich.—*Observations on the Effect of Carbon-dioxide Accumulation on Root Elongation.*

Variations of carbon-dioxide concentration affect the rate of root elongation. Plants show different degrees of sensitiveness to this factor. Attention is here restricted to the reactions exemplified by *Vicia Faba* and *Impatiens Balsamina.* Modifications of the rate of root elongation due to the addition of carbon dioxide or the removal of accumulations of this gas can be detected by direct measurement. The occurrence and duration of minute fluctuations during root elongation are affected by this treatment. The addition of carbon dioxide disturbs the equilibrium of the condition of the root as indicated by changes of its electrical resistance.

8. Mr. F. Y. Henderson.—*The Direct Effect of Light on the Rate of Water-loss from the Mesophyll of the Leaf.*

The evidence for and against the control of transpiration by stomata is reviewed. The question of the direct action of the mesophyll cells in such control is discussed, and experimental work—using Darwin's ' slitting ' method, in which the stomata are rendered non-operative—is brought forward.

9. Mr. S. G. Jones.—*The Life-history and Cytology of Rhytisma acerinum.*

(1) The ascospores : dispersal and germination; penetration and cytology of the germ-tube.

(2) Infection experiments : formation of the conidial stroma and cytology of the conidia.

(3) The apothecial stroma : its development in the epidermis; the sexual organs, their development and cytology; cytology of the ascus.

(4) Ecology of the parasite.

Friday, September 14.

10. Dr. F. F. Blackman, F.R.S.—*Oxygen and Respiration.*

11. Prof. V. H. Blackman, F.R.S., and Mr. A. T. Legg.—*The Effect of Electric Currents on the Growth of Plants in Pot Cultures.*

Pot-culture experiments carried out during a period of six years with wheat, barley, and maize show that these plants exhibit increases of dry weight when subjected to electric currents as low as 0.1×10^{-10} amp. per plant. A percentage increase in dry weight of 27 ± 5.7 was shown by maize plants grown under glass for little more than a month. Currents of the order of 1×10^{-8} amp. per plant and higher were found to be injurious. With barley plants subjected to the discharge for various periods the greatest effect was obtained from electrification during the second month of growth, when an increase of 118 per cent. in grain and 39 per cent. in dry weight was obtained.

12. Prof. V. H. Blackman, F.R.S., Mr. A. T. Legg, and Dr. F. G. Gregory.—*The Effect of a Direct Electric Current of very Low Intensity on the Rate of Growth of the Coleoptile of Barley.*

There is a marked acceleration of growth when the coleoptile of barley is exposed to an electric discharge from a point charged positively (about 10,000 volts), and placed at such a distance above it that a current of 0.5×10^{-10} amp. passes through the coleoptile. The increased rate shows itself from the first hour onward, reaching in the third hour a *percentage* increase of 7.53 ± 1.95. After the cessation of stimulation an *after-effect,* which is greater than the direct effect, is to be observed. The after-effect shows in the fifth hour a percentage increase of 15.68 ± 2.62. The after-effect is greater with a short period of discharge than with a longer period. When the point is negatively charged the rate of growth is increased at first, but it soon falls again. An after-effect follows here also, but it is markedly less than that resulting from a positive discharge.

13. Mr. J. C. Waller.—*Photo-electric Changes in Green and White Leaves.*

Variegated geranium leaves show electrical changes in response to light similar to those of green geranium leaves partly shielded by dark paper, the chlorotic portions of the former corresponding to the shielded portions of the latter. Green petals of Hydrangea act similarly to green geranium leaves, while white petals give little response. This is further evidence that the photo-electric change is specially associated with the chlorophyll function.

The ratio between intensity of light and electrical response is as might be expected from other physiological ratios.

A leaf tested after being kept under normal conditions of sunlight is different from the same leaf after many hours in the dark.

Such comparison of photographic records of electrical response under different biological conditions is more likely to be instructive than the analysis of individual curves.

14. Dr. M. Wilson and Miss E. J. Cadman.—*The Life-history and Cytology of Reticularia lycoperdon.*

Shortly after spore germination the blepharoplast arises from the nucleus and passes to the periphery of the cell, the flagellum then developing from it. Throughout its existence the blepharoplast is connected to the nucleus by a cone-shaped structure, the 'Verbindungstück.' The swarm-cell is of the usual type. Before division the flagellum is retracted, the blepharoplast divides, and the two portions function as centrosomes, a paradesmose being formed between them. The paradesmose gives rise to the spindle; four chromosomes are present. The flagella of the daughter cells grow out from the centrosomes before cell division is completed.

Fusion normally takes place between two motile swarm-cells. The flagella are withdrawn after fusion, and the cells become rounded and gradually coalesce. Nuclear fusion follows, producing a uninucleate plasmodium. This at once becomes amœboid and engulfs and digests swarm-cells which have not undergone fusion. The nucleus of the plasmodium soon divides, eight chromosomes being present, and division continues, producing a multinucleate plasmodium.

Under natural conditions the plasmodium emerges from the wood at a number of places situated close together, the separate portions later on coalescing to form the large æthalium. Two nuclear divisions have been seen in the plasmodium just before spore formation. These are the meiotic divisions. The divisions are intranuclear and centrosomes are not present. In the first meiotic (heterotype) division four U-shaped chromosomes are present. This is rapidly followed by the second (homotype) division, in which the nuclei occur in pairs. The meiotic divisions appear to take place only in certain areas of the plasmodium, and it is in these areas that spore formation goes on. The remaining cytoplasm and associated nuclei degenerate, and the resulting material forms the incomplete internal partitions and external walls of the æthalium. The sporogenous portions become divided up by irregular lines of cleavage until uninucleate masses are produced which form the spores.

15. Prof. H. H. Dixon, F.R.S., and Mr. N. G. Ball.—*The Vascular Supply of the Haustorial Cotyledon of Lodoicea and Phœnix.*

Close beneath the absorbent surface of the haustorium there is a network of bundles. This network is connected with the embryo by bundles which traverse the petiole longitudinally. The connecting bundles contain about as much phloem as xylem. The cross-section of the phloem in the haustorium is much greater than that of the xylem. In the haustorium of Lodoicea large tubular cells pass out from the sheath of the bundles into the surrounding parenchyma; sometimes chains of these cells connect the sheaths of adjacent bundles. Sheaves of narrow tubular cells are found in the vascular parenchyma, which turn out into the adjoining parenchyma. They often penetrate as far as the outer intercellular spaces of the haustorium, and there come into contact with the semi-fluid debris of the endosperm.

16. Dr. B. MURIEL BRISTOL ROACH.—*Physiological Studies of Soil Algæ.*

The ability of sub-aerial algæ to fix atmospheric nitrogen in pure culture has been critically investigated in conjunction with Mr. H. J. Page, of the Rothamsted Chemical Department. The results give no indication of fixation, as claimed by Wann (New York), there being a final recovery of 99.28 per cent. of the nitrogen supplied to the cultures, as against 99.25 per cent. from the control flasks. On the contrary, there is some evidence of denitrification in those cultures with the most luxuriant growth. Wann's results are attributable to inaccurate methods of chemical analysis.

17. Major C. C. HURST.—*On the Chromosomes of Rosa.*

Chromosome counts of Rosa give somatic numbers 14, 21, 28, 35, 42, 56. ♀ and ♂ gametic numbers are equal, 7, 14, 21, 28 each, or unequal matroclinous, 2, 3, 4, 5 ♀ : 1 ♂. All are 7 or multiples of 7, and during meiosis the chromosomes appear in definite strings of sevens, double or single. Male sterility arises through irregular behaviour of these strings. Analyses of 395 forms confirm the hypothesis that each string of seven represents definite characters, for various associations of paired and unpaired strings correspond with Linnean species. The string scheme provides a satisfactory method of classification for this polymorphic genus, based on cytological, genetical, and taxonomic results; it also elucidates origin and evolution of species, for towards the Pole the number of strings increases, while towards the Equator it decreases.

18. Mrs. NESTA FERGUSON.—*A Preliminary Account of a Survey of the Chromosomes of the Liliaceæ.*

Variations in number, size, and form of chromosomes in the Liliaceæ are illustrated. It is proposed to measure the size of the chromosomes—both linear dimensions and volume of chromatin—in the somatic and heterotypic divisions; also to compare in various species the variation in size of the chromosomes and the forms of some of the bivalents.

The underlying idea of the research is to study the chromosome groups in relation to phylogeny, and to test how far we have here another character for determining affinities Another aspect is a comparison of the chromosome complexes of the species of one area with those of another, widely separated area, in order to ascertain whether the constitution of the nucleus offers any indication of the lines along which development has occurred.

19. Miss M. G. CAMPIN.—*A Chromosomal Survey of Certain Plant Families, with Special Reference to Genetic Relationships.*

In surveying an entire family from a chromosomal point of view certain conclusions emerge: (1) Within the family a certain 'type form' of chromosomal configuration and cytological behaviour is recognisable. (2) The actual number of chromosomes in the different genera and species is of less importance in indicating affinity than the 'type form,' although sets of series, *e.g.*, 12, 24, 36 . . . 60 in the Solanaceæ, are often observed and can be interpreted on a genetic basis. Solanaceæ and Ranunculaceæ are discussed in detail. Morphological and cytological relationships of types aberrant to these families are discussed, and the significance of polypoidy in the genealogy of species is considered.

20. Miss E. M. REES.—*Chromosomes and Sterility in Muscari.*

Investigation shows that three lines of specialisation occur within the genus Muscari. Firstly, there is a series of forms which show progressive sterilisation of the inflorescence; every grade from complete fertility to complete sterility occurs. Secondly, there are variations in chromosome number; there are diploid forms, tetraploid forms, and at least one pentaploid form. Lastly, there are, within forms with a similar chromosome number, marked variations in the relative size of the chromosomes, and also variations in the total bulk of chromatinic material.

The object of the paper is to point out the probable connection between these variations, and to show how far they may be regarded as parallel series of specialisation. The possible correlation of external form with nuclear structure is discussed.

Saturday, September 15.

Excursions took place to (*a*) Ingleborough; (*b*) the Leet Valley, Flintshire.

Monday, September 17.

21. Dr. D. H. Scott, F.R.S.—*The Early History of the Stele.*

The Lower Carboniferous flora is taken as a typical Palæozoic stage, from which to work back. The varied types of stelar structures then existing are briefly recalled, as represented among the Lycopods, Sphenophylls, Equisetales, Filicales, Pteridosperms and higher Gymnosperms. Our limited knowledge of the structure of Upper Devonian plants does not suggest that organisation was appreciably simpler at that period.

In the Early Devonian the conditions were quite different. Though advanced types already existed (*Palæopitys Milleri*), it is here that we first meet with really simple vascular plants (the Psilophytales). Of these, Asteroxylon was an undoubted Pteridophyte, comparable in its stele either with the Lycopodiaceæ or the Zygopterid ferns. In the Rhyniaceæ the slender centrarch or indeterminate stele reaches the limits of simplicity; but were these plants Pteridophytes?

Taking all the early types into consideration, there appears to be no ground for the assumption that the stele had a foliar origin. The independence of the stele is manifest throughout. It is only the more advanced forms of stele that are built up of leaf-traces, and the extreme case of the Marattiaceæ appears to be exceptional and derivative.

There is much reason to believe that a solid stele is primitive, so that the term ‘protostele’ appears justified. On the other hand, there are no sufficient grounds for the hypothesis that the typical root-structure was primitive for the stem also. In particular lines such a stage may have been passed through, but this was not the case generally.

22. Prof. W. H. Lang, F.R.S.—*The Organisation of the Plant in the Vascular Cryptogams in the Light of Fossil History and Causal Morphology.*

The main morphological problems in the organisation of land-plants can be studied in the Vascular Cryptogams, which not only have a long geological history, but are suitable for experimental work. The problem of the segmentation of the shoot composed of stem and leaves was very early stated on formal lines. Comparison of existing plants, and even those of the Lower Carboniferous Period, does not provide evidence to decide between alternative views. Putting questions of relationship aside, it seems possible to obtain further evidence along both historical and experimental lines. On the historical side the plants of the Early Devonian Period are especially interesting in this respect, since they may afford examples of nascent shoots. Normal development, and especially some deviations from it, are instructive and open to physiological study. It is only possible to mention the further problems presented by the root and the spore-bearing organs of the Vascular Cryptogams, but that of the organisation of the shoot illustrates the limitations and the hopefulness of work both on historical and causal lines. Any definite conclusion would be premature, but on the whole the increase of knowledge appears to be in favour of some segmental or phytonic construction of the shoot. In the present state of morphology the usefulness of comprehensive theories, whether evolutionary or physiological, seems doubtful.

