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PROCEEDINGS

OF THE

YAL SOCIETY OF LONDON.

From January 17, *to June* 20, 1901.

VOL. LXVIII.

LONDON:
HARRISON AND SONS, ST. MARTIN'S LANE,
Printers in Ordinary to His Majesty.
SEPTEMBER, 1901.

[redacted]

LONDON:
HARRISON AND SONS, PRINTERS IN ORDINARY TO HIS MAJESTY,
ST. MARTIN'S LANE.

[redacted]

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PROCEEDINGS

OF

THE ROYAL SOCIETY.

January 17, 1901.

Sir WILLIAM HUGGINS, K.C.B., D.C.L., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "Total Eclipse of the Sun, January 22nd, 1898. Observations at Viziadrug.—Part IV. The Prismatic Cameras." By Sir NORMAN LOCKYER, K.C.B., F.R.S.

II. "Wave-length Determinations and General Results obtained from a Detailed Examination of Spectra photographed at the Solar Eclipse of January 22, 1898." By J. EVERSHED. Communicated by Dr. RAMBAUT, F.R.S.

III. "The Thermo-chemistry of the Alloys of Copper and Zinc." By T. J. BAKER. Communicated by Professor POYNTING, F.R.S.

"Mathematical Contributions to the Theory of Evolution. IX.—On the Principle of Homotyposis and its Relation to Heredity, to the Variability of the Individual, and to that of the Race. Part I.—Homotyposis in the Vegetable Kingdom." By KARL PEARSON, F.R.S., with the assistance of ALICE LEE, D.Sc., ERNEST WARREN, D.Sc., AGNES FRY, CICELY D. FAWCETT, B.Sc., and others. Received October 6,—Read November 15, 1900.

(Abstract.)

(1.) If we take two offspring from the same parental pair, we find a certain diversity and a certain degree of resemblance. In the theory

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of heredity we speak of the degree of resemblance as the fraternal correlation, while the intensity of the diversity is measured by the standard deviation of the array of offspring due to given parents. Both correlation and standard deviation are determined for any given character or organ by perfectly definite well-known statistical methods. Passing from the case of bi-parental to asexual reproduction, we may still determine the correlation and variability of the offspring. This ultimately leads us to the measurement of the diversity and likeness of the products of pure budding, or, going still one stage further, we look, not to the reproduction of new individuals, but to the production of any series of like organs by an individual. Accordingly one reaches the following problem:—If an individual produces a number of like organs, which so far as we can ascertain are not differentiated, what is the degrees of diversity and of likeness among them? Such organs may be blood-corpuscles, hairs, scales, spermatozoa, ova, buds, leaves, flowers, seed-vessels, &c., &c. Such organs I term *homotypes* when there is no trace to be found between one and another of differentiation in function. The problem which then arises is this:—Is there a greater degree of resemblance between homotypes from the same individual than between homotypes from separate individuals? If fifty leaves are gathered at random from the same tree and from twenty-five different trees, shall we be able to determine from an examination of them what has been their probable source? Are homotypes from the individual only, a random sampling, as it were, of the homotypes of the race?

By the examination of very few series from the animal and vegetable kingdoms I soon reached the result, that homotypes, like brothers, have a certain degree of resemblance and a certain degree of diversity; that undifferentiated like organs, when produced by the same individual, are, like types cast from the same mould, more alike than those cast by another mould, but yet not absolutely identical. I term this principle of the likeness and diversity of homotypes *homotyposis*. It soon became clear to me that this principle of homotyposis is very fundamental in nature. It must in some manner be the source of heredity. It does not, of course, "explain" heredity, but it shows heredity as a phase of a much wider process —the production by the individual of a series of undifferentiated-like organs with a certain degree of likeness. My first few series seemed to show that the homotyposis of the vegetable and animal kingdoms had approximately the same value, and it occurred to me that we had here the foundation of a very widespread natural law. In order to demonstrate its truth, however, the homotyposis of a large range of characters in a great number of species must be investigated, and I soon found my own unaided efforts were quite unequal to the task of collecting, tabulating, and reducing the data. As the material grew, it seemed desirable to separate the vegetable and animal kingdoms, and the present paper deals only with the former. In this field I have had the aid of a number of competent helpers. To collaborators who have long aided me, like Dr. Alice Lee, Miss C. D. Fawcett, and Mr. Leslie Bramley-Moore, I have been able to add, for the present purpose, Miss Agnes Fry, Dr. E. Warren, Dr. W. R. Macdonell, Miss M. Barwell and others, who have taken part in the labour either of collection, of measurement, or of computation. The result of this united labour is that twenty-two series, with upward of twenty-nine correlation tables, are here dealt with.* Small in number as this may seem, when we think of the vast variety of the vegetable kingdom, it means an immense amount of work—special series, which are in the memoir represented by a page of table and a few lines of numerical constants, have often cost one or other of us weeks of steady work. Hence I cannot strongly enough express my gratitude to my co-workers; they have more than ever convinced me of the great importance of co-operation for the future of scientific research, and the desirability, if possible, of organising the labour of isolated scientific workers. I will now indicate the general results we have reached.

(2.) The following series were dealt with: (1) to (3). The leaflets of the compound leaf of the Ash were counted in upwards of 300 trees from Buckinghamshire, Dorsetshire, and Monmouthshire. The results were in good agreement, and show homotyposis as a racial character of considerable constancy. (4) to (5) The veins in the leaf of the Spanish Chestnut were counted in 100 trees from Buckinghamshire and 100 trees of mixed character. Homotyposis was found to increase with heterogeneity of age and locality. (6) The veins were counted in the leaves of 100 Beech trees from Buckinghamshire. (7) and (8) The prickles were counted on the leaves of 100 Holly trees from Somersetshire and 100 from Dorsetshire. This completes the series of homotypes for trees. The tree results are in fair accordance, when we allow for the disturbing factors of environment, age, and personal selection. (9) to (13) We next investigated five series of Poppies, counting the stigmatic bands on the seed-capsules; *Papaver Rhœas* for three series, from top of Chilterns, bottom of Chilterns, and the Quantocks; Shirley Poppies for two series from Great Hampden and Chelsea. The results were again in fairly reasonable accordance with each other and with those for trees. (14) and (15) The segmentation of the seed vessels was counted in *Nigella Hispanica* and *Malva Rotundifolia*; the homotyposis was found to be much weakened, but actual differentiation was observed between the seed vessels on the main stem and on the side shoots of the former, and the 127 plants of the latter had principally arisen by stolons from a single clump, and were not thus entirely independent individuals. (16) The members of the whorls were counted

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* In the Appendix an additional fifteen series will be found.

in 201 sprays from separate plants of *Asperula odorata*; it was known that these members are differentiated in their origin; the homotyposis was found much weakened. (17) and (18) The *sori* on the fronds of 100 Hartstongue ferns and the lobes on the fronds of 100 plants of Ceterach were counted. We were told that these characters are much affected by age of plant and environment of individual; we found the homotyposis increased very sensibly beyond the value obtained for trees. (19) The veins in the tunics of 200 examples of *Allium cepa* were counted. (20) The seeds in the pods of 100 plants of Broom from Yorkshire were counted. In an Appendix the homotyposis of the seeds in the pods of leguminous plants is dealt with for a number of species. The general result is that homotypic intensity is *halved* when we deal with a character associated with fertilisation.

We then considered two cases in which we knew the growth factors to be very marked. Dr. E. Warren measured the length and breadth of twenty-five leaves of 100 plants of common ivy (*Hedera Helix*) and Dr. Lee and myself the length and breadth of ten gills of 107 Mushrooms (*Agaricus campestris*). The homotyposes of the leaf and of the gill *indices* in these two cases were determined, and form series (21) and (22). The homotypic correlation of the absolute lengths and breadths was also found in order to obtain some measure of the effect of different stages of growth on homotyposis. Omitting the last series of absolute measurements subject to growth, the mean value of the twenty-two series gave the intensity of homotypic correlation as 0·4570.

(3.) A theory of fraternal hereditary resemblance is given on the basis of the likeness of brothers being due to homotyposis in the characters of spermatozoa and ova put forth by the same two individuals and uniting for the zygotes whence the brothers arise. It is found that the mean value of fraternal correlation ought to be equal to the mean intensity of homotypic correlation. We have so far worked out nineteen cases of fraternal correlation in the animal kingdom, and their mean value = 0·4479, *i.e.*, is sensibly equal to the intensity of homotyposis in the vegetable kingdom. It is, therefore, very probable that heredity is but a phase of homotyposis, and that the latter approximates to a certain value throughout living forms.

The theory involves a certain mean relation between direct and cross homotyposis, *i.e.*, that the homotypic correlation between characters A and B in a pair of homotypes is the product of the direct homotypic correlation of A and A (or B and B) and the organic correlation of A and B in the individual. We had only the absolute lengths and breadths of Ivy leaves and Mushroom gills to test this proposition on, and the growth factor is here dominant. The results do not show complete equality, but this is hardly to be wondered at when we consider the extraneous influences at work.

(4.) The individual variation in the twenty-two series was measured and expressed as a percentage of the racial variation ; the results range from 77 to 98 per cent., with a mean value of 87 per cent. If this percentage variation occurs within the individual, it is clearly idle to speak of variation as a result of sexual reproduction. It exists in full intensity when an individual buds or throws off undifferentiated like organs. The blood-corpuscles produced by a single frog are almost as variable as the blood-corpuscles in the whole race of frogs. Thus, variation is established as a primary feature of all vital production whatever.

(5.) No relation whatever could be found between the intensity of homotyposis (and therefore *a fortiori* of heredity) and the degree of variability of the species. If species are classified in order of variability for our twenty-two series, the mean homotyposis of the first eleven is 0·4559 and of the last eleven is 0·4570. No relation whatever, as far as we were able to judge, could be found between the simplicity or complexity of the organisms dealt with and either their variability or their homotyposis. The Mushroom was quite comparable with the Poppy or the Spanish Chestnut. We conclude, accordingly, that there is no evidence at present to show that variation has decreased and heredity increased with the progress of evolution. On the contrary, without laying down any dogma, we should consider the results obtained as consistent with variability and homotyposis being primary factors of the growth of all living forms and not the product of natural selection, but factors upon which its effectiveness *ab initio* has depended. If we can show that homotypic correlation is as intense in the simplest forms of life as in the most complex, and that inheritance flows naturally from it, it is clear that our view of living forms will be considerably simplified. Homotyposis is unfortunately obscured by other factors due to growth, environment, unobserved differentiation, or heterogeneity in one or another form. But the results of this our first investigation in this field seem to support the view just expressed, and to indicate that the Principle of Homotyposis (by which we must again say we mean a *numerical* appreciation of the likeness and diversity among homotypes) is a fundamental law of nature, which will enable us to sum up in a brief formula a great variety of vital phenomena.