23. Prof. J. McLean Thompson.—*Developmental Morphology and its Bearing on Systematic Physiology.*

An attempt is made to trace by developmental methods a phyletic tendency in a group of Angiosperms from its initiation. In particular, progressive sterility in the Cæsalpiniaceæ is described and is shown to constitute a dominant feature of the group. It is held that in the group petaloidy is an early declaration of advancing sterility, whose climax is total sterility and apetaly. The organisms considered are arranged in a series to illustrate the thesis that petaloidy is an index of recent sterilisation which marks a step in the decadence of an originally apetalous group. The persistent recurrence of petaloidy must lead to total sterility. It is held that if this interpretation of petaloidy in the Cæsalpiniaceæ can be accepted broadly for Angiosperms, the latter must be viewed as decadent by a growing sterility of which petaloidy indicates an early stage. The need for systematic study of the physiology of these features is emphasised.

24. Dr. E. N. Miles Thomas.—*Observations on the Seedling Anatomy of the Ebenales.*

Several new species and genera are described, including for the first time members of the family Styracaceæ.

Mr. H. Wright described the seedling anatomy of a number of species of Diospyros in 1904, and Miss W. Smith of the Sapotaceæ in 1908. They agree apparently in the prevalence of four root poles in the *diagonal* position, which is rare in other groups so far as is known. Hexarch forms, however, are also found and much variability exists, particularly in the Ebenaceæ.

The present communication establishes the existence of ' cruciform ' tetrarchy and diarchy (*Diospyros Lotus, Styrax japonica, Halesia tetraptera*), thus minimising the importance of the absence of root poles in the cotyledonary plane (Smith, ' Trans. Linn. Soc.,' 1908).

It further establishes the existence of ' alterne ' protoxylem, which is more or less resorbed at different levels (Diospyros, &c.). Thus the seedling anatomy of this very aberrant and variable Order is linked with the more usual types.

25. Dr. W. R. G. Atkins.—*Seasonal Changes in Water in Relation to the Algal Plankton.*

Sea water off Plymouth undergoes changes in hydrogen-ion concentration from pH 8.12 in winter to pH 8.24 in early summer as the algal plankton removes CO_2; these progress from surface to bottom, uniformity being reached by October.

The increase of plankton also results in a decrease of phosphate content from 0.05mgr. of P_2O_5 per litre in winter to 0.004-0.002 for surface water in early summer, the diminution being observed at greater depths later. It appears probable that phosphate is the factor which limits algal multiplication, and consequently animal life also.

In fresh water much larger variations in pH value are found. In shallow ponds phosphate may be used up completely in early summer, whereas in deep water relatively large amounts are still available.

26. Prof. A. C. Seward, F.R.S.—*Cretaceous Floras of Greenland.*

A preliminary account was given of the Cretaceous flora of Western Greenland based on material collected by himself and Mr. R. E. Holttum in 1921.

On the east side of Disko Island and on the coast of the Nugsuak Peninsula Cretaceous and Tertiary freshwater sedimentary rocks rest on the denuded surface of the Archæan Gneiss and are covered by a succession of Tertiary basalts and volcanic ash. The vegetation present in the Cretaceous strata consists of ferns, especially species of *Gleichenites*, Conifers, Ginkgoites, and many Dicotyledons. It is clear that these plants must have lived under climatic conditions very different from those of the present day. A brief description was given of the more interesting genera and the question of the geological correlation of the Greenland beds with plant-bearing strata in other countries was discussed.

27. Prof. D. Thoday.—*The Geographical Distribution and Ecology of the Genus Passerina.*

Passerina is a genus of ericoid shrubs endemic to Southern Africa, comprising some fifteen species. The ecology and geographical distribution of the species parallel in a striking way their morphological relationships.

The marked correlation of the species with distinctive habitats, some restricted in extent, others more or less continuous over wide areas, would vitiate any inference from area to relative age. South Africa is an old land surface which has not been submerged since Cretaceous times, and it is highly probable that most of the species of Passerina have reached limits to their distribution set by climatic and edaphic factors. Willis' recent suggestion that species spread slowly enough on the whole for acclimatisation to keep pace with dispersal begs an important question.

The origin of species in this genus has involved morphological divergence, together with a physiological divergence in adaptation to distinctive habitats; a satisfactory theory must account for this. The way in which the species have divided the land between them is remarkable.

28. Prof. R. B. Thomson and Dr. H. B. Sifton.—*Resin Canals in Spruce Wood.*

29. Dr. W. L. Balls, F.R.S.—Popular Lecture on *Cotton.*

Tuesday, September 18.

30. Joint Discussion with Section M on *Virus Diseases of Plants.*

(*a*) Dr. Paul Murphy.—*Virus Diseases of Plants.*

Recent researches in plant pathology have shown that a number of obscure maladies are really infectious diseases of the so-called 'virus' type, comparable to some of the most serious diseases of man and animals, and not mere conditions of ill-health resulting from old age or from unfavourable environmental or cultural conditions.

A brief account of these investigations is given, particularly as regards the disease of potatoes long known as 'Curl,' which is analysed and described. The traditional control measures are considered in the light of the new conception of the disease, and a sketch is given of the new avenues of approach to more rational and effective methods of combating the disease which are being opened.

(*b*) Prof. H. M. Quanjer.—*So-called 'Virus Diseases' of Plants: their Symptoms, Causation, Mode of Dissemination, and Economic Importance from a Physiological Point of View.*

Opinion was formerly divided in ascribing 'virus diseases' to physiological influences, degeneration, and parasites. In the majority of fungoid, bacterial, eelworm, and insect diseases attacks are local, but in so-called 'virus diseases' these are general. In animal diseases, spreading through blood-vessels is possible. The plant tissue most comparable with blood-vessels is the sieve-tube system. Diseases which spread through sieve tubes are more generalised in host than are most other diseases. The hypothesis that in 'virus diseases' the phloem is the seat of disturbance is confirmed by :—

(1) *Microscopical* evidence in the case of potato leaf-roll, curly-top of beet, raspberry leaf-curl, &c.

(2) *Physiological* evidence by prevention of movement of assimilates in the same diseases and in some others—*e.g.* peach yellows and sandal spike.

(3) *Experimental* evidence given by grafting experiments where the phloem joins first and the symptoms follow the downward sap flow in certain potato diseases and mosaic diseases of other plants.

(4) *Biological* evidence that disease is spread by aphides sucking the phloem

in certain potato diseases and mosaic diseases of various plants. Curly-top of beet is spread by leaf-hoppers sucking the phloem. Where infection by means of juice can be easily performed, as in tobacco and cucumber mosaics, biting insects also act as carriers.

The potato diseases of this group spread more in warmer and sheltered regions where aphides flourish than in colder and rougher climates.

Since the term 'virus diseases' tends to cause confusion, the author calls them 'phloem diseases.' The idea that they are caused by specific micro-organisms spreading in the phloem has served him as a working hypothesis for the last ten years, but their etiology will be a subject of discussion so long as successful inoculation experiments with pure cultures of these organisms have not established their exact relation to these diseases.

Their economic importance in the light of this hypothesis, especially as regards the cultivation of potatoes, is explained either by the slowing-down of the functions of the phloem, or by its *rôle* in generalising infection not only in 'plant' but in 'clone.'

A considerable degree of resemblance exists between sieve tubes and latex vessels. A number of diseases induced by protozoa, spread through latex vessels, and carried by sucking insects, have now been detected; these results are stimulating to workers on 'phloem diseases.'

(*c*) Dr. W. B. Brierley.

The Virus group of plant diseases is an important limiting factor in the world's agriculture, and general experience indicates that the several diseases are rapidly spreading. The only statistics available are contained in the publications of the Plant Disease Survey of the United States. These date from 1918 and show that in the succeeding four years an average of twenty-two States lost nearly a million tons of potatoes from mosaic disease alone. In energy values this is food for about 170,000 people during that period. From leaf-roll disease the loss of potatoes in twelve States was about half a million tons. In an average of four States the loss of beans during 1918-21 was approximately 850,000 tons. There is little doubt that, were statistics available for other crops and other countries, similar losses would be found to occur.

(*d*) Mr. T. Whitehead.

(1) Relative importance of different potato virus diseases not yet ascertained, though leaf-roll, crinkle, and stipple-streak are probably the most serious.

(2) Leaf-roll resulted in a loss of 55.8 per cent. and 51.8 per cent. of the crop in 1921 and 1922 respectively. In some localities loss in second year may amount to over 80 per cent.

(3) As a result of infection by leaf-roll there was no appreciable reduction in size of tubers, but the total number produced was reduced by 54.4 per cent.

(4) The effect on the yield was not seen during the year in which infection took place, but only in the crop from the infected tubers.

(5) Transmission may be by aerial insects or through the soil by some means unknown.

(6) Rate of spread varies in same ground in different seasons; in 1921 disease spread only from plant to plant in the same row, but across the rows in 1922.

(7) Virus frequently fails to reach all tubers.

(8) Rogueing, selection of healthy plants, and early lifting may enable healthy 'seed' to be maintained in many localities.

(*e*) Mr. Holmes Smith.

(*f*) Dr. R. N. Salaman.

In regard to Mosaic Disease and Leaf-Roll amongst potato seedlings :—

(1) Seedlings receive no protection against mosaic disease or roll by periodic nicotine spraying from the day of sowing.

(2) Infection is only very exceptionally congenital.

(3) *Solanum nigrum*, so far as ascertained, does not appear to be a source of infection.

(4) Infection by insects would appear to be an insufficient explanation for the spread of mosaic disease and roll.

(5) Seedlings isolated in soil not hitherto used for potato culture remained during 1923 free from mosaic disease or roll.

(6) Susceptibility to mosaic disease is inherited; its degree is variable, and possibly the result of several genetic factors. Susceptibility to roll is also inherited apart from that to mosaic.

(7) Susceptibility is not necessarily linked with a high mortality, but lack of vigour will allow of intensification of the lesion after infection.

(8) There is a definite relation between earliness and mortality amongst seedlings.

31. Dr. D. Ellis.—*Sulphur Bacteria.*

32. Dr. T. L. Prankerd.—*The Ontogeny of Gravitational Irritability in Osmunda regalis.*

The author's work on ferns has shown that ferns are sensitive to gravity—*i.e.*, that the frond perceives the pull of the earth. If displaced from its normal upright position, the young frond makes a twist to regain it, though the possibility of its doing so was doubted by Charles Darwin.

The sensitivity of fern fronds to gravity has been measured for the first time and shown to vary with various factors, the most important of which is the stage of development. A very young frond is far less sensitive than one unfolding its leaflets. It has also been shown that this sensibility is not present in the very young plant, but, though unseen, gradually rises as the plant develops, and to a much greater degree than the growth in length which can be seen. Plants differ greatly in their sensitivity to gravity—*e.g.*, the Royal Fern has been shown to be sixty times as sensitive as *Asplenium sp.* It is probably the most sensitive vascular plant known in this connection.

In the afternoon an excursion took place to the West Lancashire Sand Dunes.

Wednesday, September 19.

33. Discussion on *The Effect of Soil Sourness on Plants.*

(*a*) Mr. A. G. Tansley, F.R.S.—*Soil 'Sourness' as an Ecological Factor.*

Vegetation as an 'integration' of climatic and soil factors. The task of ecology proper. The water factor. 'Sour' soil vegetation. Its importance in the British Isles. Relation to xerophilous structure. The theory of 'physiological dryness.' Inadequacy of this theory. Relation of roots to basic ions. Adsorption of basic ions by colloids. Saturated and unsaturated humus.