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"Total Eclipse of the Sun, January 22nd, 1898. Observations at Viziadrug.—Part IV. The Prismatic Cameras." By Sir NORMAN LOCKYER, K.C.B., F.R.S. Received December 22, 1900—Read January 17, 1901.

(Abstract.)

The report gives full particulars concerning the 6-inch and 9-inch prismatic cameras which were used during the eclipse, and the results obtained. Twenty-four of the photographs are reproduced. A table is given indicating the wave-lengths and probable origins of the 856 lines which have been measured between D and λ 3663.

The investigation shows the probable presence of both arc and enhanced lines of calcium, chromium, iron, manganese, nickel, strontium, titanium and possibly cobalt, copper, indium, lead, molybdenum, potassium, and rubidium; arc lines of aluminium, barium, carbon, magnesium, sodium, scandium and possibly cerium, lanthanum, lithium, rhodium, and tantalum; enhanced lines of vanadium, and possibly of bismuth, cæsium, gold, ruthenium, selenium, silicium, thallium, tin, tungsten, yttrium, zinc, and zirconium. Hydrogen, helium, and asterium are also present.

No evidence has been found of the presence of antimony, arsenic, cadmium, iridium, mercury, osmium, palladium, platinum, silver or thorium. Further investigations of the coronal rings have led to no definite results regarding their origins.

"Wave-length Determinations and General Results obtained from a Detailed Examination of Spectra photographed at the Solar Eclipse of January 22, 1898." By J. EVERSHED. Communicated by Dr. RAMBAUT, F.R.S. Received December 12, 1900—Read January 17, 1901.

(Abstract.)

In this paper the results are given of a detailed study and measurement of a series of spectra photographed at the eclipse of 1898, with a glass prismatic camera of 2¼ inches aperture. Ten exposures were made, all yielding good negatives, in which the great extension in the ultra-violet is a marked feature.

The first two photographs of the series were exposed at 20 seconds and 10 seconds before totality respectively, and are images of the cusp spectrum. They show the Fraunhofer lines with great distinctness, although the latter are much less dark than in the

ordinary solar spectrum. The lines were measured and identified for the purpose of facilitating the reduction of the bright line spectra obtained during totality.

Spectrum No. 3 was exposed for four seconds, beginning two seconds before second contact. In this the flash spectrum is fully developed, and extends from λ 3340 to λ 6000. The majority of the bright arcs, including those due to the upper chromosphere, extend over 40° of the limb, implying a depth of 1″·3 for the gases composing this layer. The total depth of the chromosphere deduced from the hydrogen arcs is 8″·2, and from the calcium arcs 11″·6. There are 313 measurable lines in this negative, and the wave-lengths and identifications of these are given in Table I.

Spectrum No. 4, exposed for half a second shortly after second contact, gives the spectrum of the upper chromosphere and prominences. Seven of the latter are shown. The images are about equally dense in calcium radiations, although in hydrogen there is a marked variation of intensity between the different prominences.

A conspicuous feature in the spectrum of two of the prominences is a band of continuous spectrum, beginning at λ 3668 near the end of the hydrogen series, and extending indefinitely in the ultra violet.

Good measures were obtained of the images of a small prominence at the centre of the plate, the wave-lengths being given in Table II.

Spectrum No. 5.—This plate had a long exposure near mid-totality. The continuous spectrum of the corona is strongly marked, and the green corona line is well shown at position angles 60° to 78°, and 95° to 105°. A new corona line is faintly impressed at λ 3388 ±, the maxima of intensity being at the same position angles as those of the green line.

Spectrum No. 7 shows the re-appearing arcs of the flash spectrum, the exposure ending about four seconds before third contact. The green corona line is shown on both east and west limbs, and there is a faint corona line near H. The wave-length values of the lines measured on this plate are given in Table I.

Spectrum No. 8.—This was exposed almost at the instant of third contact, the re-appearing photosphere showing as four narrow bands of continuous spectrum due to Baily's beads. The flash spectrum arcs extend between and across the bands, and can be traced over an arc of 55°, the depth of the layer, in this case exceeding 2″.

The focus in this negative is poor, and no measures were made; but as far as can be judged, comparing this plate and No. 3, the spectra of the east and west limbs of the sun are identical.

Spectra Nos. 9 *and* 10.—These are cusp spectra, very similar to Nos. 1 and 2.

General Results and Conclusions.

The Flash Spectrum.—Comparing the wave-length values of the flash spectra given in Table I with Rowland's wave-lengths of the solar lines, it is at once evident that practically all the strong dark solar lines are present in the flash as bright lines; and all the bright lines in the flash, excepting hydrogen and helium, coincide with dark lines having an intensity greater than three on Rowland's scale.

The relative intensities of the lines in the two spectra are, however, widely different, many conspicuous flash lines coinciding with weak solar lines, and some of the strong solar lines being represented by weak lines in the flash spectrum.

This, however, applies only to the spectrum taken as a whole. Selecting the lines of any one element, it is found that the relative intensities in the flash spectrum agree closely with those of the same element in the solar spectrum. This is particularly well shown in the case of the elements iron and titanium.

The want of agreement in the relative intensities of the lines of different elements in the bright line and dark line spectra is probably due to the unequal heights to which the various elements ascend in the chromosphere, a low-lying gas of great density giving strong absorption lines, but weak emission lines, on account of the excessively small angular width of the radiating area.

The more extensively diffused gases of small density, on the other hand, give strong emission lines in the flash spectrum, and weak absorption lines.

The spectrum arcs obtained with a prismatic camera are not true images of the strata producing them, but *diffraction* images more or less enlarged by photographic irradiation. Monochromatic radiations from a layer 2″ in depth will produce arcs or "lines" which are as narrow as can be defined by instruments of ordinary resolving power.

The intensities of these images do not represent the intrinsic intensities of the bright lines of the different elements; the apparent intensity of the radiation from an element depending on the extent of diffusion of that element above the photosphere.

But in the dark line spectrum the intensities depend on the total quantity of each absorbing gas above the photosphere irrespective of the state of diffusion of the different elements.

The flash spectrum as a whole appears from these results to represent the upper, more extensively diffused portion of a stratum of gas, which, by its absorption, gives the Fraunhofer spectrum.

Fifteen elements are recognised with certainty in the flash spectrum (No. 3), and five are doubtfully present. The atomic weights of these elements in no case exceed 91. All the known metals having atomic weights between 20 and 60 seem to be present in the lower chromosphere, but among these there does not seem to be any relation between the atomic weights and the elevations to which the gases ascend in the chromosphere.

The only non-metals found are H, He, C, and possibly Si.

Of the 225 lines measured in the ultra-violet region of the spectrum only 29 remain unidentified.

The Hydrogen Spectrum.—Twenty-eight hydrogen lines are shown in spectrum No. 3. The wave-lengths obtained are compared in Table III with the theoretical values derived from Balmer's formula. With the exception of $H\delta$, which seems to be unaccountably displaced towards the red, the wave-lengths of the ultra-violet lines are found to agree closely with the formula. A slight deviation occurs in the most refrangible lines, the positions of which seem to be distinctly more refrangible than those assigned by theory.

The continuous spectrum given by the prominences in the ultra-violet, beginning at the end of the hydrogen series, seems analogous to a feature noticed by Sir William Huggins in the absorption spectra of 1st type stars, and is possibly due to hydrogen.

Hydrogen and Helium in the Lower Chromosphere.—From the character of some of the helium lines it is inferred that this element is probably absent from the lowest strata, whilst parhelium appears to be separated from helium, and to exist at a lower level.

Unlike helium, hydrogen gives very intense lines in the flash layer. These lines are well defined and narrow, even in the very lowest strata.

Reasons are given to show that the absence of hydrogen absorption in the ultra-violet, and of helium absorption in the visible spectrum, may be due to insufficient quantity of these elements above the photosphere, not to equality of temperature between the radiating gas and photospheric background.

The Corona Spectrum.—The wave-length of the green line deduced from measures of No. 3 and No. 7 spectra confirms the value obtained by Sir Norman Lockyer at the same eclipse. The only other lines shown on these photographs are at λ 3388 and near H.

"The Thermo-chemistry of the Alloys of Copper and Zinc." By T. J. Baker, B.Sc., King Edward's School, Birmingham. Communicated by Professor Poynting, F.R.S. Received December 4, 1900.—Read January 17, 1901.

(Abstract.)

The heats of formation of a number of alloys of copper and zinc, containing those metals in very diverse proportions, have been ascertained.

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The method consists in finding the difference between the heats of dissolution, in suitable solvents, of an alloy and of an equal weight of a mere mixture containing the metals in the same proportion.

The first series of experiments was made with an aqueous solution of chlorine as solvent. Its application was limited to those alloys containing less than 40 per cent. of copper, as it was impossible to obtain those richer in copper in a sufficiently fine state of division to enable them to dissolve.

The results, though not altogether satisfactory, showed that the heat of dissolution of an alloy was sensibly less than that of the merely mixed metals.

Incidentally it was found that the equation $Cl_2.Aq = 2600$ (Thomsen's 'Thermochemische Untersuchungen') is erroneous and, on inquiry, Professor Thomsen gave a corrected value, 4870. The author finds $Cl_2.Aq = 4970$.

The most suitable solvents of the alloys are—

(*a.*) Mixture of ammonium chloride and ferric chloride solutions.

(*b.*) Mixture of ammonium chloride and cupric chloride solutions.

The chemical actions involved are simple reductions, and no gases are evolved.

Two series of experiments made on twenty-one alloys yielded very concordant results. They show that heat is evolved in the formation of every alloy of copper and zinc yet tested.

A sharply defined maximum heat of formation is found in the alloy containing 32 per cent. of copper, *i.e.*, corresponding to the formula $CuZn_2$. It amounts to 52·5 calories per gramme of alloy or 10,143 calories per gramme-molecule. There is some evidence of a sub-maximum in the alloy nearly corresponding to CuZn.

From these points there is a steady decrease in the heat of formation, both in the case of alloys containing less than 32 per cent. of copper as the amount of copper decreases, and also in the case of those containing more than 50 per cent. of copper as the quantity of copper increases.

The results, in general, confirm the existence of intermetallic compounds, and the values obtained are in accordance with those demanded by Lord Kelvin's calculation of the molecular dimensions of copper and zinc.

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"A Chemical Study of the Phosphoric Acid and Potash Contents of the Wheat Soils of Broadbalk Field, Rothamsted." By BERNARD DYER, D.Sc., F.I.C. Communicated by Sir J. HENRY GILBERT, F.R.S. Received November 9,—Read November 15, 1900.

(Abstract.)

In the 'Journal of the Chemical Society' for 1894 (vol. 65, 'Transactions'), there appeared a paper by the author, "On the Analytical Determination of probably available 'Mineral' Plant Food in Soils," in which the use of a 1 per cent. solution of citric acid was proposed as a means of approximate differentiation between the total and probably available phosphoric acid and potash, the method proposed being the result of an attempt to imitate, in the solvent, the acidity of root-sap, based on a preliminary examination of the acidity of 100 specimens of flowering plants of some twenty natural orders. To test the method, it was then applied to samples of the soils of the various barley plots in Hoos Field, Rothamsted, kindly placed at the author's disposal by the late Sir John Lawes and Sir Henry Gilbert. The method, having yielded results fairly consistent with the greatly varying mineral history and known fertility of these various soils, has now been applied by the author to the investigation of the soils of a number of the Wheat plots of Broadbalk Field, also kindly placed at his disposal by Sir John Lawes and Sir Henry Gilbert on behalf of the Lawes Agricultural Trust Committee. Twelve representative plots were selected, and the samples examined include not only the surface soils to a depth of 9 inches, but also, for each plot, the second and third consecutive 9 inches of subsoil. The samples were drawn on the completion of the fiftieth season of continuous wheat growing, but earlier sets of samples, of both soils and subsoils, taken in 1865 and 1881, were also simultaneously examined.

The present paper gives an account of this work. It includes a summarised history of the manurial treatment and crop yields of each plot at the different periods, and gives, for each sample of soil and subsoil—fifty-one in all—the results of determinations of total phosphoric acid and of potash soluble in hydrochloric acid; and also of phosphoric acid and potash soluble in a 1 per cent. solution of citric acid.

The differences between the total percentages of phosphoric acid in different soils, unmanured and variously manured, correspond fairly well with their history; but in the absence of a knowledge of such history, these differences would not suffice to give any indication of the profound differences known to exist in the phosphatic condition and fertility of the soils. The relative proportions of citric acid

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soluble phosphoric acid, however, appear to afford a striking index to the relative phosphatic fertility of the soils. In the subsoils, the irregularities and variations in the natural and original phosphoric acid of the subsoils themselves are such that the total percentage tells us nothing; while the citric acid results frequently show striking and consistent differences, and are also of considerable interest when studied in connection with the problems of root-range and subsoil-feeding, which are discussed in examining the results of the individual plots. In the surface soils, the average ratio of phosphoric acid, on the plots manured with superphosphate and ammonium salts, with and without various additions of alkaline salts, to that in plots not manured with phosphates for fifty years, was 1·65 : 1, while the citric acid soluble phosphoric acid ratio for the same groups was 5·46 : 1. On the two dunged plots the ratio of total phosphoric acid to that of the plots not phosphatically manured is 1·78 : 1 and 1·36 : 1 respectively; while the corresponding ratios for citric acid soluble phosphoric acid are 6·83 : 1 and 3·91 : 1.

The probable limit denoting phosphatic deficiency for cereals seems to be, as deduced from this investigation, between 0·01 per cent. and 0·03 per cent. of citric acid soluble phosphoric acid in the surface soil. That is to say, a percentage as low as 0·01 seems to denote an imperative necessity for phosphatic manure, while as much as 0·03 would seem to indicate that there is no such immediate necessity. For root-crops —more especially turnips—the limit would probably be higher.

The results, generally, show that by far the greater proportion of unconsumed manurial phosphoric acid, though originally water-soluble, is accumulated in the surface or first 9 inches, but that in the case of dung there is considerable descent into the second and third 9 inches, and that, in the case of superphosphate accompanied by constant dressings of potassium, sodium and magnesium salts without nitrogen (full supply and small utilisation), there is evidence of a tangible descent into the second and even the third 9 inches. In the case of the chemically manured plots, not only is the greater part of the calculated accumulation found by analysis in the surface soil, but a large proportion of it is found in a condition in which it dissolves in a weak solution of citric acid. This reagent also enables us to trace qualitatively the descent alluded to in the subsoils. Potassium, sodium, and magnesium salts have a distinct influence in the retention of the phosphoric acid in a less fixed and presumably more available condition, the effect increasing as the saline applications are greater.

The superabundance of phosphoric acid estimated to have been supplied in dung for fifty years is less satisfactorily accounted for than is that on the chemically manured plots; and even allowing for the difficulty of accurately estimating the phosphoric acid in the dung, it seems probable that there has been a considerably greater descent from the surface soil into the subsoil than on the chemically manured plots, probably accompanied by fixation of some portion in an unavailable state.

Strong hydrochloric acid, as a solvent for potash in soil analysis, is shown to be practically useless as a gauge of potash fertility where there is an abundance of total potash in mineral combination, as silicates, &c. No concordant results are obtainable except by working under the strictest arbitrary conditions, and the results, even when concordant, have little meaning apart from an independent knowledge of the history of the soil. With this knowledge the results are interesting, but in its absence are of little use except in extreme cases.

The results obtained by citric acid, however, are strikingly instructive and consistent. To illustrate this, it may be stated that the ratio of the average quantity of hydrochloric acid soluble potash in the surface soil of three potash-dressed plots to the average quantity found in seven plots not dressed with potash was 1·20 : 1. The citric acid soluble potash ratio, however, was 6·75 : 1. The plots dressed with dung for fifty years and nine years respectively gave, as compared with the same seven non-potash plots, hydrochloric acid soluble potash ratios of 1·27 : 1 and 1·23 : 1, while the citric acid soluble potash ratios were 10·67 : 1 and 9·17 : 1.

Probably when a soil in the surface depth contains as much as 0·01 per cent. of citric acid soluble potash, the special application of potassium salts is not needed.

The largest accumulation of unused manurial potash, whether applied as dung or as potassium salts, is in the surface soil; but a large proportion is also found by citric acid in the second and even in the third 9 inches. The subsoil accumulation is most evident in the dunged plots, and on the plot which, in addition to potassium salts, has received superphosphate with sodium and magnesium sulphates, but without nitrogen (abundant supply and small utilisation). Both sodium and magnesium salts, in presence of phosphates and nitrogen, have exercised a distinct influence in increasing the proportion of citric acid soluble potash in all depths on the plots on which no potash has been applied for fifty years, and which still maintain a higher yield of potash in their crops than that given by the plot with superphosphate and ammonium salts alone, though the equivalent of the potash added originally has been practically exhausted. Furthermore, sodium and magnesium salts, used in conjunction with potassium salts, have caused a larger retention of potash in a citric acid soluble condition than when potash has been applied without them, although the potash yielded in the crops has been greater under the influence of the other alkalies alluded to.

It is usually supposed that potash is pretty fairly retained by the surface soil of land containing, like the Rothamsted land, a fair pro-

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portion of clay. That this is the case, as compared with sodium salts, is beyond doubt (see paper by the late Dr. A. Voelcker, "On the Composition of the Waters of Land Drainage," 'Journal of the Royal Agricultural Society of England,' 1874); but the series of analyses of the Broadbalk subsoils that has now been made by means of weak citric acid solution, shows that potash, though "fixed" relatively to soda, is far more migratory than phosphoric acid, and descends much lower into the subsoil. At the same time it appears probable that a portion of it passes into a fixed and stable form of combination, from which weak citric acid fails to dislodge it.

The results yielded by the samples of soil and subsoil taken from the same plots at the different periods afford instructive comparisons, notwithstanding the age of the earlier samples at the time of their examination, which might have been expected to be responsible for considerable modifications in the condition of the less stable chemical compounds contained in them.

In consequence of the death of Her Most Gracious Majesty Queen Victoria, which took place on the 22nd of January, the meetings of the Society were suspended, by order of the President, until after the funeral of Her late Majesty, which took place on the 2nd February.

February 7, 1901.

Sir WILLIAM HUGGINS, K.C.B., D.C.L., President, in the Chair.

The President, in moving that a dutiful Address of Condolence and Homage be drawn up and presented by the Council of the Society to His Most Gracious Majesty the King, said:—

"The crape upon our Mace would remind us, if indeed we needed to be reminded, of the sorrow which is uppermost in every heart. We mourn to-day the greatest Queen the world has known—truly great by the supreme example She set, in Her own person, of sustained nobility of purpose, and of devotion to duty, and by the influence of Her wise and understanding heart, for the world's good, upon the councils of the Empire. We mourn more than a great Queen—a gracious Lady who by the brightness of Her domestic virtues, and Her rare power of kindly sympathy with Her subjects in all their joys and sorrows, had in a real sense become the Mother of Her Peoples. As Fellows of this Society, we mourn further a Sovereign Patron, who by Her enlightened encouragement and protection, has made possible through the sixty-three years of Her reign, an 'improvement of natural knowledge,' not only unprecedented, but even beyond the wildest dreams of the most enthusiastic of the Fellows who welcomed Her at Her accession—so much so, indeed, that *the Victorian Age* has become synonymous with *the Scientific Age*.

"But, though dead She yet speaketh to us through His Gracious Majesty the King, Her Son, a Fellow of this Society, whose words of yesterday are still in our ears, 'that it would be his constant endeavour to walk in Her footsteps.' We join in most loyal and heartfelt wishes that His Majesty may long reign over a united and prosperous Empire; and that under His fostering care Science may continue to advance with even accelerated steps."

The motion was seconded by Lord Lister and carried in silence, the Fellows present rising from their seats.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read:—

"The Boiling Point of Liquid Hydrogen, determined by Hydrogen and Helium Gas Thermometers." By Professor Dewar, F.R.S.

"On the Brightness of the Corona of January 22, 1898. Preliminary Note." By Professor H. H. Turner, F.R.S.

"Preliminary Determination of the Wave-lengths of the Hydrogen Lines, derived from Photographs taken at Ovar at the Eclipse of the Sun, May 28, 1900." By F. W. Dyson. Communicated by the Astronomer Royal, F.R.S.

"Investigations on the Abnormal Outgrowths or Intumescences on *Hibiscus vitifolius*, Linn.: a Study in Experimental Plant Pathology." By Miss E. Dale. Communicated by Professor Marshall Ward, F.R.S.

"On the Proteid Reaction of Adamkiewicz, with Contributions to the Chemistry of Glyoxylic Acid." By F. G. Hopkins and Sydney W. Cole. Communicated by Dr. Langley, F.R.S.

"The Integration of the Equations of Propagation of Electric Waves." By Professor Love, F.R.S.

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"Further Investigations on the Abnormal Outgrowths or Intumescences in *Hibiscus vitifolius*, Linn.: a Study in Experimental Plant Pathology."