Sourness (acidity) in the chemical sense. Hydrogen-ion concentration. Correlation with vegetation. Exceptions. Theory of 'buffer action.' Direct effect of hydrogen-ion concentration on roots, and on the soil flora and fauna. The theory of 'basic ratios.' Interpretation in terms of reaction of different basic ions with the tissues. Specific effect of basic lime. Hydroxyl-ion concentration. Other factors. Carbon-dioxide concentration. Badly aerated soils. Poverty in oxygen. Soil 'sourness' probably a complex phenomenon. Correlation of factors in nature. The disentangling of the various factors.

(*b*) Dr. E. J. Salisbury.—*Plant Distribution in Relation to Acidity.*

The occurrence of particular species in relation to the hydrogen-ion concentration as exemplified by *Mercurialis perennis, Pteris aquilina,* &c. The incidence of wild species with respect to this factor can be presented as variation curves in which an 'optimum' is clearly recognisable. The effect of water supply in ameliorating acidity of the soil as shown in nature and the diminished effect of acidity in water cultures.

The inadequacy of the 'basic ratio hypothesis' as a general explanation of the facts of distribution, and the experimental demonstration that change in this ratio does not bring about vegetation changes in the direction postulated.

(*c*) Dr. N. M. Comber.—*The Sourness of Soils.*

Sourness is recognised from the agricultural point of view by the characteristic failure of certain crops, the dominance of certain weeds, the prevalence of certain diseases, and a rectification of these conditions immediately following the use of lime or chalk.

The cause of sourness is not the hydrogen-ion concentration, since this is sometimes high when sourness, as above defined, is absent. Also it is not merely the ratio of calcium to other metals (*e.g.* potassium and sodium), since the addition of neutral calcium salts does not reduce the sourness and the addition of potassium and sodium salts does not enhance it. There is, however, considerable evidence that the ratio of *basic* lime to weak bases (chiefly alumina) is a fundamental cause of sourness.

The dominant functions of lime in arable soil appear to be, first, to act as a mutual flocculant of the soil colloids and the root hair colloids, and, second, to prevent too great an uptake of alumina and other toxic substances.

(*d*) Dr. W. H. Pearsall.—*Basic Ratios and Plant Distribution.*

To the plant ecologist the most reliable indication of soil sourness is that such soils bear a characteristic heathy type of vegetation. The presence or absence of these types of vegetation can apparently be correlated more reliably with scarcity of calcium in the soil than with absence of oxygen or high hydrogen-ion concentration, although calcium deficiency in uncultivated soils is commonly coupled with the two latter factors.

The typical heathy plants themselves are remarkable for their very high fat content. This necessitates a relatively high basic ratio $\frac{K+Na}{Ca}$ in the nutrient medium, if the absorbing surfaces are to remain unimpaired. The algæ characteristic of heathy types of vegetation are also found to require water in which potassium and sodium salts rather than calcium salts are predominant.

(*e*) Prof. J. H. Priestley.—*The Cell Wall and the External Medium.*

Evidence is supplied that the cell wall differentiates from a complex plasma surface into an inner lamella—namely, cellulose and pectin—and an outer (the middle) lamella of pectic and fatty acids. These acids form gelatinous soluble salts with Na, K and Mg, but insoluble flocculent salts with Ca. Hansteen-Cranner has shown that one result is the disintegration of the differentiated tissue behind the root apex when placed in dilute solutions containing only a salt of either Na, K, or Mg, owing to the solution of the middle lamella; the tissue, on the other hand, remains coherent in the solution of a Ca salt.

It can be shown experimentally that the relative proportion of these bases in the soil materially affects the migration of fatty substances along the walls. As a consequence the presence and extent of fat deposition in such layers as endodermis and exodermis may be materially modified by the bases in the soil, whilst plants forming unusually large quantities of fatty acids, such as the plants characteristic of peat habitats, may be disorganised when grown on soils containing more Ca as the result of the choking of the tissue immediately behind the meristem through the accumulation of insoluble Ca soaps. From this standpoint the important 'basic ratio' in the soil is the proportion of Na+K+Mg to Ca.

34. Dr. R. C. Knight.—*The Response of Plants in Soil and Water-culture to Aeration of the Roots.*

Maize grown in aerated soil cultures produced a greater weight of dry matter than control plants in non-aerated soil. The concentration of CO_2 in the soil atmosphere was markedly higher in the non-aerated series than in the controls. If normal aeration of the soil was prevented by covering the soil with a seal, the concentration of CO_2 rose as high as 15 per cent. In soil in trial-pots without plants the CO_2 concentration rose as high as 34 per cent. in twenty-three days. Maize and white mustard did not respond to aeration in water-culture, but aerated water-cultures of wallflower and *Chenopodium album* showed an increase in dry weight over controls.

SECTION L.—EDUCATION.

(For references to the publication elsewhere of communications entered in the following list of transactions, see p. 507.)

Thursday, September 13.

1. Prof. O. Jespersen.—*Grammar and Logic.*

There are two opposite views—one that grammar is nothing but applied logic, the other that language has nothing to do with logic (is 'alogical'). Both are one-sided and wrong. Grammar embodies the common-sense of untold generations as applied to the complex phenomena of human life; language is never illogical where strict logic is required for the sake of comprehension, but neither is it pedantically logical where no ambiguity is to be feared. Sometimes its logic is suppler, and even subtler, than the stiff formal logic of the schools (negation, &c.). But in order rightly to appreciate the logic of grammar it is necessary to face grammatical facts squarely and to respect the individuality of each language. Grammar can and should be considered from three points of view: (*a*) form, (*b*) syntactic function, (*c*) natural or logical ('notional') meaning. (*a*) and (*b*) differ from language to language, (*c*) is common to all mankind. Syntax Janus-like faces both ways, towards (*a*) and (*c*). Gender (masculine, feminine, neuter) and tense are syntactic, sex (male, female, sexless) and time notional categories, which do not always correspond to one another: the preterit does not always denote past time ('if I *had* money,' 'it is time he *went* to bed'). Case and mood do not exist as purely notional categories (*c*), but belong to (*a*) and (*b*). To speak of five cases in English is a falsification of scientific facts.

2. Mr. R. J. McAlpine.—*Education and Business Life.*

(1) (*a*) The average business man's attitude to schools.

(*b*) The average school's attitude towards business men.

(2) The greatest problem in business to-day is to fill vacancies.

(3) Tendency of schools to put their brightest and best in for scholarships, whereas business has little or no use for the University standard or type. Eighteen is quite old enough to begin a business career. Too much purely cultural education can be a handicap.

(4) Business in essence is the combined processes of buying and selling, and operations such as banking and insurance which are incidental thereto. There is nothing technically difficult, but the best work requires the best talent. The scholarship fetish should go and business be given the first refusal.

(5) This involves a new standard in schools. The replacement of the scholarship standard by the business standard.

(6) The necessary modification in curricula should follow on the establishment of more intimate relationships between head teachers and heads of businesses. The head teachers should visit big businesses, see the machinery in working, and find out what it is all about. Joint Committees would help, but the superman will always be hard to seek, in spite of the growth of educational facilities, until the schools and businesses can be brought to work together for the common end of selecting the right material, giving it the right training, and then seeing that it gets the right opportunities.

3. Mr. W. O. Lester Smith.—*The Older Children in the Elementary Schools.*

The paper dealt with the problem from a practical standpoint, considered in the light of actual conditions, and subject to present-day restrictions as to ways and means. The problem is an old one, but specially urgent to-day. New factors outside and inside the school. Changes in the law and their reactions on public opinion. The extent of the problem, and the practical difficulties. How it is being dealt with. Central schools, and methods of selection for admission to them. The curriculum. The question of 'overcrowding' the curriculum. Vocational training. Curriculum of boys and girls. Practical instruction. The parents' point of view. The influence of managers.

4. Dr. C. S. Grundy.—*The Education of Children in Music.*

The essential value of music in life. Its share in character building and culture. Its necessity in a general education. Advantages of early training. Developing the ordered mind. Methods of imparting music appreciation. What Manchester and Liverpool are doing. The co-operation of educational authorities and private enterprise. Organising educational orchestral concerts for children. The peculiar function of the orchestra in this work. Sympathy of ideals between lecturer and conductor. Care in selecting programmes and preparing illustrations. Demonstration. Necessity for permanent organisation. The municipal orchestra as a continuation class.

Dr. Grundy was assisted by a full professional orchestra, kindly arranged by Messrs. Rushworth & Dreaper, of Liverpool.

Friday, September 14.

5. Presidential Address by Principal T. P. Nunn on *The Education of the People.* (See p. 261.)

6. Dr. William Heron.—*Literary Appreciation in Elementary Schools.*

Introduction : Aims and Methods, past and present, in the Teaching of English.

(1) *Appreciation of Poetry*—how far possible in the Elementary School—'Art for Art's Sake' as a pedagogical principle.

(2) *The Elements of Appreciation*—(1) Musical and Suggestive; (2) Imaginative and Symbolical—What they mean for us—How far training is essential.

(3) *Towards the Cultivation of these Elements*—(1) Lessons in Preparation : (*a*) The Teacher's Part—anticipatory interest—proper atmosphere—removal of distracting hindrances. (*b*) Preliminary Research by classes. (*c*) Poetry and Music : Appreciation of Rhythm—experiments and results. Appreciation of Melody in Verse—rhyme, tone and tone colour, alliteration, &c. Appreciation of Recurrence. (*d*) The Training of the Imagination—experiments wrought. (*e*) Mythology—Preparation for appreciation of references. (*f*) Appreciation of Figures of Speech and Epithets. (*g*) Verse-making—examples. (2) The Appreciation Lesson—first impressions. (3) Discussion.

(4) *The Approach to English Literature* for children—Private study methods : Are they successful? Results of experiments.

Monday, September 17.

7. Joint Meeting with Section J on *The Delinquent Child.*

Dr. C. Burt.—An analysis has been made of 200 consecutive cases of juvenile delinquency, occurring in the County of London, and referred for psychological examination.

A classification of the commonest delinquencies according to their psychological nature—theft, truancy, running away, personal assault, damage and destruction, and various forms of sexual misbehaviour—at once suggests that criminal conduct is at bottom instinctive conduct. In almost every case, however, a plurality of converging causes are found co-operating in the production of crime.

The contributory factors may be grouped into four broad classes.

I. *Hereditary factors.*—Inheritance appears to operate, not directly through the transmission of a criminal disposition as such, but rather indirectly through congenital conditions, of a predisposing tendency, such as mental deficiency, innate dullness, general instability, and the excessive development of some single instinct, like sex, acquisitiveness, pugnacity, and migration.

II. *Environmental factors.*—Of these the conditions of the child's own home seem the most significant, the moral and emotional conditions being far more important than the economic—lax discipline (for example) being far more serious than mere poverty.

III. *Physical factors.*—Anything that weakens health, tends also to weaken self-control; anything that heightens irritability, tends also to increase liability to anti-social outbreaks. Conditions that lower social efficiency (*e.g.* poor physique) are commoner among delinquent boys; those that affect emotional life (*e.g.* precocious physical development) are commoner among delinquent girls.

IV. *Psychological factors.*—These are the commonest and most powerful of all. Emotional conditions are more significant than intellectual; temperamental instability than mental deficiency. Psycho-analytic mechanisms are frequently encountered—repressed parental complexes being commoner than repressed sexual complexes.

Dr. Gordon.—*The Disposal of the Delinquent Child.*—The great problem in dealing with delinquents is what to do with them. Much has been written as to causes and nature of delinquency, but little progress made towards practical treatment. Necessity of children's courts presided over by magistrates with an appreciation of the child mind. The individuality of the delinquent. The necessity of punishment, but also of understanding causes so as to prevent occurrence of juvenile crime. Universal potentiality towards delinquency. Establishment and breakdown of control. Physical conditions leading to destruction of brain tissue. Lack of balance in development of the personality. Mental defects. Physical defects. Aberrant types of behaviour. Environmental conditions. Necessity for advisory institutes. The composition and training of the staff. The duties of the assistants. Social work. Mental testing and analysis of personality. Disposal of the delinquent. Single care. Special schools and training institutions. The type that must be punished.

Dr. W. A. Potts.—There are certain primitive instincts which cannot have free expression. Their development depends both on Nature and nurture. Civilised life demands that the child should learn to control or express them along healthy channels. If he fails he is a delinquent. It is so difficult even for the best endowed to adjust satisfactorily to modern town life that it may be said that a fundamental cause of delinquency is civilisation, remembering that the child is hungry for country life, and all the country connotes.