By ELIZABETH DALE. Communicated by Professor H. MARSHALL WARD, F.R.S.

Received November 22, 1900,—Read February 7, 1901.

(Abstract.)

During the summer of 1899 some preliminary experiments were made in order to investigate the conditions determining the formation of certain outgrowths of which the structure had previously been examined.* These outgrowths consist chiefly of greatly enlarged and multiplied epidermal cells, with very thin walls; but the underlying parenchyma is often also affected. The cells concerned always lie immediately around a stoma, so that the guard-cells are lifted up as the outgrowth developes. The distribution of the outgrowths is therefore dependent upon that of the stomata, and they are pathological in origin and nature.

This year (1900) further experiments have been undertaken, which confirm and extend the conclusions suggested by the earlier work, and which show that we have here a clear case of a pathological phenomenon brought under control.

The plants used were chiefly *Hibiscus vitifolius*, but some observations were also made on *Ipomea Woodii*.

The experiments were designed to test the effects of moisture and light in inducing the formation of the intumescences, but they also served to show the influence of temperature. Most of them were made in the open air, as the outgrowths always arise on plants growing in a greenhouse.

I. In order to test the effects of *moisture* in the air and in the soil, plants were kept with their shoots in dry or moist air, and their roots in dry or damp soil. Various combinations of dry or damp air or soil were used, with the result that outgrowths were always formed in damp air (provided there was sufficient light and heat), whereas damp soil had no effect.

II. The effects of *light* were tested by growing plants in white light of varied intensity, and under glass of different colours. Outgrowths were developed under clear and whitewashed glass, and under red and yellow glass, but not under blue or green glass, nor in poor light, and never in darkness.

III. Observations as to the influence of temperature showed that,

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* Dale, "On Certain Outgrowths (Intumescences) on the Green Parts of *Hibiscus vitifolius*, Linn.," 'Proc. Camb. Phil. Soc.,' vol. 10, Part 4.

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given the other necessary conditions, the formation of outgrowths is promoted by heat.

Large outgrowths may be artifically induced with certainty in about two days on a single healthy branch (still attached to the plant), by isolating it in a damp atmosphere, and exposing it to a strong light at a high temperature.

The following is a brief summary of the principal experiments and conclusions:—

Effects of Moisture.

Number of experiment.	Conditions of experiment.	Result.	Remarks.
1	Shoot in open air; root in moderately damp soil	No outgrowths formed	Growth rapid and plant very healthy.
1*a*	Shoot in air of greenhouse; root in wet, undrained soil	Outgrowths formed	The leaves soon dropped off, and the plant ultimately died, after experiment was stopped.
1*b*	Shoot in open air; root in wet, undrained soil	No outgrowths formed	Leaves dropped off, but the plant recovered when experiment was stopped.
2*a*	Shoot in air of greenhouse; root in damp, undrained soil	Outgrowths formed	
2*b*	Shoot in open air; root in damp, drained soil	No outgrowths formed	Leaves became yellow and curled under.
3*a*	Shoot in air of greenhouse; root in damp, drained soil	Outgrowths formed	
3*b*	Shoot in damp air; root in damp, drained soil	,, ,,	
3*c*	,, ,, ,,	,, ,,	
4	Shoot in damp air: root in dry soil	,, ,,	
5	Shoot in dry air; root in dry soil	No outgrowths formed	Growth retarded.
6	Shoot in very dry air; root in dry soil	,, ,,	,, ,,
7*a*	One shoot (attached to the plant) isolated in damp air	Many outgrowths, on the isolated shoot only	In bright sunlight and hot weather.
7*b*	,, ,, ,,	,, ,,	,, ,, ,,
7*c*	,, ,, ,,	A few outgrowths, on the isolated branch only	In cool, almost sunless weather.
8	One shoot (attached to plant) isolated in water	No outgrowths formed	

Effects of Light.

Number of experiment.	Conditions of experiment.	Result.	Remarks.
9	Poor light; no sun......	No outgrowths formed	
10*a*	Light passing through yellow glass	Outgrowths formed	
10*b*	Light passing through a solution of potassium chromate	,, ,,	
11	Light passing through red glass	,, ,,	
12*a*	Light passing through blue glass	No outgrowths formed	
12*b*	Light passing through a solution of copper sulphate and ammonia	,, ,,	
13	Light passing through green glass	,, ,,	
14	Light passing through whitewashed glass	Outgrowths formed	
15*a*	Plant in darkness in a greenhouse	No outgrowths formed	
15*b*	Plant in darkness under a zinc cylinder in the open	,, ,,	

Effects of Temperature.

The formation of outgrowths (provided there is adequate moisture and light) is promoted by a high temperature.

The conclusions drawn from the above experiments are, that the outgrowths are formed in a moist atmosphere, provided that there is also adequate light and heat.

The immediate effect of the damp atmosphere is to check transpiration. This, in its turn, by blocking the tissues with water, disturbs the normal course of metabolism, and so leads (when the light and heat are sufficient) to changes in the metabolic activity of the plant, as is shown by the following facts:—

1. The outgrowths only develop if transpiration is reduced.
2. The outgrowths are chiefly formed on organs which are actively assimilating, *e.g.*, under ordinary, red or yellow glass; but only if transpiratory activity is lowered: they are not formed in the open.
3. They only occur (*ceteris paribus*) in plants in which there is an accumulation of starch.
4. They are formed under clear glass and under red and yellow glass, but not under blue or green glass, and in no case in darkness.

5. Their formation is accompanied by the production of oil, which is not found in normal leaves.
6. The presence of this oil suggests that events similar to those occurring in succulent plants are taking place, viz., reduced respiration and the development of osmotically active substances in excess.
7. It is therefore probable that the intumescences are due to the local accumulation of osmotically active substances, produced under the abnormal conditions, viz., reduced transpiration and consequent lack of minerals, while carbohydrates are being developed in excess.

"The Integration of the Equations of Propagation of Electric Waves."

By A. E. H. Love, F.R.S.

Received December 29, 1900,—Read February 7, 1901.

(Abstract.)

The equations of propagation of electric waves, through a dielectric medium, involve two vector quantities, which may be taken to be the electric force and the magnetic force; and they express the rate of change, per unit of time, of either vector, in terms of the local values of the other. Various forms may be given to the equations, notably, that employed by Larmor, in which the magnetic force is regarded as a velocity, and the electric force as the corresponding rotation. In this form there is one fundamental vector, viz., the displacement corresponding to the magnetic force, regarded as a velocity; and this displacement-vector may, in turn, be derived from a vector potential. Every one of the vectors in question is circuital; and the several components of them satisfy the partial differential equation of wave propagation, viz., $\ddot{\phi} = c^2\nabla^2\phi$, c being the velocity of radiation.

One way of integrating the equations is to seek *particular* systems of functions of the co-ordinates and the time, which, being substituted for the components of the vectors, satisfy the equations; more general solutions can be deduced by synthesis of such particular solutions. Owing to the circuital relations, certain known solutions of the partial differential equation of wave propagation are not available, for representing the components of the vectors. A very general system of particular solutions, which are available for this purpose, is obtained. These particular solutions are expressed in terms of spherical harmonics and arbitrary functions of the time; and they can be regarded as generalisations of others, given by Lamb, which depend in the same way upon spherical harmonics, and contain simple harmonic functions of the time. By means of them, we can describe two types of sources of electric

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radiation :—The sources of one type are similar to infinitesimal Hertzian vibrators, being related in the same way to an axis, but the dependence of the emitted radiation on time is arbitrary; the sources of the other type are obtained therefrom by interchanging the *rôles* of the electric and magnetic forces.

Another way of integrating the equations is to seek to express the values of the vectors, at one place and time, in terms of their values, at other places and times. The model for all investigations of this kind is Green's Theory of the Potential. The main steps are (1) the determination of particular solutions, which tend to become infinite, in definite ways, in the neighbourhood of chosen points; (2) the discovery of a theorem of reciprocity, connecting the values, on any chosen surfaces, of two sets of solutions; (3) the determination of the limiting form, assumed by the theorem of reciprocity, when the solutions of one system have the assigned character of infinity at a given point. The result is the expression of the values of the functions of the other system, at that point, and at a chosen instant of time, in terms of their values, at all points on an arbitrary surface, and at determinate instants of time. In the present theory, the solutions required for the first step are among those already found; the theorem of reciprocity is obtained by a modification of the process by which the fundamental equations can be deduced from the Action principle; and the limiting form of the theorem is found by adapting a process due to Kirchhoff. The result is that the radiation which arrives at a chosen point may be regarded as due to a distribution of imagined sources of radiation upon an arbitrary closed surface, separating the point from all the actual sources of radiation. The imagined sources are of the two types previously specified; and the directions of their axes, and the intensities of the radiation sent out from them, are determined simply and directly by the values, on the surface, of the vectors involved in the propagation of the waves. A method for replacing the imagined sources of either type by sources of the other type is indicated. The general theorem is verified by choosing, for the arbitrary surface and the point, a sphere and its centre; it then becomes equivalent to Poisson's well-known solution of the differential equation of wave propagation in terms of initial values. The "law of disturbance in secondary waves," to which the theorem would give rise, is also determined; it is, in essentials, the same as has been found by previous writers.

The general theorem is applied to the problem of the passage of radiation through an aperture. When a train of radiation comes to a perforated screen, or when electric vibrations take place in the dielectric on one side (the nearer side) of a conducting surface, in which there is an aperture, waves are sent out into the medium on the farther side; but the aperture also has the effect of generating a system of standing waves on the nearer side. These systems of waves become, to a great extent, determinate, if we combine with the general theorem the conditions of continuity of state of the dielectric on the two sides of the aperture. The determination is practically complete when the medium on the nearer side is the dielectric plate of a condenser, in which electric vibrations are taking place; and the result can be applied to determine the rate of decay of the vibrations due to transference of the energy to the external dielectric. The example of a condenser, with concentric spherical conducting surfaces, the outer conducting sheet being perforated by a small circular aperture, is worked out in detail; and the results suggest that the maintenance of the vibrations depends on the screening action of the outer conductor rather than on the largeness of the capacity of the condenser; in fact, the vibrations of the spherical condenser are much more slowly damped when the capacity of the condenser is small than when it is large, the outer conductor and the aperture remaining the same.

"On the Proteid Reaction of Adamkiewicz, with Contributions to the Chemistry of Glyoxylic Acid."

By F. GOWLAND HOPKINS, M.A., M.B., University Lecturer in Chemical Physiology, and SYDNEY W. COLE, B.A., Trinity College. (From the Physiological Laboratories, Cambridge.)