So the delinquent receives treatment, not punishment. The necessary treatment can only be determined after thorough examination, physical and psychological. The condition of the endocrine glands (thyroid, &c.) must not be overlooked, though conduct can seldom be explained in endocrine terms.

The first step in psychological examination is evaluation of the mental capacity, and a decision whether the child comes under the Mental Deficiency Act. This simple solution occurs only in 3 to 5 per cent. even of delinquents who get into the hands of the police.

Further examination will decide if the child is psycho-pathic, not overlooking delinquency as an epileptiform equivalent. The effect of life on the child may produce a mental conflict; this may be primarily in the child, or reflected from the parents, so that their attitude to life requires investigation. Hygiene and training, education and recreation must be considered.

Special psychological conflicts of children must be described in detail. To clarify the problem certain delinquent acts, such as truancy and stealing, must be discussed separately.

Miss Crossland.—*Some Social Problems of Delinquency.*—(1) Home Office Report on the work of its Children's Branch. (2) Administration of the Probation of Offenders Act as applied to children. (3) Probation work in London. (4) 'Juvenile Courts Metropolis Act, 1920.' (5) Probation officer's duties. (6) Difficulties of probation work. Quotation from Home Office Report. (7) Some cases of difficult children. (8) Girls' cases. (9) Problems arising out of overcrowding. (10) Housing question.

8. Joint Meeting with Section E on *Geography as a Basis of a General Science Course.*

Tuesday, September 18.

9. Joint Meeting with Section G on *The Teaching of Dynamics.*

10. Rt. Rev. Bishop Welldon.—*How Far the Value of Education in Elementary Schools has Corresponded with the Increase of Expenditure upon it.*

History of education in Great Britain. Foundation of the British and Foreign School Society and the National Society for the education of the poor in the principles of the Established Church at the beginning of the nineteenth century. Education Bills of Mr. Forster, Mr. (now Earl) Balfour, and Mr. Fisher. Dangers inherent in education, but greater dangers in ignorance. Education and political power. Payment of teachers before and under the Burnham scale. Increasing cost of education from 1871 to the present time. Education not in itself an unmixed gain, for if it lessens certain offences, *e.g.* drunkenness, it may increase others, *e.g.* fraud. Danger of lowering the moral standard of the educational profession. Anxiety about the results of elementary education as in letters addressed to 'The Times' by Sir P. Magnus and Mr. W. L. Hichens. Complaints made by men of business as to ignorance of spelling, literary expression and geography among the pupils coming out of elementary schools. Examination of time-table in schools. Some reason to fear that teachers have concentrated their attention far too much upon intellectual knowledge, and not enough upon moral character. Teachers themselves have not always taken a high patriotic view of their vocation as, *e.g.* if they have refused to spend a few minutes' overtime in the care of their pupils, and perhaps their infant pupils, or have gone on strike, to the serious injury of their pupils, against a reduction of salaries. The National Union of Teachers has not prepared teachers to accept their due share of the national burden after the Great War by not pressing for the full amount of the salaries due to them under the Burnham scale or otherwise. The first thought of all teachers should be the good of the children entrusted to them. It is fully as important that individuals should discharge their responsibility to the State as the State its responsibility to the individuals. The educational profession is distinguishable from a trade union. Selfishness of class which is a serious peril to-day is no less deplorable than personal selfishness. (It is difficult to overrate the influence of the educational profession upon the national life. In Germany before the War that influence tended to evil; in Japan and in the United States it has tended to good.) But the State cannot feel that it has attained an adequate value for its expenditure upon education unless the citizens of the future are not only better instructed than their fathers and forefathers, but are actuated by a higher, or at least an equally high, spirit of patriotism. The public school spirit, as it is called, has signally justified itself in the War.

The unhappy discord between the Christian Churches has set an obstacle in the way of the moral and religious teaching which is essential to the creation of good citizenship. The State needs unity, and unity is hardly attainable if the children of different Churches are educated in different schools without ever learning to co-operate with citizens of different religious creeds from their own.

Upon the whole it seems clear that the time has come when the educational system inaugurated in 1871 may well be reviewed, and may so be brought into conformity with the opportunities and aspirations of a people who know that culture plays an ever-increasing part in the national life, but who know, too, that character is a more valuable element than culture in the life of a nation and an Empire like the British.

11. Mr. T. Samuel.—*Qualifying and Competitive Tests for Admission to Secondary Schools: An Account of Experiments in Wallasey.*

The paper traced the development of the annual school examination, instituted in 1920, for the award of free places in secondary and central schools. The chief points dealt with were the conditions of admission to the examination, the methods of conducting the tests, standardising the marking, and setting and marking the papers. The various modifications adopted year by year, and the reasons for adopting them, were described in detail.

The examination consisted of two tests. The first test was a qualifying test. Those who gained 50 per cent. of the total marks could enter the secondary schools as fee-payers, or could pass on to a second competitive test on the results of which free places were awarded.

The first test was purely internal. The papers were set and marked by the head teachers, and the test was held in all the elementary schools.

The papers of the second test were sent by an examination board, consisting of representatives of the secondary and elementary and central schools and of the local authority. H.M. inspectors were also in attendance. The examination is open to all children of the borough. Scholars in the junior departments of the secondary schools or in private schools take the same test as elementary school children. The age of admission is 11-12. All elementary scholars of this age who have reached Standard IV. must be presented. Under special circumstances, bright younger children, and older children who previously missed the examination, may be nominated by the head teachers for the test.

The subjects of the examination were originally arithmetic, composition, dictation, general intelligence and general knowledge (geography, history, and nature study), but have now been reduced to English and arithmetic in both tests. The school record is taken into account, and carries 100 out of 300 marks. This is examined at the schools and where necessary is supplemented by an oral test.

The marking is standardised by the local authority working in conjunction with the members of the examination board appointed as markers. The standard required has been fixed by a minimum curriculum, which states the attainment to be expected from normal children at the age of 11-12. This was settled by a conference of head and assistant teachers from all grades of schools under the authority.

The examination has proved beneficial to all branches of the educational system. It has defined and invigorated the work of the elementary schools, and has led to important reforms in their curricula and organisation. It has given a uniform standard of admission to the central and secondary schools. It has brought the various types of schools into close co-operation, so that they are now intimately related parts of one harmonious system. Finally, it has suggested for the administrative side many problems leading to new lines of investigation, organisation, and development.

12. Miss Margaret Einert.—*Rhythmic Dancing.* (Illustrated by a demonstration.)

Rhythmic dancing has been called the very symbol of a new spirit in nature rhythms, stories in movement and dance studies.

The growing recognition of the need in physical education for something less formal, more spontaneous, and more in harmony with the interests and activities of everyday life has drawn considerable attention to this form of dancing recently, for to physical benefit is added the cultivation of a sense of beauty in music, movement, and the drama.

Rhythmic Dancing has been called the very symbol of a new spirit in physical education, for though the dancing of Ancient Greece was its inspiration, its development is modern in essence, and is exercising a powerful influence upon our whole scheme of education for girls to-day.

SECTION M.—AGRICULTURE.

(For references to the publication elsewhere of communications entered in the following list of transactions, see p. 507.)

Thursday, September 13.

1. Miss E. R. Hiscox, Mrs. E. C. V. Mattick, and Mr. A. Todd.—*The Influence of Research upon the Making of Milk Products.*

2. Messrs. W. A. Hoy, A. T. R. Mattick, and Dr. R. Stenhouse-Williams.—*The Influence of Research upon the Methods of Handling Whole Milk.*

3. Presidential Address by Dr. C. Crowther on *Science and the Agricultural Crisis.* (See p. 273.)

4. Mr. A. Hay.—*Farm Management and Agricultural Economics in Relation to the Development of Agricultural Education.*

Farming is a commercial undertaking, and as much a business as cotton manufacturing, shipbuilding, or coal-mining. It is subject to business principles, and reacts to economic influences. Success is largely the result of individual effort, and the farmer must have some knowledge of the economic principles which underlie the effective administration of the farm.

It must be admitted, however, that to be successful a farmer must possess a knowledge of the sciences underlying the practice of agriculture, and he must have a detailed knowledge of agricultural practice and farm routine.

The object of farm management is to obtain from the various enterprises the highest returns consistent with a broad-minded and far-sighted policy, and the study of the subject revolves round the administration and organisation of the farm.

Agricultural economics, on the other hand, are more widespread in their scope, and deal with the study of commercial and political economics as applied to agriculture from a national welfare and an international point of view.

The methods of study are described in some detail, and stress is laid on the value of such training for the young farmer or future teacher, advisory officer and administrator in agriculture.

Friday, September 14.

5. Mr. G. R. Clarke.—*Ammonia and Nitrate in Woodland Soils.*

6. Joint Discussion with Section F on *The Economic Outlook for British Agriculture.* Opened by Mr. A. W. Ashby.

Competition of imported goods not only in quantity but in quality. Some imports setting standards of quality and of presentation. Organisation of the trade in imports. Inspection and standardisation. The connection between systems of marketing and of production at home and abroad. The British methods of distribution of farm products and their costs and results. Possible improvement of British systems of marketing, transport, and distribution of goods. Success of British agriculture depends upon the appeal of its products to the consumer, and the costs and prices at which they can be delivered.

Saturday, September 15.

An excursion took place to Lactose Factory, Haslington, and Farms in the Nantwich area.

Monday, September 17.

7. Mr. E. H. Rideout.—*The Soils of Wirral.*

The Geological Survey recognises here Triassic sandstones, Glacial clays and sands, alluvium and recent sands. This general classification has been adopted as a basis for soil survey, samples being taken on each formation to establish their characteristics by chemical and mechanical analysis.

A rapid preliminary survey of the vegetation justifies the subdivision of soils adopted. Examination of the crops and the distribution of permanent grassland in the area show similar relationships; field observations being compared with maps derived from official statistics.

In order to determine whether soil types so distinguished have an existence apart from the theoretical, and to show that the work has a practical bearing, experiments on grassland and arable land have been commenced on each type of soil.

8. Prof. Sven Odén and Dr. B. A. Keen.—*The Odén-Keen Apparatus for Automatic Mechanical Analysis.*

The mechanical analysis of soil is one of the fundamental operations of the soil scientist. It is, however, somewhat arbitrary, in that there is no general agreement on the sizes chosen for the various groups, and further, the representation of the soil as a mixture of a few fractions is not in accordance with facts. These anomalies may be removed, if we can by any experimental method construct a distribution curve connecting particle dimensions with the amount of particles corresponding to every size.

There are five possible methods which can be used for this purpose. Starting with a soil suspension, which is completely deflocculated and dispersed, we may measure (1) the change of specific gravity of the suspension with (*a*) depth or (*b*) time; (2) the change in hydrostatic pressure with (*a*) depth or (*b*) time; and (3) the rate of accumulation of particles on a plate suspended in the liquid. The experimental difficulties are least in methods (2) (*b*) and (3). The former is illustrated by a modification of Wiegner's apparatus and is most suitable for coarse and rapidly settling particles. The latter method is illustrated by the Odén-Keen automatic recording balance, which has been constructed in collaboration with the Cambridge-Paul Scientific Instrument Company. The suspended plate is attached to one arm of a balance, which is kept in equilibrium by an automatic adjustment of the current through a solenoid attracting a permanent magnet suspended from the second arm of the balance. When the weight of the sediment reaches a given amount—*i.e.* when the solenoid current reaches a given value—a small metal sphere is automatically placed on the second pan of the balance, and the solenoid current returns to a smaller value. The strength of the current is recorded on a moving paper band, and the operation just described results in this curve presenting a series of steps. A very open and sensitive scale can, therefore, be used for the curve, although the actual trace is confined within narrow limits of width. The sensitiveness of the record can be modified or increased by suitable adjustments of the component parts of the apparatus. The periodic replacement of the electro-magnetic attraction by the metal spheres results in the sensitiveness in any given experiment remaining constant.

9. Mr. E. A. Fisher.—*Imbibitional Soil Water.*

Water is held by soil in two ways: by *capillarity* between the soil grains, and by *imbibition* within the material of the soil colloids. In sand, water is held by capillarity only. Sand does not swell appreciably while absorbing water; soil swells considerably. This swelling is due to imbibitional water. If xylol be substituted for water no swelling of soil occurs: xylol is held by capillarity only. If the moisture equivalent (ME) and the 'xylol equivalent' (XE) (calculated in a volume basis) are determined for sand the two values are identical; with soil ME—XE is considerable, and is a measure of the imbibitional water present. When ME is determined under different centrifugal forces (f), ME plotted against 1/f is a straight line the slope of which measures the *intrinsic swelling capacity* of the soil colloids.

These phenomena can be explained on the basis of a Donnan equilibrium.

10. Prof. D. R. Hoagland and Dr. A. R. Davis.—*Suggestions Concerning the Absorption of Ions by Plants in Relation to Soil Problems.*

In the afternoon an excursion to Wirral Farms took place.

Tuesday, September 18.

11. Joint Discussion with Section K on *Virus Diseases of Plants.* (See p. 492.)

12. Mr. G. P. Miln.—*The Commercial Value of Indigenous Strains of Pasture Grasses.*

Results obtained from pure line breeds of the pasture species of indigenous grasses as compared with ordinary commercial strains.

Results of cultivated grass seeds in this country as compared with Denmark and other foreign countries.

13. Dr. W. R. G. Atkins and Mr. E. W. Fenton.—*The Hydrogen Ion Concentration of the Soil in Relation to the Distribution of Pasture Plants.*

Grasses and clovers sown to form pastures are frequently found to disappear, being ousted by species native to the particular soil type. Accordingly an investigation seemed advisable to ascertain the limits within which different species flourish naturally. It is noticeable that wild white clover may be found on soil as acid P.H. 5.6, whereas *Medicago maculata* is found from P.H. 6.7—7.8. *Holcus mollis*, H. *lanatus*, and *Cynosurus cristatus* have been observed to occur from P.H. 5.4–7.2, whereas *Agrostis vulgaris, Agropyrum repens*, and *Lolium perenne* extend from P.H. 5.8–8.0.

In the afternoon an excursion took place to Messrs. Garton's at Warrington and to Col. Lyon's Farm at Appleton.

REFERENCES TO PUBLICATION OF COMMUNICATIONS TO THE SECTIONS

AND OTHER REFERENCES SUPPLIED BY AUTHORS.

Under each Section, the index-numbers correspond with those of the papers in the sectional programmes (pp. 424–503).

References indicated by 'cf.' are to appropriate works quoted by the authors of papers, not to the papers themselves.

General reference may be made to the issues of *Nature* (weekly) during and subsequent to the meeting, in which résumés of the work of the sections are furnished.

Section A.

4. Cf. W. M. Smart, *Navigation, Position Line Tables* (J. D. Potter, shortly).

10. Cf. T. Smith, 'On Balancing Errors of Different Orders,' in Proc. Physical Soc. **32,** p. 141 (1919-20).

11. *Observatory,* **46,** No. 593, Oct. 1923. Cf. *Monthly Notices,* R.A.S., 82, pp. 170-1, Jan. 1922; 83, pp. 204-15, Jan. 1923.

19. *Nature,* **112,** No. 2816, p. 589, Oct. 20, 1923.

22. *Nature,* Sept. 22, 1923 (Summary); to be published in full in *Phil. Mag.* Cf. *Isotopes* (Arnold, London, 1922).

23. Expected to be published in *Phil. Mag.* Cf. Roberts, Smith, and Richardson, in *Phil. Mag.,* Nov. 1922, p. 912.

24. Cf. 'An investigation of the Angle of Contact between Paraffin Wax and Water,' in *Phil. Mag.,* Ser. 6, **46,** No. 272, pp. 244-256, Aug. 1923.

SECTION B.

1. *Engineering*, Sept. Also *Chemistry and Industry*, **42,** p. 930, 1923, W. Rosenhain, *J. Inst. Metals*, 1923, ii (May Lecture).

6. *Chemistry and Industry*, **42,** p. 901, Sept. 21, 1923. Cf. *Journ. Chem. Soc.*, 1923, **123,** p. 725; *Trans. Faraday Soc.* (meeting of July 1923, when published).

7. *Chemistry and Industry*, **42,** p. 929, 1923.

10. *Trans. Chem. Soc.*, **121,** p. 1604, 1922; **123,** p. 1717, 1923.

12. (Dr. K. G. Falk). The papers dealing with the earlier work have appeared in the *Journal of Cancer Research*, **6,** pp. 285-303 (1921); *Journal of Biological Chemistry*, **53,** pp. 75-102 (1922); **55,** pp. 653-669 (1923); **56,** pp. 903-920 (1923).

13. *Proc. Roy. Soc.*, **101***A*, p. 175; **103***A*, p. 444.

15. *Chemistry and Industry*, **42,** Oct. 5, 1923.

17. *Journ. Textile Inst.* (Birtwell, Clibbens, and Ridge), **14,** p. T297, 1923.

18. *Journ. Soc. Chem. Industry*, Nov. 1923; 'Die Disulphration des Naphthalins' in *Helvetica Chimica Acta*, Nov.-Dec. 1923.

SECTION C.

4. Cf. 'Pebbles of the Middle Bunter Sandstones in the neighbourhood of Liverpool,' in *Proc. Liverpool Geol. Soc.*, **12,** pt. iv, pp. 281-308.

9. Cf. *Rock-Salt and Brine* (Special Reports on Mineral Resources of Gt. Britain, **18,**) *Mem. Geol. Surv.*, 1921; 'Datum-lines in the English Keuper,' *Geol. Mag.*, 1918, pp. 120-5.

10. 'Petrology of the Permian Sandstones of the Parbold District' in *Proc Liverpool Geol. Soc.*, **13,** p. 308.

12. Expected to be published in *Geol. Mag.*

13. *Report on Geology of Antigua* (Leeward Is. Government).

SECTION D.

2. Cf. W. J. Kaye, in *Proc. Ent. Soc. Lond.*, 1922, p. xcviii, and 1923, p. xxxvii, E. B. Poulton, *ibid.*, 1923, xxxix; Lord Rayleigh, *ibid.*, 1923, p. xl.

8. *Rep. Dove Marine Lab.*, n.s. **12,** 1923; cf. *ibid.* n.s. **1-12,** papers dealing with herring investigations.

9. *Journ. Marine Biol. Assoc.*, **13,** No. 1.

10. Cf. *Fisheries Investigations*, Series II, **6** (Ministry of Agric. and Fisheries); report on 'Torpedo' plankton collector in preparation for *Publications de Circonstance*, Conseil Permanent International pour l'Exploration de la Mer.

14. Cf. Th. Mortensen, 'The Danish Expedition to the Kei Islands, 1922,' in *Vidensk. Medd. fra Dansk Naturhist. Forening*, **76,** 1923.

15. To be published in *Brit. Journ. Exper. Biol.*; cf. *Internat. Journ. d'Hydrobiologie*, 1910-11; *Biochem. Journ.*, **6,** part iii, 1912.

18. Cf. *Trans. Roy. Soc. Edinb.*, **53,** pp. 301-342, 5 plates, 1923.

20. Cf. Report of Committee on Parthenogenesis, B. A. *Report* 1922; 'Observations on the Biology of Sawflies' in *Entomologist*, **15,** Oct. 1922; 'Pairing and Parthenogenesis in Sawflies' in *Nature*, Aug. 12, 1922; E. F. Chawner and A. D. Peacock; 'Observations on the Life Histories and Habits of *Allantus pallipes* Spin. and *Pristiphora pallipes* Lep. (Hym. Tenth.)' in *Entomologist*, **16,** June and Aug. 1923; 'Biology of *Thrinax mixta* Kl. and *Thrinax macula* Kl. (Hym. Tenth.)' in *Proc. Univ. of Durham Phil. Soc.*, **6,** part v. A series of papers entitled 'Studies in the Biology of Sawflies,' dealing with the conditions of parthenogenesis existing in the group Tenthredinidae, intersexuality and sexuality and experiments in sex-reversal, is in preparation.

22. Expected to be published in *Journ. Linnean Soc.*

25. To be published in *Phil. Trans. R. S.*

26. *Proc. Roy. Soc.*, B, **95,** 1923 ; *Brit. Journ. Experimental Biology,* **1,** No. 1, 1923.

29. *Brit. Journ. of Exp. Biology,* **1,** No. 2.

31. Cf. *Proc. Roy. Soc.* ' Studies on the Sex-ratio and Related Phenomena : (1) Natal Retrogression in Mice ' ; *Journ. Gen.* ' Ditto : (2) Influence of the Mother on the Sex-ratio in Mammals : ' *Science Progress,* ' Factors Governing the Mammalian Sex-ratio ' (all in press).

33. To be published in *Records of the Indian Museum.*

34. Expected to be published in enlarged form, probably in *Q.J. Microscopical Science.*

SECTION E.

2a. Cf. *Merseyside* (local handbook for the meeting) ; also W. Hewitt, *The Wirral Peninsula.*

4. To be published in *Scot. Geog. Mag.*

5. *Man,* 1923, p. 104.

6. Cf. ' Railway Development as a National and International Function ' in *Discovery,* Jan. 1924 ; ' Economic Development of Central Australia,' *ibid.* Dec. 1922.

7. Cf. R. R. Walls, ' The Rock Crystal of Brazil ' in *Trans. Optical Soc.,* **21,** No. 4, 1919 ; ' The Existence of Diamond-bearing Pipes in Brazil,' in *Geol. Mag.* **57,** No. 676, Oct. 1920 ; ' The Geology of the High Plateau of Brazil,' in *Geol. Mag.* **60,** No. 709, July 1923 ; ' The Evolution of the High Plateau of Brazil,' in *Scot. Geog. Mag.* **39,** No. 4, Oct. 1923.

9. Cf. ' Influence of Nature on Japanese Character,' to be given before Royal Geog. Soc., Dec. 17, 1923 ; W. Weston, ' Mountaineering and Exploration in the Japanese Alps ' (London, Murray, 1896) ; ' The Playground of the Far East ' (London, Murray, 1918).

12. Expected to be published in *Scot. Geog. Mag.,* Jan. 1925.

14. To be published in *Scot. Geog. Mag.*

SECTION F.

3. To be published in *Economic Journ.,* Mar. 1924.

7. Expected to be published (in English) in *Weltwirtschaftliches Archiv,* Jan. 1924 (Kiel Univ.) ; Summary in *Journ. Nat. Inst. Industrial Psychology,* Apr. 1924 ; cf. Public Health Bulletin 106, Washington, U.S.A. ; Reports B.A. Committee on Fatigue from Economic Standpoint, 1915-16.

8. *Econ. Journ.,* Dec. 1923 (a sequel to the author's presidential address to Section F, 1922 ; see p. 105 of B.A. *Report* for that year).

9. Cf. J. A. Bowie, Sharing Profits with Employees (London, Pitman, 2nd ed., 1923).

10. Pubd. by Univ. Press of Liverpool, and Hodder & Stoughton, London, 1923.

SECTION G.

4. *Engineering,* Sept. 21, 1923 ; possibly to be published more fully in *Journ. Inst. Automobile Engineers.*

5. *The Engineer,* Sept. 21, 1923.

7. *Engineering,* Sept. 21, 1923.

8. *Surveyor,* Sept. 21 ; *Engineering,* Oct. 12, 1923.

9. *Engineering,* Sept. 28, 1923.

10. *Engineering,* Oct. 12 ; *Iron and Coal Trades Review,* Oct. 5 ; *Mining Mag.,* Nov. ; *Quarry Managers' Journ.,* Nov. ; *South African Engineering,* Oct. 31, 1923.

11. *Fortnightly Review,* Dec. 1923 ; J. B. C. Kershaw, *Smoke Prevention and Fuel Economy* (London, Constable, 3rd ed., 1924) ; ' Aims and Work of the Hamburg Smoke Abatement Society,' read before London Smoke Abatement Conference, 1905 obtainable from author.

12. *Engineering*, Oct. 26, 1923. Cf. ‘Analytical and Experimental Investigations Relating to Centrifugal Pumps,’ in *Proc. Inst. C.E.*, **201**, pt. 1 (1915-16).

13. *Engineering*, Oct. 5, 1923.

17. *Engineering*, Oct. 19, 1923.