Communicated by Dr. LANGLEY, F.R.S. Received January 7,—Read February 7, 1901.

In 1874 Adamkiewicz[*] described the now familiar reaction which results in the production of a violet colour when strong sulphuric acid is added to the solution of a proteid in glacial acetic acid. Adamkiewicz did not apparently look upon the employment of the acetic acid as introducing anything beyond a certain modification of the action of sulphuric acid. His original communication opens with a description of the colour phenomena seen when egg-white is dissolved in strong sulphuric acid: and he begins the description of this reaction, since associated with his name, by speaking of "a special influence which the presence of glacial acetic acid has upon the colour of the sulphuric acid proteid solution." The view has since been generally held that the coloured product of the reaction arises entirely from the proteid molecule itself, as the result of an interaction between precursors liberated under the influence of the strong acids employed.

V. Udranszky[†] believed that the colour change which occurs is, as a matter of fact, to be classed as a furfurol reaction. It is therefore to be compared with the result of such a procedure as that of Molisch's

[*] 'Pflüger's Archiv,' 1874, vol. 9, p. 156.

[†] 'Zeitsch. f. physiol. Chem.,' 1888, vol. 12, p. 395.

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test, in which β-naphthol and sulphuric acid are added to a proteid solution. While in the latter the added naphthol is held to react with furfurol from the proteid; in the Adamkiewicz reaction both the furfurol and a substance capable of reacting with it are supposed to be liberated from the proteid molecule. Such we believe is the prevalent view. Of late years, the Adamkiewicz reaction has been much employed as giving evidence for the presence of carbohydrate groups in certain proteid derivatives, and of its absence from others. More than one writer,* however, has referred to an element of uncertainty in the reaction, and it is easy to gather from the literature that this has been commonly observed.†

In what follows it will be shown that the mechanism of the reaction has been wholly misunderstood. Proof will be given that the use of acetic acid introduces an extraneous and perfectly specific factor into the reaction, involving the addition of a substance quite necessary to the formation of the coloured product. This substance, moreover, is not acetic acid itself but an impurity, which, though very generally present, is admixed in varying quantity, and is occasionally absent.

I. *The Reaction due to an Impurity in Acetic Acid.*

We were led to pursue the following investigation by observing that, with a specimen of acetic acid in use in this laboratory last year, it was impossible under any circumstances to obtain the Adamkiewicz reaction.

No matter what form of proteid might be employed, when its solution in this acetic acid was mixed with sulphuric acid, a yellow or brown, slightly fluorescent mixture was all that could be obtained. No modification in the order of the procedure, or in the proportion of the two acids employed, resulted in the production of any trace of red or violet colour.

We afterwards obtained a number of specimens of acetic acid from various makers, and were surprised to find that no small proportion of these gave equally negative results; while, of the remainder, some yielded a much more intense reaction than others, although employed under precisely similar conditions.

Either, therefore, the negative result with particular specimens was due to the presence of some impurity capable of interfering with the production of colour, or the reaction itself must be due to a substance commonly, though not universally, present as an impurity in acetic acid.

We soon obtained evidence that the latter alternative must be accepted. For we found that whenever a specimen of glacial acetic

* *Cf.* Halliburton, 'Schäfer's Text Book of Physiology,' vol. 1, p. 47.

† *Cf.* Salkowski, 'Zeitsch. f. physiol. Chem.,' vol. 12, pp. 220, 222.

acid yielding a positive result is partially crystallised by freezing, the power to yield the reaction is diminished in the crystals and increased in the mother liquor. It is possible indeed, by repeated recrystallisation, to obtain glacial acid wholly incapable of giving the reaction.

Much more readily, however, is the reactive substance to be concentrated by distillation. Any specimen of glacial acetic acid, if distilled, will yield the whole of any chromogenic substance it may contain in the first runnings. After concentration to about half-bulk—more or less according to the proportion of reactive substance originally present —the residue will yield no trace of red or violet colour when mixed with proteid and sulphuric acid; while, on the other hand, the distillate twice or thrice fractionated yields the reaction with greatly increased intensity.*

It is easy to understand, therefore, why different specimens of acetic acid obtained in the market yield the reaction with different degrees of intensity, as this will depend upon the stage at which they were collected during distillation in bulk. It is also clear why the reaction has been looked upon by different observers as an uncertain one.

The accepted view, that the colour phenomenon is due to the interaction of two chromogenic groups, both derived from the proteid molecule under the action of the mixed sulphuric and acetic acids, is certainly erroneous. One factor necessary to the reaction is supplied by a substance admixed with the acetic acid. That it is in no sense a furfurol reaction is indicated by the fact that the addition of furfurol confers no power of yielding the colour with proteid upon a specimen of acetic acid previously without it; and, on the other hand, when furfurol is added to acetic acid containing the chromogenic substance in abundance, there is equally a complete absence of the reaction upon mixing with strong sulphuric acid.

II. *Nature of the Substance responsible for the Reaction.*

Our earlier attempts actually to isolate the active substance from acetic acid by fractional distillation were unsuccessful; and, having regard to the fact that, in a reagent so familiar as acetic acid, no admixture could well have been hitherto overlooked unless the substances were present in very small amount, we determined to seek first for indirect evidence, such as might give at least some indication as to the kind of substance we had to deal with.

To this end we set out to add to acetic acid, previously deprived by distillation of its chromogenic admixture, various compounds of typical constitution, in the hope that we might find among these some that would yield at least an analogous reaction.

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* This applies to glacial acid; with dilute acid of lower boiling point, concentration of the product by distillation is less easy.

Wholly negative results were obtained with various homologous fatty acids; with formic, acetic, and propionic aldehydes; with acetone, and with various ethereal acetates and other esters.

But, during this preliminary stage of our investigation, the interesting observation was made that formic acid, prepared from pure glycerin and pure oxalic acid, and used instead of acetic acid under the ordinary conditions necessary for the reaction, may yield the colour in a perfectly typical manner; the spectroscopic absorption of the product obtained being identical with that seen when acetic acid is used. But from the formic no less than from acetic acid, the chromogenic substance may be distilled off, appearing always in the earlier portions of the distillates, and leaving the remainder of the formic acid to yield wholly negative results.

This result—the explanation of which becomes clear in the sequel—appeared to limit somewhat the ground we had to traverse in our search.

A further and still more definite limitation came to light when we found that the reactive substance in acetic acid is not an impurity of wholly extraneous origin, but is a derivative of acetic acid itself. When a quantity of acetic acid wholly free from the reactive substance has stood for a few weeks, a reaction may always be obtained once more from the earliest portions of a distillate; and, after standing for a month or two, even the bulk may yield a colour of moderate intensity. (*Cf. infra.*)

When, again, a pure acetate, and especially calcium acetate, is distilled with excess of sulphuric acid, the first runnings always give a marked Adamkiewicz reaction, though later portions give none. This is true even when the acetate has been made by neutralising acid which was itself wholly incapable of giving a reaction.

Lastly, among the products of the dry distillation of most acetates small quantities of a substance are found which react with proteid in a typical manner. In the case of calcium acetate the reaction obtainable is a marked one—though, as stated above, the active substance is certainly not acetone—while with an aqueous extract of the products of the dry decomposition of mercuric (not mercurous) acetate the reaction with proteid is intense.

With such indications as these facts afforded, we now fortunately elected to experiment with various two-carbon compounds of typical structure, such as might conceivably arise from acetic acid, by oxidation or otherwise.

The first positive evidence came to light when we set out to prepare glycollic aldehyde by Fenton's method.* As a mere preliminary observation, we oxidised tartaric acid in solution, by means of peroxide of hydrogen in the presence of a little ferrous sulphate, without taking

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* 'Journ. Chem. Soc.,' 1895, vol. 67, p. 778.

especial care to keep the mixture at 0°, and without attempting to separate the dioxymaleic acid formed. A little of the oxidised solution was heated direct on the water bath till all evolution of CO_2 had ceased, and then cooled. A trace of Witte's peptone was added to the solution, which was free from excess of peroxide, and then strong sulphuric acid. An intense colour reaction was obtained exactly similar to that seen in a normal Adamkiewicz reaction when carried out with acetic acid rich in the chromogenic substance. The solution gave also in the spectroscope an exactly similar absorption band.

We found subsequently, however, that glycollic aldehyde, isolated, either in the syrupy or crystalline condition,* and whether in aqueous or acetic acid solution, gave no colour reaction under like conditions, but yielded only a charred product when the sulphuric acid was added. Moreover, acetic acid, however rich in the chromogenic substance, never reduces (after neutralising) alkaline copper solutions. A reduction of ammoniacal silver solutions may be obtained, but never any effect upon Fehling's solution.

We came to the conclusion, therefore, that the substance sought must be an oxidation product of glycollic aldehyde; and we now found that the latter needs only to be treated by Fenton's oxidation method carried out at the temperature of the water bath to give a product, which, when free from excess of peroxide, yields in acetic or aqueous solution the proteid reaction abundantly.

At this time we made another observation of the greatest assistance to our inquiry, finding that the chromogenic substance is produced in abundance when oxalic acid is reduced in aqueous solution by means of zinc and sulphuric acid, or, more conveniently, by sodium amalgam. The reduction need last for a few minutes only, and a little of the solution, without further treatment, will then be found to give an intense colour with proteid and sulphuric acid, the product showing spectroscopic appearances identical with those of the ordinary Adamkiewicz reaction.

There was now no doubt that a colour reaction, not to be distinguished from that of Adamkiewicz, is yielded by a substance which is at once an oxidation product of glycollic aldehyde and a reduction product of oxalic acid. It was difficult to see how this substance could be other than glycollic acid, glyoxylic acid, or glyoxal.

Pure glycollic acid was obtained from Merck. It gave no trace of a colour reaction with proteid solution and sulphuric acid. The product of its oxidation by Fenton's method reacted, however, in a perfectly typical manner, and Fenton and Jones have found that this product is glyoxylic acid.

The latter was therefore prepared from alcohol by the method of

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* Fenton and Jackson, 'Journ. Chem. Soc.,' vol. 75, p. 575, 1899. We were indebted to Mr. Hy. Jackson for a supply of the crystalline aldehyde.

Debus. The calcium glyoxylate first obtained was recrystallised thrice. A minute crystal of the salt dissolved in water, together with a little proteid, gave, upon the addition of strong sulphuric acid, a vivid colour reaction not to be distinguished, spectroscopically or otherwise, from the reaction of Adamkiewicz.

Glyoxal, prepared subsequently from the products of the same Debus oxidation, gave no trace of such a reaction.* When glyoxylic acid is added to glacial acetic acid, previously deprived of its chromogenic power by distillation, further distillation now yields a distillate which reacts typically, and the glyoxylic acid comes over characteristically, like the original chromogenic substance in the earlier fractions.