18, 19. *Engineering*, Oct. 5, 1923.

21. *Engineering*, Oct. 19, 26, 1923.

22. *Engineering*, Sept. 28, p. 394 ; *Electrical Review*, Oct. 5, 1923. Cf. ‘Squirrel-cage Induction Motors with high starting Torque’ in *Engineering*, Aug. 19, 1923 ; ‘Starting Torque of Squirrel-cage Induction Motors’ in *Electrical Review*, July 13, Aug. 10, 1923 ; *Electrical Engineering* (London, Methuen).

23. Cf. Paper to appear in *Journ. Inst. Electrical Engineers*, 1923-4, with bibliography.

25. *Modern Wireless* **2,** No. 1 (Oct. 1923) ; *Wireless Weekly*, **2,** No. 11 (Sept. 26, 1923).

Section H.

1. Cf. ‘Les statues en pierre de la région centrale de Célèbes,’ in *Revue Anthrop.*, No. 7-8, July-Aug. 1923.

2. Cf. ‘Rossel Island Religion,’ in *Anthropos* (prob. Jan. 1924).

4. To be published in *Folklore.*

7. Cf. A. G. Pape, ‘Is there a new Race Type ? and the Philosophy behind’ (Edinburgh, Fyall & Mayne, 1923).

8. Cf. ‘The Place-names of Lancashire’ (Manchester, 1922) ; ‘Scandinavians and Celts in the North-West of England’ (Lund, 1918) ; portions of paper to be embodied in chapters (‘The Celtic Element’ and ‘The Scandinavian Element’) in forthcoming introductory vol. of English Place-name Soc.

10. To be published in *Archæologia Cambrensis.*

11. Cf. *Trans. Hon. Soc. of Cymmrodorion*, 1920-21, pp. 40-96.

15. *Journ. Gypsy Lore Soc.*, third series, **2,** part 4, 1923.

24. To be published in *The Ancient Egypt*, ed. Prof. W. M. Flinders Petrie.

26. A life of Harrison by de B. Crawshay and Sir E. Harrison is in preparation.

27. Probably to be published in *Proc. Prehistoric Soc. of E. Anglia.*

Section I.

7. *Nature,* Nov. 3, 1923.

9. *Biochemical Journ.*, **17,** p. 579, 1923.

12. *Journ. General Physiol.* **5**, pp. 365-381, 1923 (in part).

14. Cf. Lovatt Evans and S. W. F. Underhill in *Journ. Physiol.*, **58,** p. 1 (1923) ; Lovatt Evans, *ibid.*, p. 22.

15. To be published in *Q. J. Exper. Physiol.*

16. Cf. Edridge-Green, *The Physiology of Vision* (London, Bell & Sons, 1920), p. 100.

17. *Brit. Medical Journ.*, Oct. 6, 1923.

19. Expected to be published in *Annals of Botany.*

Section J.

1. Expected to be published in *Brit. Journ. Psychol.*, Jan. 1924.

8. *Studies in Mental Inefficiency,* **4,** No. 4, Oct. 1923.

9. Expected to be published in *Brit. Journ. Psychol.* ; cf. ‘Preliminary Note on a new method of determining the Race Effect in the Localization of Sound,’ *ibid.*, **13,** p. 435, 1923.

15. Cf. R. H. Thouless, *An Introduction to the Psychology of Religion* (Cambridge U. Press, 1923).

20. To be published in *Brit. Journ. Psychol.*

24. To be published in *Journ. Nat. Inst. Industrial Psychology* and in forthcoming publications of Industrial Fatigue Research Board.

26. *School Government Chronicle*, **110**, Sept. 22, 1923; to be published also in *Journ. Nat. Inst. Industrial Psychology.*

SECTION K.

2. *Annals of Botany*, **37**, No. cxlvii, July 1923.

3. Expected to be published in *Proc. Roy. Dublin Soc.* and in *Notes from the Botanical School of Trinity College, Dublin.*

5. Cf. 'Symbiosis in Calluna Vulgaris,' in *Ann. Bot.*, **29**, Jan. 1915, p. 99; 'Nitrogen Fixation in Ericaceae,' in *Bot. Gaz.*, **73**, No. 3, p. 226 (1922); 'Mycorrhiza in the Ericaceae,' in *Trans. Brit. Mycol. Soc.*, **8**, parts 1 and 2, Dec. 1922, p. 61.

9. *Ann. Bot.*, Oct. 1923.

11. To be published probably in *Journ. Agric. Sci.*

12. *Proc. Roy. Soc.*, B, **95**, pp. 214-228, 1923.

13. Expected to be published in *Annals of Botany.*

15. *Proc. Roy. Dublin Soc.*, **17**, No. 21, 1923; *Notes from the Botanical School of Trinity College, Dublin*, **3**, No. 4, July 1923.

16. B. Muriel Bristol and H. J. Page. 'Critical Enquiry into the alleged Fixation of Atmospheric Nitrogen by green Algae' in *Ann. Applied Biol.*, **10**.

23. Intended for communication to Royal Society.

25. *Journ. Marine Biol. Assoc.*, 1922, **12**, pp. 717-771; 1923, **13**, No. 1; cf. 'The Phosphate Content of Fresh and Salt Waters in its Relationship to the Growth of the Algal Plankton,' *loc. cit.*, 1923, **13**, No. 1.

29. Cf. W. L. Balls, 'The Existence of Daily Growth Rings in the Cell-wall of Cotton Hairs,' in *Proc. Roy. Soc.*, B, **90**, 1919; 'Further Observations on Cell-wall Structure as seen in Cotton Hairs,' in *Proc. Roy. Soc.*, B, **93**, 1922 (jointly with H. A. Hancock); 'The Determiners of Cellulose Structure as seen in the Cell-wall of Cotton Hairs,' in *Proc. Roy. Soc.*, B, **95**, 1923.

30 (*b*). Cf. H. M. Quanjer, 'Un nouveau chapitre de la pathologie végétale reliant cette science à la pathologie animale,' in *Revue de Pathologie végétale et d'Entomologie agricole*, **10**, No. 1, Feb.-Mar. 1923.

31. Expected to be published in *Proc. Roy. Soc. Edinb.*

33 (*d*). Cf. 'Plant Distribution and Basic Ratios,' in *Naturalist*, No. 787, pp. 269-271 (1922).

SECTION L.

1. To be published as one of the *Tracts* of the Soc. for Pure English (Oxford).

2. *Journ. of Education*; *The Times Educational Supplement*, Sept. 26, 1923.

3. *Education*, Sept. 28, 1923.

12. *Dancing Times*, Oct. 1923; cf. M. Einert, *The Rhythmic Dance Book* (London, Longmans, Green).

SECTION M.

4. *Estates Gazette*, Sept. 29, 1923.

9. To be published in *Journ. Agric. Sci.*, **14**, 1924. Cf. *Proc. Roy. Soc.*, A, **103**, 1923, pp. 139, 664, and *Journ. Agric. Sci.*, **13**, 1923, p. 121.

13. Cf. W. R. G. Atkins, 'Relation of Hydrogen Ion Concentration of the Soil to Plant Distribution,' in *Nature*, Sept. 15, 1921, **108**, p. 80; 'Some Factors affecting the Hydrogen Ion Concentration of the Soil and its Relation to Plant Distribution,' in *Sci. Proc. R. Dublin Soc.*, 1922, Feb., **16**, pp. 369-434, also *Notes Bot. School, Trinity Coll., Dublin*, 1922, **3**, No. 3; 'The Hydrogen Ion Concentrations of some Indian Soils and Plant Juices,' in *Agric. Research Inst. Pusa*, 1922, Bull. No. 136, pp. 1-12; 'The Hydrogen Ion Concentration of the Soil in Relation to the Flowe Colour of *Hydrangea hortensis* W., and the Availability of Iron,' in *Sci. Proc. R Dublin Soc.*, 1923, **17**, pp. 201-210, and *Notes Bot. School, Trin. Coll., Dublin*, 1923 **3**, No. 4.

SECTIONAL COMMUNICATIONS

ORDERED BY THE GENERAL COMMITTEE TO BE PRINTED *in extenso.*

REMARKS ON QUANTISATION.

Can the motion of a System of s degrees of freedom be more than (2s—1-) *fold periodical ?*

By Professor P. EHRENFEST.

(1) In the following paragraphs will be formulated a conjecture which it may perhaps be not too difficult either to disprove or to establish strictly by the application of suitable mathematical learning. Should this conjecture—eventually in a somewhat modified form—prove correct, it would not be without importance for the quantum theory.

(2) Consider first the motion of a point mass in a plane under the influence of a field of force of potential $\varphi = \alpha q_1^2 + \beta q_2^2 + \gamma(q_1^2 + q_2^2)^2$. If the particle has a finite total energy E, it will perform a continuous motion without going outside a finite region of the plane. In the 4-dimensional space of the co-ordinates $q_1\ q_2$ and momenta $p_1\ p_2$ the 'phase point' describes a 'phase path' which is completely embedded in the energy (hyper)-surface

$$T(q_1 p) + \varphi(q) = E.$$

When the motion of the particle is simply periodic, the phase path is a closed curve. In other cases the phase point in the course of its motion comes arbitrarily close to each point of a 2-dimensional region G_2 or perhaps even of a 3-dimensional region G_3. The last case occurs when the motion is '*quasi-ergodic.*'[1]

[1] L. BOLTZMANN (Sitzber. Wien. Akad. **63**, p. 679, 1871=Wiss. Abhandl. I., p. 284 ; *Journ. für Math.* **98**, p. 201, 1884-5=Wiss. Abhandl. III., p. 134) used the term '*ergodic*' to mean a motion for which the phase path passes '*through*' each point of the energy surface. P. and T. EHRENFEST (Enzyclop. d. Mathem. Bd. IV., Art. 32 'Statist. Mechanik,' p. 10a (1909) expressed the opinion that this definition contained a self-contradiction, and used the term '*quasi-ergodic*' to denote those motions for which the phase point approaches *arbitrarily near* to each point of the energy surface ; they also emphasised the fact that no certain example of such a quasi-ergodic motion was then known. A. ROSENTHAL [(Ann. d. Phys. 42, p. 796 (1913)], and M. PLANCHEREL (ditto, p. 1061) followed this up, and gave a strict proof of the impossibility of *ergodic* systems. As to *quasi*-ergodic systems on the other hand, HERGLOTZ and ARTIN succeeded some time ago in constructing an example which they could prove strictly to be quasi-ergodic. (Short communication in 'Naturforscher-Versammlung,' Leipzig, September 1922. Will appear in full in BLASCHKE, Differential geom. Bd. III.). See also E. FERMI 'Beweis, dass ein mechanisches Normal system im allgemeinen quasi-ergodisch ist' (Phys. Zschr. **24**, p. 261, 1923). In a conversation some years ago Prof. HERGLOTZ raised the question whether the following simple system possessed quasi-ergodic motions : A point which undergoes perfectly elastic reflections at the sides of a 'billiard table' of the form of a scalene triangle. So far as I know, *this question has not yet been answered !*

(3) Consider now a system of s degrees of freedom, with co-ordinates $q_1, \ldots q_s$ and momenta $p_1, \ldots p_s$ and the Hamiltonian-Function H (q, p). Then in general the phase point in the course of its motion comes arbitrarily close to every point of a ρ-dimensional region $G\rho$, which is of course embedded in the $(2s-1)$-dimensional energy-surface H $(q, p)=E$. When the motion is simply periodic $\rho=1$; when it is quasi-ergodic ρ takes its greatest possible value $\rho=2s-1$. We will speak for shortness of a '$G\rho$-motion.'

In the case of suitable regularity of the Hamiltonian-Function (Hq, p)—say something like the example quoted in §2—the region $G\rho$ will not only be spun through, 'smooth-combed,' by the phase path, but, further, the system has this property: each time the phase point in its path comes back to the neighbourhood of a specified point P which it has once previously passed through, the motion repeats itself approximately in all its characteristics (not only in q, p and $\dot{q}$, $\dot{p}$ but also in $\ddot{q}$, $\ddot{p}$, etc.); and, further, the repetition will be more nearly exact, the smaller the deviation with which the phase path passes by P.