III. *Glyoxylic Acid from Acetic Acid.*

It now became necessary to ascertain whether glyoxylic acid is, as a matter of fact, present in such specimens of acetic acid as yield the Adamkiewicz reaction.

In seeking for evidence as to this, it was necessary to remember that exceedingly little glyoxylic acid is necessary to the reaction. With an aqueous solution of such strength as will give no more than an opalescence with phenyl hydrazine, the colour reaction with proteid is well marked.

It was found, however, that oxidation with hydrogen peroxide confers abundant chromogenic power upon acetic acid previously giving no proteid reaction; and it was our first endeavour to ascertain whether, as a result of this, glyoxylic acid is produced in quantity sufficient for its easier identification.

The presence of small quantities of ferrous iron accelerates the oxidation, and is, perhaps, essential to it.† The process occurs most rapidly at boiling temperature, and proceeds most satisfactorily when the acetic acid is repeatedly distilled with the peroxide. The limit of the oxidation is in any case soon reached. Using twenty volumes strength, the peroxide is found to be rapidly destroyed till a volume has been added about equal to that of the acetic acid taken; after this the reaction becomes very slow.

We proceeded as follows:—A litre of glacial acetic acid was mixed with an equal bulk of twenty-volume peroxide and some ammonio ferrous sulphate added (half a gramme per litre, or less). The mixture

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* Many specimens of commercial glyoxal give the reaction, but only, as we have found, when they contain glyoxylic acid; preparations of glycollic acid may contain traces of the latter.

† We have found that some specimens of peroxide bring about the oxidation without the addition of iron; others undoubtedly act much less readily, unless a ferrous salt is added. While we have been unable to detect the presence of iron in the former, so small a quantity appears to affect the reaction that it is possible a trace of the metal present as an impurity may account for the difference.

was slowly distilled nearly to dryness, and the distillate returned and again distilled. The second or third distillate usually showed freedom from peroxide when tested with chromic acid; if not, distillation was repeated.

One-tenth of the final distillate was set aside, and the remainder neutralised with potash. The still acid portion being then mixed with the rest, the whole was distilled as low as possible, avoiding, however, any separation of potassium acetate in the retort. The distillate always gave an abundant proteid reaction, and if any trace of free peroxide had been left at the previous stage, it always disappeared during the distillation of the partially neutralised mixture as just described. A small trace of free peroxide will interfere with the proteid reaction. On adding phenyl hydrazine hydrochloride (without acetate) to the distillate thus obtained, a light yellow precipitate begins to separate almost at once, and after standing it becomes considerable in amount, and is crystalline. But although, as we were able to show, the hydrazone of glyoxylic acid is present in this precipitate, it is mixed with a considerable proportion of a compound much less soluble in acetic ether and in hot water. If the original precipitate be recrystallised from a minimal quantity of acetic ether, the substance which separates first consists of perfectly colourless glistening plates, which after recrystallising from acetic ether may assume the form of rosetted prismatic needles. These melt sharply at 184°.

The nature of this substance became clear after the publication of certain recent observations. Gerhard Ollendorff has shown that formic aldehyde is formed when glycollic acid is oxidised with peroxide of hydrogen, and Fenton* calls attention to the fact that glyoxylic acid must in this case be the intermediate product. The product we obtained from acetic acid was undoubtedly the compound of formaldehyde described by Wellington and Tollens.†

A portion repeatedly recrystallised from acetic ether and showing a constant melting point (184°) was analysed.

0·147 gramme gave 27·4 c.c. moist N, at 12°, and 758 mm. N = 22·07 per cent.

Another preparation, recrystallised from a mixture of alcohol and toluol, melted at 182—183°; of this

0·211 gramme gave 39·3 c.c. moist N, at 14°, and 758 mm. N = 21·87 per cent.

I.	II.	Calculated for $C_{15}H_{16}N_4$.
22·07	21·87	22·22

This hydrazone can be obtained pure in the above manner with

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* Fenton, 'Journ. Chem. Soc.,' 1900, vol. 77, p. 1296.

† 'Deutsch. Chem. Ges. Berichte,' 1885, vol. 18, p. 3330.

[redacted]

great ease if not more than 4 to 5 grammes of phenylhydrazine hydrochloride have been added to the final distillate obtained after oxidising, as above, 1 litre of acetic acid, nearly neutralising the mixture and distilling. We prepared the compound from formaldehyde, and found it to agree with our product in every particular.

Formaldehyde certainly does not yield the proteid reaction, and its formation when acetic acid is treated as described seems to be in itself evidence for the formation of glyoxylic acid during the process, as it is difficult to see how it could arise during the oxidation of acetic acid if not from a preliminary formation of glyoxylic acid with subsequent loss of carbon dioxide.

But its formation adds greatly to the difficulty of obtaining pure the hydrazone of glyoxylic acid itself, especially as the precipitate produced by phenylhydrazine undoubtedly contains, in addition to the compound of Wellington and Tollens, smaller amounts of the derivatives described by J. W. Walker.[*]

After the nature of this bye-product was recognised we modified our procedure by neglecting the earlier portions of the final distillate which contains, of course, the greater part of the formaldehyde. Phenylhydrazine hydrochloride added to the latter half, or two-thirds, of such a distillate yields a precipitate which forms more slowly than that obtained when the whole is dealt with. After twenty-four hours it is usually crystalline and of a yellow colour, growing darker with further standing.

We found it easier to obtain a product with a constant melting point by recrystallising from hot water rather than from an organic solvent, prolonged heating with the water being at any stage avoided. This treatment involves considerable loss, however, and we obtained only about 4 decigrammes of the hydrazone after oxidising 3 litres of acetic acid. This, however, had all the characters of glyoxylic hydrazone, and melted sharply at 137°.

0·204 gramme gave 30·4 c.c. moist N at 16° and 750 mm. N = 17·14 per cent. Calculated for $C_8H_8O_2N_2$ = 17·07.

When acetic acid has been oxidised as described and the mixture partially neutralised and distilled, the distillate, when treated with excess of chalk, will yield, after standing and filtering, the reaction for glyoxylic acid described by Perkin and Duppa. If after treatment with chalk a slight excess of calcium hydrate be added, and the mixture concentrated *in vacuo* to about one-third its original bulk, this reaction with aniline oxalate is obtained in a highly characteristic manner.

The methods we have hitherto employed do not yield the glyoxylic acid in solutions of sufficient strength to permit of its calcium salt

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[*] 'Journ. Chem. Soc.,' 1896, vol. 69, p. 1280.

being separated from the associated acetate and isolated in substance. The ease with which the salt dissociates and the volatility of the acid with water vapour make concentration of small avail.

The evidence for the formation of glyoxylic acid during oxidation appears, however, to be conclusive, and it is interesting to note that, judging from the gradual development of the reaction with proteid, this oxidation goes on slowly when acetic acid is exposed to air, and especially under the influence of light. Ferrous iron undoubtedly accelerates this, and if acetic acid giving no proteid reaction be somewhat diluted, and a little ferrous salt added, exposure to direct sunlight will confer a reactive power in the course of a few hours.

We have not been able to separate the hydrazone in quantity sufficient for its identification from average specimens of untreated acetic acid; but it appears equally difficult to do so when small quantities of glyoxylic acid, sufficient to confer an average chromogenic power, have been added to a specimen previously giving no reaction.

On one occasion we obtained a quantity of glacial acid giving the reaction with special intensity. This acid had crystallised in bulk, and we were supplied with drainings from the crystals. Seven litres were fractionally distilled until the chromogenic substance was concentrated into about 1 litre. This was nearly neutralised and again distilled. Phenylhydrazine acetate added to the distillate gave a considerable quantity of crystalline precipitate, yellow at first, darkening on standing. This was obtained before we had identified glyoxylic acid as the substance sought, and most of the hydrazone was lost in preliminary solubility tests. A small quantity was reserved, however, and this, recrystallised thrice from hot water, melted sharply at 137°.

The observations we have hitherto made give no quantitative indications of any value. In this paper we have been mainly concerned with the endeavour to prove the nature of the active substance in the proteid reaction. We propose to study the oxidation of acetic acid further, and to define if possible the conditions necessary for a maximal yield of glyoxylic acid.

IV. *Remarks on the Colour Reaction: Spectroscopic Phenomena.*

Adamkiewicz* observed that the colour produced in the reaction varies from red to violet, the blue element increasing with increase in the amount of acetic acid employed. When glyoxylic acid in aqueous solution is used, unless the solution be very dilute, the colour partakes more of a blue shade than is usually seen with ordinary specimens of acetic acid. But after concentrating the reactive substance of the latter by fractional distillation (*supra*) or upon large dilution of the

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* *Loc. cit.*, p. 158.

glyoxylic acid solution, the colours obtained become identical. The spectroscopic absorption is identical whichever reagent is employed.

When sulphuric acid is added to a solution of proteid in acetic acid wholly free from glyoxylic acid, a considerable amount of charring occurs, and the mixture becomes somewhat fluorescent. When, under similar circumstances, very little glyoxylic acid is present, the reddish colour obtained is still associated with fluorescence. But, when sufficient of the glyoxylic acid is present, whether in acetic or aqueous solution, to combine with the whole of the proteid product concerned in the reaction, there is complete absence of charring and little or no fluorescence. The solution becomes of a pure violet-blue colour.

The coloured product of the Adamkiewicz reaction is usually stated to show an absorption band between *b* and F in the position of the urobilin band; and Krukenberg described another between D and E. Salkowski found the former to be inconstant, and we are convinced that the latter alone is proper to the real product of the colour reaction: the former, when seen, being due to some accessory effect of the strong acids upon proteids. It is never seen in the original form of the reaction unless the acetic acid employed is greatly deficient in reactive power, and it is not observed with glyoxylic acid. The other band is always present, and is identical after the use of a satisfactory specimen of acetic acid and when a solution of glyoxylic acid is used.

The band shrinks rapidly from its more refrangible edge on dilution of the solution, its redward edge shifting but little.

The following readings show the correspondence seen after employing acetic acid as obtained in the market (but with its active substance concentrated by distillation) and that seen after the use of glyoxylic acid in aqueous solution. The strengths were so arranged that, before dilution, the colour of each solution appeared to be of the same intensity. Witte's peptone was the proteid employed to obtain the reaction:—

	Acetic acid.	Aqueous glyoxylic acid.
Strong	λ 480—λ 625	λ 480—λ 630
Diluted with an equal volume of sulphuric acid	λ 495—λ 625	λ 495—λ 625
Diluted with thrice its volume of sulphuric acid	λ 530—λ 610	λ 530—λ 615

V. *Other Sources of the Reactive Substance.*

Of the typical two-carbon compounds—glycol, glycollic aldehyde, glycollic acid, glyoxal, glyoxylic acid, and oxalic acid—none but the aldehyde-acid (glyoxylic acid, HCO.COOH or CH(OH)$_2$.COOH), gives the smallest indications of yielding a colour-reaction with proteid on addition of sulphuric acid.. It would seem that the reaction is not common to aldehyde-acids, as glycuronic acid, $HCO(CH.OH)_4COOH$, gives wholly negative results. Again, a ketonic acid so closely related to glyoxylic acid as pyruvic acid, $CH_3.CO.COOH$, gives no indication of a reaction.

Glyoxylic acid stands, of course, alone in containing the aldehydic and carboxylic groups in juxtaposition. Our observations are far from being complete enough to enable us to assert that a reaction with proteid of the special type under consideration depends essentially upon this particular structure. But the preliminary observations we have made tend to give some probability to this view. At least it may be said that hitherto we have never obtained a reaction except with products in which either glyoxylic acid has been shown to be present, or in which its presence is extremely probable.

For instance, we have found that mesoxalic acid (prepared from barium alloxanate) in aqueous solution gives with proteid and sulphuric acid a perfectly typical Adamkiewicz reaction; but under the conditions employed we have found that a portion at least of the mesoxalic acid present loses carbon dioxide, so that it is in the highest degree probable that glyoxylic acid is in this case also the substance which reacts.

Pyruvic acid gives, as we have said, no trace of a reaction, but the product of its oxidation by peroxide of hydrogen undoubtedly reacts. *Paralactic acid*, itself inactive, yields also an active product on oxidation by Fenton's method at the temperature of the water bath. These two cases go together, as Fenton and Jones have shown that lactic acid yields pyruvic acid when oxidised at 0° in the presence of ferrous iron. It seems extremely probable that the oxidation of the pyruvic acid at the higher temperature yields mesoxalic acid, and that the reaction obtained is therefore due in each case to glyoxylic acid.

One abundant source of a reactive substance is found in the oxidation of *glycerin* by Fenton's method, carried out at the temperature of the water bath. *Glyceric acid* yields the substance under like conditions; and, as Fenton and Jones* have shown that glyceric acid, when the oxidation is carried out in the cold, gives a product which is almost certainly either hydroxy-pyruvic acid or the tautomeric substance dihydroxyacrylic acid, the facts here quite probably fall into line with those just enumerated. The substance which reacts with proteid is only obtained in quantity in these cases when the oxidation is carried out at higher temperatures than those used by Fenton, and if the oxidised products are distilled, it is always found that the distillate gives the reaction.

When *dextrose* solutions are boiled with peroxide in the presence of ferrous salts a substance is formed, volatile with steam, which yields

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* 'Journ. Chem. Soc.,' 1900, vol. 77, p. 72.

[redacted]

the proteid reaction abundantly. Preliminary observations that we have made leave little doubt that this is glyoxylic acid itself.

If it should prove that the reaction is, as a matter of fact, peculiar to glyoxylic acid, it certainly forms a very delicate test for that substance.

VI. *Glyoxylic Acid Solutions a Practical Test for Proteids.*

By replacing the acetic acid of the Adamkiewicz reaction by weak aqueous solutions of glyoxylic acid a very beautiful and reliable test for proteids is obtained. The colour reaction is brilliant, and the test is, of course, subject to none of the uncertainty inseparable from the use of acetic acid.*

In preparing such a test solution, there is usually no need to separate the glyoxylic acid from associated products. Excellent test solutions may be made by oxidising upon the water bath, in the presence of small quantities of ferrous iron, either weak solutions of tartaric acid or mixtures of glycerin and water, great care being taken to ensure that no trace of free peroxide remains at the close of the operation. But we strongly recommend the use of reduced oxalic acid for the purpose, as a solution can be prepared with great ease, and almost without regard to conditions. In a moderately strong solution of oxalic acid a few lumps of sodium amalgam are placed, the amount taken of the latter being less than sufficient to neutralise the acid. When the evolution of hydrogen has ceased, the solution is poured off from the mercury and filtered. It will be found, even after large dilution, to yield an intense reaction with proteids if used instead of acetic acid under the familiar conditions of the Adamkiewicz test. The proteid, or the proteid solution to be tested, should be first added to the reagent, and then strong sulphuric acid poured down the side of the test-tube. The reaction may be first observed at the junction of the fluids and the latter subsequently mixed. At least one-third volume of sulphuric acid should be used, but the quantity may be almost indefinitely increased. There is no tendency to charring.

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* It is certainly rare to find a specimen of acetic acid which yields no reaction, though many contain too little glyoxylic acid to give a satisfactory colour. It seems to be possible, however, that there have been cases of a proteid derivative being found to yield no Adamkiewicz reaction, in which the negative result was really due to the acetic acid employed. We have, for instance, prepared and carefully purified the primary albumoses from Witte's peptone by the method of E. P. Pick ('Zeitsch. f. physiol. Chem.,' 1899, vol. 28, p. 219). Unlike this observer, we have found these products to yield a marked Adamkiewicz reaction; and with all reserve, we venture to suggest that the acetic acid employed by Pick at this stage of his observations may have chanced to be free from chromogenic power.

[redacted]

Summary.

The proteid reaction described by Adamkiewicz is not a furfurol reaction, but depends upon the presence of small quantities of an impurity in the acetic acid employed. Some specimens of acetic acid yield no reaction, and all may be deprived of chromogenic power by distillation.

The substance essential to the reaction is glyoxylic acid.

Small quantities of glyoxylic acid are produced during the oxidation of acetic acid by hydrogen-peroxide in the presence of ferrous iron. Under the conditions used in this research, part of the glyoxylic acid thus formed is split up, yielding formaldehyde.

Glyoxylic acid is slowly formed when acetic acid stands in the air, and more rapidly in the presence of ferrous iron and under the influence of direct sunlight. Most specimens of acetic acid contain small amounts of glyoxylic acid as an admixture.

A dilute aqueous solution of glyoxylic acid, which may be readily prepared by the reduction of oxalic acid with sodium amalgam, forms an admirable test for proteids when used instead of acetic acid under the ordinary conditions of the Adamkiewicz test.

In carrying out this investigation we have been led to employ extensively the method of oxidation described by H. J. H. Fenton, and as a result we have in some degree trenched upon the systematic study of the oxidation of organic acids which he has in hand. It is with his consent that such of our observations are published.

The expenses of the research were met by a grant awarded to one of us by the Government Grant Committee of the Royal Society.

"Preliminary Determination of the Wave-lengths of the Hydrogen Lines, derived from Photographs taken at Ovar at the Eclipse of the Sun, 1900, May 28." By F. W. Dyson, M.A., Sec. R.A.S. Communicated by W. H. M. Christie, C.B., M.A., F.R.S. Received January 17,—Read February 7, 1901.

The spectrum of the "flash" obtained in observations of solar eclipses furnishes a method of determining the wave-lengths of the hydrogen series with great accuracy, as these lines are strongly shown and sharply defined. As the determination of these wave-lengths is somewhat removed from the general subject of eclipse spectroscopy, it seemed suitable for a separate paper.

The following determination is made from four photographs taken near the beginning of totality at Ovar, at the eclipse of 1900, May 28, in the expedition from the Royal Observatory, Greenwich. The spectroscope used is a four-prism quartz spectroscope, kindly lent by Captain Hills. The length of the spectrum from *h* (λ 4102) to the limit of the hydrogen series (λ 3640) is 40 mm., so that the scale is about 10 tenth-metres to the millimetre.

The spectra were measured with one of the astrographic micrometers of the Royal Observatory (a micrometer originally designed for measuring the photographs taken at the transit of Venus) by comparison with a glass scale divided to millimetres. The errors of the 5-mm. divisions have been accurately determined in the course of investigations of the errors of the réseaux used in the photographic chart of the heavens. The errors of the intermediate divisions were determined by Mr. Davidson. The value of one revolution of the screw of the micrometer is approximately $\frac{1}{3}$ mm.

The wave-lengths were deduced from the measures by an interpolation formula, derived principally from the following lines, whose wave lengths are taken from Rowland's tables :—

Ca	3968·625	Ti.........	3761·464
Ca	3933·825	Ti.........	3759·447
Ti	3913·609	Cr Ti ...	3757·824
Ti	3900·681	Ti.........	3741·791
Mg	3838·435	Ti Fe ...	3722·729
Mg	3832·450	Y	3710·431
Mg	3829·501	Ti.........	3685·339
Y.........	3788·839	Fe Ti ...	3659·901
Y.........	3774·473		

These lines are the strongest lines in this part of the "flash" spectrum. In some of the photographs a number of the strongest iron lines were also used as lines of reference. On the photographs taken a few seconds before the eclipse became total the iron lines are unsuitable as lines of reference, as in some cases both a bright line and an absorption line are seen, and in other cases the lines have a grey appearance, and are not sharp and clear like the lines given above.

The wave-length of *h* is only derived from one photograph, and is not determined accurately. The value obtained agrees with the result given by Mr. Wright,* in showing a correction of 0·1 of a tenth-metre to the value given by Rowland.

The intensities of the lines are given somewhat roughly. With the exception of the cases noted where other lines apparently interfere, the diminution of intensity is sensibly uniform.

A comparison has been made with the wave-lengths given by Balmer's law, using the formula $\lambda = 3646{\cdot}140 \frac{n^2}{n^2 - 4}$, the constant of

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* 'Astroph. Journ.,' vol. 9.

which agrees very closely with the wave-lengths of the three lines H_α, H_β, H_γ given by Rowland. No correction to the formula has been deduced, as only a small one is indicated, and it is desirable to use a larger number of lines of reference than has been employed in this investigation. The wave-lengths were determined from each series of measures separately, and from the accordance of these the probable errors of the resulting determination of wave-lengths lie between ± 0·01 and ± 0·02 of a tenth-metre for the different lines.