(4) We appeal particularly to this '*quasi-periodic*' behaviour in the following '*$u=\rho$-conjecture*': *If*[2] for a $G\rho$-motion the *q's* and *p's* can be expressed as functions of the time by means of u-multiple Fourier series, then *u is equal to* ρ (and this is at most equal to $2s-1$, which is the value it takes for quasi-ergodic motions).

That is to say, let the general term of such a Fourier-expansion be

$$(1)\ \begin{matrix}\cos\\ \sin\end{matrix}\ 2\pi(\tau_1\omega_1+\ \ldots\ldots\ +\tau_u\omega_u)t\ \left\{\begin{matrix}\tau_1\ \ldots\ \tau_u \text{ any positive or}\\ \text{negative integers,}\end{matrix}\right.$$

where no relation of the form

$$(2)\ k_1\omega_1+k_2\omega_2+\ \ldots\ldots\ +k_u\omega_u=o\ [k_1\ \ldots\ldots\ k_n \text{ integers.}$$

exists. This implies u independent fundamental frequencies characteristic of the given motion, and the conjecture is that $u=\rho \leqq 2s-1$.

(5) For another point of view, consider a u-dimensional space of co-ordinates $\xi_1\ \xi_2\ \ldots\ \xi u$, and in it consider the straight line

$$\xi_1=\omega_1 t,\ \xi_2=\omega_2 t\ \ldots\ldots\ \xi_u=\omega_u t \qquad (3)$$

The Fourier series establishes a one-to-one correspondence between the points of the phase path in $G\rho$ in the (q, p) space and the points of the straight line (3). Imagine the ξ-space divided into unit- (hyper-) cubes. The straight line (3) passes through one cube after another, and each cube through which it passes cuts off a segment from it. Replace these segments by homologous straight lines in a single cube. [Addition of integers—positive or negative—to the quantities (3) leaves all Fourier-terms (1) unaltered.] On account of the absence of relations of the form (2) these mutually parallel lines fill up the single cube densely everywhere

[2] We must leave open the question whether such a motion—say something like the example of §2—*is* always describable exactly (not only approximately) by multiple Fourier series.

[3] See *e.g.*, O. PERRON, Irrationalzahlen, Leipzig, 1921, p. 156, 'Inhomogene diophantische Approximationen' and index of original papers on the subject.

and therefore this 'ξ-path' comes arbitrarily close to all points of a u-dimensional region, while the phase path itself comes arbitrarily close to all points of the ρ-dimensional region $G\rho$. We should now have to consider more closely the correspondence between these two regions, using the property remarked on at the end of §5[4]. If we could succeed in showing that this correspondence is *one-to-one* and *continuous*, the '$u=\rho$-conjecture' would be proved, as it is known that in such transformations the number of dimensions is preserved.[5]

(6) As it is still uncertain whether the '$u=\rho$-conjecture' is correct, the following remark on its relation to the quantum theory must suffice for the present. If in the sense of the above explanations we did succeed in designing systems which possess *multiple periodic* motions with u independent frequencies where $s < u \leq 2s-1$, the quantum rules as we know them could not be applied to such systems, for those rules are restricted to systems for which $u \leqq s$.[6, 7]

[4] The following example at first sight against the '$u=\rho$-conjecture,' shows how important it is to pay heed to this property. Let $q=\cos \varphi(t)$ and $p=\sin \varphi(t)$ where $\varphi(t)$ is expansible in multiple Fourier series, for example with $u=3$. The (q,p) point remains the whole time on the circle $q^2+p^2=1$. Thus $\rho=1$ and $u=\rho$. But here we also have violation of the condition that $\dot{q}\,\dot{p}$, $\ddot{q}\,\ddot{p}$, etc., always return to their initial values when q and p do so, as must be the case for a system obeying Hamilton's equations with a time-free $H(q, p)$. Starting from this remark it is easy to see clearly how the 'quasi-periodicity' of the motion imposes very strict relations between the Fourier expansions of the q's and p's, and those of all their time derivatives on account of their common periodic character.

[5] L. E. Brouwer, Math. Ann. **70**, p. 161 (1911); **71**, p. 305 (1912); **72**, p. 55 (1912).

[6] In an extremely simple case of one degree of freedom an 'excess of frequencies' of somewhat similar though really different kind has been treated with the helps of the correspondence principle by P. Ehrenfest and G. Breit [Proc. Amsterd. **25**, p. 2, 1922=Zsch. f. Phys. **9**, p. 207, 1922]. Cf. N. Bohr, Zsch. f. Ph. **13**, p. 147, 1923.

[7] Bohr has given his ideas about those cases, in which a multiple periodic motion is not to be expected, in Zsch. f. Ph. **13** (1923) [p. 134—particularly in the comment on A. Smekal, Zsch. f. Ph. **11**, p. 294, 1922], and also about those cases in which the motion can be very closely represented by a u-multiple periodic motion with $u \leq s$ [in 'Quantentheorie der Linienspectra (1918).' Vieweg 1923, pp. 69, 70, 134]. But see particularly Bohr's remarks on the failure of the quantum theory of multiple-periodic systems and how it shows itself in some problems of the complex structure of spectral lines, and of the anomalous Zeeman effect [Ann. d. Phys. **71**, pp. 275-277, 1923].

NOTE.

Prof. P. LANGEVIN's paper on *The Structure of Atoms and their Magnetic Properties* was ordered by the General Committee to be printed in extended abstract. This has not been received in time for inclusion, and the original abstract is therefore appended:—

THE STRUCTURE OF ATOMS AND THEIR MAGNETIC PROPERTIES.

By Professor P. LANGEVIN.

(1) In order to account for magnetic properties it is necessary to assume that each atom or molecule possesses in its normal state a quite definite magnetic moment which is proportional to the total moment of the quantity of electron movement. This moment can be zero when the symmetry of the edifice is sufficient, and always becomes modified in the diamagnetic sense under the action of an external magnetic field.

(2) From the point of view of classical dynamics a system of electrified particles which participates in thermal agitation cannot exhibit when it is isolated, nor assume under the action of an external magnetic field, any resultant magnetic moment, and consequently cannot possess any magnetic property.

(3) The laws of quanta, on the contrary, allow us immediately to predict the existence of molecular magnetic moments which are integral multiples of the Bohr magneton, and they alone permit us to develop in a completely coherent manner an electronic theory of magnetism in the same way as they have rendered possible a theory of atomic structure and of the emission of spectra.

(4) Magnetic measurements contribute their information regarding atomic structure, and atomic models ought to be in quantitative agreement with them. The family of rare gases seems to give rise to some interesting difficulties from this point of view.

(5) The variation of magnetic properties with the state of chemical combination furnishes in like manner important indications and confirmations of the theory. The progressive disappearance of ferro- and para-magnetism when the magnetic atoms (iron, cobalt, platinum, &c.) enter into more and more complex combinations shows that chemical affinity tends to constitute molecules with no resultant magnetic moment —to realise electronic edifices which present a higher and higher symmetry.

CORRESPONDING SOCIETIES COMMITTEE.

Report of Committee (Mr. T. SHEPPARD, *Vice-Chairman*; Dr. F. A. BATHER, Mr. O. G. S. CRAWFORD, Prof. P. F. KENDALL, Mr. MARK L. SYKES, Dr. CLARENCE TIERNEY, Prof. W. W. WATTS, Mr. W. WHITAKER, *and the* PRESIDENT *and* GENERAL OFFICERS).[1] *Drawn up by the General Secretaries.*

[1] As reported last year, the Committee co-opted the following representatives of the scientific societies of Liverpool and its neighbourhood to assist in preparing the programme of the Liverpool Conference of Delegates :—

Prof. P. G. H. Boswell, Liverpool Geological Society.
Prof. W. J. Dakin, Liverpool Biological Society.
Prof. P. M. Roxby, Liverpool Geographical Society.
Dr. H. F. Coward, Manchester Literary and Philosophical Society.
Prof. F. E. Weiss, Manchester Literary and Philosophical Society.
Mr. T. W. Sowerbutts, Manchester Geographical Society.
Mr. W. H. Barker, Manchester Geographical Society.
Mr. J. S. Broome, Warrington Literary and Philosophical Society.

THE Committee recommended to the Council that at the Conference of Delegates at the Liverpool meeting the *President* should be Professor H. H. Turner, F.R.S., Savilian Professor of Astronomy in the University of Oxford; the *Local Vice-President* Professor P. G. H. Boswell, Professor of Geology in the University of Liverpool; and the *Local Secretary* Miss Edith Warhurst. These nominations were accepted, and the Committee desires to express its thanks to these officers for their conduct of the business of the Conference, of which a report follows.

After discussion with officers of Section M (Agriculture) and representatives of the Societies in question, the Committee recommended, and Council resolved, that the National Farmers' Union and the Central Landowners' Association be added to the list of affiliated Societies; and that the local branch of each in the district where the British Association's meeting is held be empowered to send a delegate to the Conference of that year.

The Conchological Society, the Gilbert White Fellowship, the Scottish Marine Biological Association, and the Worthing Archæological Society were recommended for admission as Corresponding Societies, together with the following Societies, if qualified, which sent delegates to the Hull meeting, but had not since applied specifically for admission :—Bath and West and Southern Counties Society, Huddersfield Naturalist, Photographic, and Antiquarian Society, Stirling Natural History and Archæological Society, Manchester Astronomical Society, Manchester Entomological Society.

The subject of 'Peat Beds and Submerged Forests,' commended by Section C (Geology) for systematic research by the Corresponding Societies, having been referred at the Liverpool Meeting to a Committee of the British Association on Quaternary Peats, the Corresponding Societies are requested to put themselves in communication with the Secretary of that Committee, Mr. L. H. Tonks, Red Bank House, Birtle, near Bury.

The Committee asks that it may be reappointed, with a grant of 40*l.*, for the preparation of its Report and Bibliography.

CONFERENCE OF DELEGATES OF CORRESPONDING SOCIETIES.

LIVERPOOL, 1923.

The Conference met in the Civil Court, St. George's Hall, Liverpool, on Thursday, September 13, at 2 P.M., Professor H. H. Turner, F.R.S., in the chair. Thirty-nine delegates were present, representing forty-nine Societies.

The President addressed the delegates on

The Work and Relations of Corresponding Societies.

Sundry proposals submitted to the Conference by delegates and others were discussed briefly, and referred to the Corresponding Societies Committees for examination and report. The Conference adjourned until Tuesday, September 18, at 2 P.M.

At the adjourned meeting the following recommendations, submitted by the Corresponding Societies Committee, were adopted, and forwarded to the Committee of Recommendations :—

(*a*) To represent to His Majesty's Government the urgent need for more ample provision for the Science Museum, and for closer co-ordination between the principal national collections of scientific material.

(*b*) To represent to His Majesty's Government, in view of recent proposals to utilise for naval, military, or commercial purposes sites of historic or scientific interest or of natural beauty, such as Avebury, Holmbury Hill, and Lulworth Cove and its neighbourhood, the urgent need of more effective protection of such sites from disfigurement or obstruction.

(*c*) To request the Director-General of the Ordnance Survey to reconsider his decision to discontinue the issue by the Ordnance Survey of quarter-sheets of the six-inch map on the ground that, if quarter-sheets are not available, teachers. students, and others engaged in various kinds of research on local and regional distributions will be put to expense and inconvenience in providing themselves with the sheets necessary for their work.

(*d*) To recommend that the publications of scientific societies should conform so far as possible to a standard size of page for convenience in dealing with off-prints; and that for octavo publications the size of the British Association's Report be adopted as the standard.

(*e*) To urge the adoption by scientific societies of the bibliographical recommendations contained in the current Report of the Zoological Publications Committee.

(*f*) To call the attention of local scientific societies to the need for prompt and systematic supervision, in the interests of scientific record, of all sections and other excavations which were opened during the construction of new roads or other public works.

(*g*) That this Conference suggests for the consideration of the Council that the change of the British gallon to 4 litres would be objectionable, because the gallon of water weighs 10 lb., which is an important fact in physical and engineering practice.

Various proposals were discussed for conducting the business of the Conference of 1924 in view of the visit of the British Association to Toronto, and it was resolved :—

To recommend the General Committee to accept the invitation received from the President of the Museums Association to hold the Conference of Delegates in connection with that Association's meeting at Wembley in July 1924, without prejudice to any provision which may be possible for a Conference of Representatives of local societies at the Toronto meeting.

Mr. Grierson Macara (Greenock Philosophical Society) asked if the Canadian Government would be willing to allow delegates to the British Association meetings in Toronto, 1924, to have free railway tickets from Toronto to

Vancouver. He hoped the Council would do all they could to get this privilege for delegates.

In reply to questions as to the authority of delegates to represent the British Association in their own districts, it was pointed out by Professor J. L. Myres (General Secretary) that as delegates are appointed not by the British Association but by their respective Societies for the purposes of the annual Conference, they are not in any sense accredited representatives of the Association; but that at the Hull Conference a resolution was submitted that the Association should 'invite the delegates sent to the Conference by the Corresponding Societies to render any assistance in their power in making known, in their respective districts, the objects and methods of the British Association, and to communicate to the Secretary of the Association the names and addresses of scientific workers and others to whom the preliminary programme of the next meeting should be sent.' This recommendation had been adopted by the Association, and was in force. He had some hope that delegates would respond to this invitation, which had been made at their own request, and undertook that it should be brought to the notice of Societies which had not sent delegates to the present Conference. Delegates could obtain from the office of the Association for distribution copies of a printed statement of its objects and methods.

A discussion followed on the *Function of Local Scientific Societies in regard to Schemes of Town Planning.*

Professor P. Abercrombie (University of Liverpool) gave an address on 'Town Planning.' He traced the history of the 'town' from ancient to modern times, showing that the community was all-important formerly and the individual sacrificed. The growth of the town was in close touch with the growth of industrial progress. The 'Town Planning Act' of 1909 gave powers of road design. Formerly, country roads were the only visible suggestion of arteries. Scientific study of the community is required for civic and regional survey. Far less damage would be done to villages if the interests were safeguarded and new roads made round a village instead of destroying places of historic interest.

Mr. G. L. Pepler (Ministry of Health, Whitehall), in his opening remarks, hoped that local Societies would take an interest in the subject and help the local authorities by making civic and regional surveys. Reports could be made as to land suitable for market-gardens, &c., so these places would not be built upon.

Mr. Webb Shennan (Wirral) spoke of the help given in the Wirral district to local authorities by landowners giving land suitable for new roads and expansion of old ones.

Mr. T. Sheppard (Yorkshire Naturalists' Union) moved a vote of thanks to the speakers, and stated that all local Societies were in sympathy with Professor Abercrombie's schemes.

Mr. Mark L. Sykes (Manchester Microscopical Society) moved a vote of thanks to Professor Turner for the genial way in which he had presided over the Conference. The thanks were heartily accorded.

LIST OF PAPERS,

BEARING UPON THE ZOOLOGY, BOTANY, AND PREHISTORIC ARCHÆOLOGY OF THE BRITISH ISLES, ISSUED DURING 1922.

By T. Sheppard, M.Sc., F.G.S., *The Museum, Hull.*

Zoology.

Anon. Economic Ornithology. *Bird Notes and News.* Vol. X., No. 1, pp. 11-12
—— Oil on the Water, *tom. cit.* Vol. X., No. 2, pp. 17-21.
—— Economic Ornithology, *tom. cit.* Vol. X., No. 2, pp. 21-23.
—— [Bird] Notes, *tom. cit.* Vol. X., No. 2, pp. 27-29.
—— Watchers and Watching : Britain's Rare Birds, *tom. cit.* Vol. X., No. 4, pp. 49-51.
—— [Grey of Fallodon], Address [Waterfowl at Fallodon]. *Proc. Berwicks. Nat. Club.* 1921, pp. 249-261.
—— Reports of Meetings. Cockburn Low, Holy Island, Belford, Kelso, Berwick, *tom. cit.*, pp. 262-291.
—— Report of the Museum and Art Gallery Committee. [Bristol.] Sept. 30, 23 pp.
—— Account of the Annual and General Meetings. *Ann. Rep. Bristol Nat. Soc.* Vol. V., pt. iv., pp. 163-169.
—— Recovery of Marked Birds. *Brit. Birds.* June, pp. 13-18.
—— Catalogue of the Books, Manuscripts, Maps and Drawings in the British Museum. Vol. 6, Supplement, pp. 511.
—— Guide to the Whales, Porpoises, and Dolphins in the Dept. of Zoology, British Museum. Second Ed., 56 pp.
—— *Trogederma khapra. Bull. Bureau Bio-Technology.* Mar., pp. 132-133.
—— Riddle of the Eel : A Deep-sea Problem. *Conquest.* Feb., p. 132.
—— Music-loving Tawny Owl. *Country Life.* Jan. 21, p. 92.
—— Gadwall in Westmorland, *tom. cit.* Feb. 11, p. 187.
—— Birds of the Sea and Shore, *tom. cit.* Mar. 4, pp. 304-306.
—— Shelduck, *tom. cit.* Apr. 15, p. 516.
—— Barn Owls Hunting in the Daytime, *tom. cit.* June 3, p. 763.
—— Golden Oriole, *loc. cit.*
—— Hoopoe in South Devon, *tom. cit.* July 1, p. 902.
—— Fur and Feather in the Woodlands, *tom. cit.* July 8, pp. 22-23.
—— 'The Most Stateliest Beast' [Red Deer], *tom. cit.* Aug. 12, pp. 167-171.
—— How the Tree Creeper Sleeps, *tom. cit.* Sept. 2, p. 285.
—— Variation of Colour in Eagles' Eggs, *tom. cit.* Sept. 9, p. 322.
—— Insect Photography [Ants' Nests], *tom. cit.* Sept. 16, p. 354.
—— Flight Shooting [Dunlin], *tom. cit.* Oct. 21, pp. 526-527.
—— Flight of Birds with Injured Wings, *tom. cit.* Dec. 2, p. 742.
—— Smelling power of Birds, *tom. cit.* Dec. 9, p. 791.
—— Burton R. F. L. [Obituary]. *Ent.* June, p. 144.
—— *Colias croceus*, Fourc. (*edusa*, Fab.), *tom. cit.* Sept., p. 211.
—— Obituary : F. B. Newnham, M.A., *tom. cit.* Sept., p. 216.
—— Entomological Society of London [Report], *tom. cit.* Jan., pp. 23-24; Mar., p. 68; July, pp. 167-168. *Ent. Rec.* Mar., pp. 53-54; Apr., pp. 79-80; May, pp. 98-99; June, pp. 116-117; July, pp. 143-144; Sept., pp. 166-167; Nov., p. 205; Dec., pp. 221-222. *Ent. Mo. Mag.* May, pp. 117-118.
—— Obituary : Francis George Whittle. *Ent. Mo. Mag.* Jan., p. 22.
—— Obituary : William Lucas Distant, *tom. cit.* Mar., pp. 66-67.
—— Obituary : Vincent Robert Perkins, *tom. cit.* May, pp. 110-111.
—— Obituary : Frederick William Lambart Sladen, *tom. cit.* May, pp. 111-113.
—— Obituary : George Alexander James Rothney, *tom. cit.* May, pp. 113-114.
—— Ghost Swift Moth and the 'Will-o'-the-Wisp,' *tom. cit.* Nov., p. 252.
—— South London Entomological Society [Report]. *Ent. Rec.* Jan., pp. 19-20; Mar., pp. 54-57; June, p. 117; July, pp. 144-147; Sept., pp. 167-168; Oct., pp. 185-186; Nov., pp. 206-207; Dec., pp. 223-224.

ANON. Sale of the Farn Collection, *tom. cit.* Mar., pp. 48-50; Apr., pp. 75-77.
—— Lancashire and Cheshire Entomological Society [Report], *tom. cit.* Mar., pp. 57-58; June, pp. 117-118; July, pp. 147-148; Dec., pp. 222-223.
—— Mosquitoes, *tom. cit.* Oct., p. 184.
—— Obituary: Dr. David Sharp, *tom. cit.* Oct., pp. 186-188.
—— Essex Field Club: Reports of Meetings. *Essex Nat.* Mar., pp. 34-43; Apr., pp. 86-106.
—— Zoological Section. *Rep. Felsted School Sci. Soc.* No. 27, p. 15.
—— Zoological Notes, 1919-1920, *tom. cit.*, pp. 18-22; 1920-1921, pp. 28-34.
—— Entomological Notes, *tom. cit.*, p. 37.
—— Scottish and New Zealand Red Deer. *Field.* Jan. 14, pp. 38-39.
—— White-fronted Geese in Hants, *tom. cit.* Jan. 14, p. 66.
—— Herons and Trout Streams, *tom. cit.* Jan. 21, p. 95.
—— Proposed Consolidation of the Wild Birds Protection Act, *tom. cit.* Jan. 28, p. 131.
—— Recovery from Wounds in a Woodcock, *tom. cit.* Feb. 4, p. 172.
—— White Woodcock, *tom. cit.* May 6, p. 622.
—— Smews and other Wild Fowl at Barnes, *tom. cit.* Mar. 11, p. 344.
—— Arrival of Summer Birds, *tom. cit.* Mar. 25, p. 419; Apr. 1, p. 431; Apr. 8, p. 469; Apr. 15, p. 513; Apr. 22, p. 547; Apr. 29, p. 590; May 6, p. 622; May 13, p. 658; May 20, p. 692; May 27, p. 729.
—— Blue-winged Teal in Sussex, *tom. cit.* Apr. 1, p. 431.
—— Remarkable varieties of the Short-tailed Vole, *tom. cit.* May 6, p. 621.
—— White Quail, *tom. cit.* June 10, p. 778.
—— Badger Dig in the Cottesmore Country, *tom. cit.* Apr. 8, p. 470.
—— Cuckoo's Mate, *tom. cit.* Apr. 15, p. 513.
—— Destruction of Sea Birds by Floating Oil, *tom. cit.* Apr. 22, p. 547.
—— Food of the Little Owl, *tom. cit.* May 6, pp. 621-622.
—— Otter in Eel Trap, *tom. cit.* May 20, p. 692.
—— Buff-coloured Woodcock, *loc. cit.*
—— Cuckoo in Kensington, *tom. cit.* June 10, p. 778.
—— Black Tern in Cornwall, *tom. cit.* June 24, p. 882.
—— Chaffinch Feeding Young Blackbirds, *tom. cit.* July 8, p. 57.
—— Three Curious Cases of Deformity in Young Rooks, *tom. cit.* July 22, p. 135.
—— Sawfly on Solomon's Seal, *tom. cit.* Aug. 26, p. 323.
—— Ancient Haunt of the Raven, *loc. cit.*
—— Clouded Yellow at Deal, *tom. cit.* Sept. 9, p. 387.
—— Weasel Annexing Golden Plover, *tom. cit.* Sept. 16, p. 405.
—— Bees and Lime Flowers, *tom. cit.* Sept. 23, p. 443.
—— Clouded Yellow in Hants, *loc. cit.*
—— Monster [14 lb. Trout] from the Wharfe, *tom. cit.* Sept. 30, p. 487.
—— Otter in Essex, *tom. cit.* Oct. 7, p. 539.
—— Fearless Stoat, *tom. cit.* Nov. 11, p. 714.
—— Bees Dead under Lime Trees, *tom. cit.* Nov. 18, p. 729.
—— Blackbird pursued by Owl, *tom. cit.* Nov. 25, p. 784.
—— Wing of Woodcock, *loc. cit.*
—— Stoat on the Defensive, *tom. cit.* Dec. 2, p. 793.
—— Fishery Board (Scotland)—Scientific Investigations, 1922. I. Herring Investigations.
—— Salmon Investigations in Scotland: Salmon of the River Spey. *Fishery Board for Scotland.* 1921, No. 2.
—— Results of Salmon and Sea Trout Marking in sea and river. *Fishery Board for Scotland.* 1922, No. 1.
—— Natural History Section [Reports]. *Rep. Hampstead Sci. Soc.* 1920-22, pp. 40-43.
—— Handbook to the Collections illustrating Survey of the Animal Kingdom. *Horniman Mus. and Library.* Pamphlet No. 12.
—— Notices of recent Ornithological Publications. *Ibis.* Apr., pp. 352-387; July, pp. 573-598.
—— Birds of Hillsborough, Co. Down. *Irish Nat.* Jan., p. 12.
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