Hydrogen line.	Int.	*n*.	Observed wave-length.	Wave-length by Balmer's law.	Diff.	Remarks.
δ	40	6	4101·88	·907	+ ·03	Only measured on one photograph.
ε	40	7	3970·229	·241	+ ·012	
ζ	60	8	3889·101	·216	—	Helium line at 3888·785 not separated.
η	40	9	3835·540	·550	+ ·010	
θ	30	10	3798·057	·063	+ ·006	
ι	30	11	3770·765	·794	+ ·029	
κ	25	12	3750·322	·315	− ·007	
λ	18	13	3734·565	·531	− ·034	Touching Fe line at 3735·014.
μ	18	14	3722·060	·101	+ ·041	
ν	16	15	3712·109	·133	+ ·024	
ξ	16	16	3703·981	·015	+ ·034	
ο	15	17	3697·283	·313	+ ·030	
π	13	18	3691·670	·717	+ ·047	
ρ	11	19	3686·950	·992	+ ·042	
σ	9	20	3682·954	·967	+ ·013	
τ	7	21	3679·483	·514	+ ·038	
υ	6	22	3676·568	·525	− ·043	3676·457 Fe Cr 3676·698 Co } probably interfere.
φ	4	23	3673·914	·920	+ ·006	
χ	5	24	3671·574	·638	+ ·064	Probably Zr 3671·412 interferes.
ψ	3	25	3669·595	·625	+ ·030	
ω	1	26	3667·891	·843	− ·048	
α′	2	27	3666·185	·256	+ ·071	
β′	4	28	3664·770	·838	+ ·068	Partly due to Y at 3664·760.
γ′	1	29	3663·565	·553	− ·012	
δ′	5	30	3662·373	·418	+ ·043	Mainly due to Ti at 3662·378.
ε′	1	31	3661·475	·330	− ·095	Possibly 6661·509 Fe interferes.

[redacted]

"On the Brightness of the Corona of January 22, 1898. Preliminary Note." By H. H. Turner, D.Sc., F.R.S., Savilian Professor. Received January 18,—Read February 7, 1901.

1. In a former note* I gave some account of measures of brightness made on photographs of the corona of 1893 by Abney's method. The same method has been used on the coronal photographs taken in 1898 and in 1900 (in 1896 none were obtained owing to cloud), and a large number of measures have been made, though the work is not yet complete. Pending the completion and publication of this work, it seems advisable to publish the present note, as one or two results have been arrived at which may be useful to others in the forthcoming eclipse.

2. As regards the method of measurement, sufficient has been said (for the present purpose) in the paper already quoted. It need only be added that in place of the revolving sectors a graduated wedge of gelatine was used to diminish the comparison beam, according to Sir W. Abney's more recent methods. The wedge or sectors are mere intermediaries between the coronal image and the standard squares, and no considerations beyond those of convenience are involved. The wedge is much more convenient, and the work can be done with it twice as rapidly.

3. But a new method has been adopted of representing the results, which, though an elementary change in some respects, has had the important consequence of suggesting a more satisfactory law for the variation of coronal brightness with distance from the sun. The only simple law (so far as I am aware) which has hitherto been formulated was that proposed by Professor Harkness in 1878, viz.:—

$$\text{Brightness} \propto (\text{distance from sun's limb})^{-2}.$$

Visual measures made by Thorpe and Abney in 1886 and 1893 could not be reconciled with this law; though I showed in the paper already quoted that if the distance be measured from a point *within* the limit (about $\frac{1}{5}$ radius within), the law approximately satisfied the photographic measures.

I have now been led to a completely new law, viz.:—

$$\text{Brightness} \propto (\text{distance from sun's } \textit{centre})^{-6},$$

which, though still on trial, is supported by a fair amount of evidence, and the suggestion arose in the following way:—

4. The brightness curve in the previous paper was obtained by plotting brightness against distance. This gives a curve of hyperbolic

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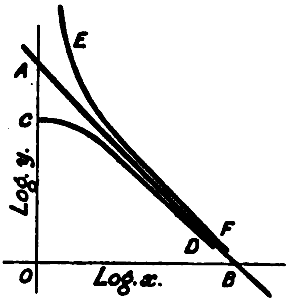
* 'Roy. Soc. Proc.,' vol. 66, p. 403.

form close to the two axes of reference, and difficult to compare the observations with, for reasons which are tolerably obvious. The curve is still hyperbolic if log (brightness) be plotted against distance; but if the brightness varies as any power of the distance, and we plot log (brightness) against log (distance), we get a straight line, which is particularly easy to compare observations with. The only difficulty is that we must know where to measure our distance from; for if we add or subtract a constant to the distance, it will change the straight line into a curve. And unfortunately the point from which the distance was to be measured seemed just one of the things to be determined.

5. But after some preliminary experiments I found that it was not difficult to find the proper origin from which to measure the distance, by the very condition that the curve was to be a straight line.

FIG. 1.



If in the equation

$$\log y + n \log x = \text{const.}$$

represented by the straight line AB in fig. 1, we write $(x + a)$ for x, then the calculated values of $\log y$, when x is large compared with a, will be nearly the same as before; but when x is small $\log (x + a)$ will be increased, and $\log y$ therefore diminished, and we get a curve such as CD. (If a be negative, we get a curve such as EF.) And a very few trials (perhaps one alone suffices) give the value of a, which will straighten the curve.

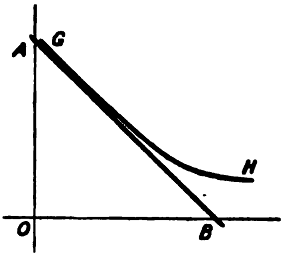
6. These values immediately pointed to the sun's centre as the proper origin for measurement; and when the observations were plotted on this assumption, the curve was practically a straight line, and the slope of this line indicated that the index n was 6, giving the law already stated, viz.:—

$$\text{Brightness} \propto (\text{distance from sun's centre})^{-6}.$$

7. But one further point is to be noted. The curve was practically straight for some distance from the limb, but then always turned

upwards like the curve GH in fig. 2. Now comparing this with CD in fig. 1, it suggests that just as CD could be explained by the addition of a constant to the *distance*, which made a variable alteration in the log distance, so GH may be explained by the addition of a constant to the *brightness*, making a variable alteration in the log brightness. And there is a possible physical cause for this constant addition, viz., the general sky illumination or glare which is added to the coronal brightness. A value of about 0·012 of the average brightness of the full moon for this illumination seems to satisfy requirements for the 1898 photographs.

Fig. 2.



8. I proceed to give a brief summary of the measures on the photographs of 1898 so far as they have gone.

Four photographs have been selected for measurement, three of them taken by me at Sahdol with exposures of 1 sec., 2 secs. and 20 secs., and one taken by Capt. Hills at Pulgaon with exposure 8 secs. On these, measures have been made along six radii extending approximately N., S., E., W., N.E., and S.W., the last two being as nearly as possible in the direction of the main streamers.

9. The exposures given to the standard squares were all the same. These squares transmit fractions of the light ranging from 0 to 4 on a scale of powers of 2, a range which might be extended with advantage, seeing that measures on the corona can be profitably made over a range of 0 to 7 at least. But the smallness of the range is made up for in practice by the measurement of photographs with different exposures. Thus the longer exposures of 20 secs. and 8 secs. in the above series control the fainter parts of the corona, and the shorter of 1 sec. and 2 secs. control the brighter parts near the limb.

10. In comparing the results from the different plates, it is found that the brightnesses shown by one plate differ from those shown by another in a constant *ratio*. Since the log (brightness) is tabulated this means a constant *difference* between similar numbers for the two plates. Following Sir W. Abney's practice, I have used the base 2 for the logarithms of brightness, and recorded to 0·1, which represents a

ratio of $2^{0\cdot 1} = 1\cdot 07$. (The logarithms of distance have been taken to base 10 in the ordinary way.) These differences between the plates may be due to any combination of the following causes:—

(*a.*) Accidental error in exposure to corona. The exposures were made without any mechanism, and the short ones especially may be sensibly in error. Thus the difference between the 1 sec. and 20 secs. exposure is 0·8. If the whole of this be due to accidental error in the 1 sec. exposure, it would mean that the exposure was for $1 \text{ sec.} \times 2^{-0\cdot 8} = 0\cdot 58$ sec. instead of for 1·0 sec., which is not an extravagant supposition.

(*b.*) Accidental error in exposure to squares. This should be much smaller than (*a.*).

(*c.*) Difference in sensitiveness of the film near the edge of the plate where the squares are impressed, and in the centre where the corona is impresssed. There is independent evidence of sensible differences of this kind, and the point is under investigation.

(*d.*) Differences in the behaviour of the candle which impressed the squares on the various plates.

(*e.*) Climatic differences between Sahdol and Pulgaon.

11. It becomes necessary to decide which plate to take as the standard. Cause (*a.*) ought not to affect the 8 secs. and 20 secs. appreciably, but cause (*e.*) may. They differ by 0·5, and we may perhaps take the mean. The corrections to be applied to the plates are then

Plate	I	II	III	IV
Exposure......	1 sec.	2 sec.	8 sec.	20 sec.
Place	Sahdol	Sahdol	Pulgaon	Sahdol
Correction ...	+0·6	−0·2	+0·3	−0·2

If any other selection is preferred, it is easily applicable as a constant to the final numbers.

12. The correction for constant illumination of the plate due to skyglare has been adopted as $2^{-6\cdot 4}$ moon, taking the moon as equal to 0·02 of a candle at 1 foot. If at any point the corona has a brightness represented by x, meaning $2^x \times$ moon, then the brightness measured on the plate will appear as y where

$$2^x + 2^{-6\cdot 4} = 2^y.$$

A table was formed giving y in terms of x, of which the following is a portion:—

[redacted]

x.	Correction to x.	y.
−2·0	0·0	−2·0
−3·0	+0·1	−2·9
−4·0	+0·2	−3·8
−5·0	+0·4	−4·6
−6·0	+0·8	−5·2
−7·0	+1·3	−5·7
−8·0	+2·0	−6·0

13. The measures on the plates were then corrected—

(*a*.) For the particular plate, as in § 10;
(*b*.) For the sky-glare, as in § 11;

and compared with the curve

$$\text{brightness} \times (\text{distance})^6 = \text{A}$$

to get the value of the constant A for each of the six radii measured. As above explained, the curve used was a straight line, obtained by plotting log brightness as ordinate and log distance as abscissa. The constants found for the six radii were as follows—adopting as unit of brightness that of the moon (assumed 0·02 candle at 1 foot), and of distance that of the sun's radius, so that the constants represent the brightness of the corona at the sun's limb expressed in moons:—

Radius.	**N.**	**N.E.**	**E.**	**S.**	**S.W.**	**W.**	**Mean.**
A =	+0·4	+1·9	+1·7	0·0	+2·3	+0·6	+1·15

Thus at the sun's limb the corona is more than twice as bright as the full moon on the average.

14. Finally, the individual measures were compared with the adopted law, with the following results. In the column "Typical Curve" the calculated brightness is given for A = + 0·6, the actual figures for the different streamers differing from this throughout by constants which are easily inferred from the values of A given above.

Table I.—Comparison of Observed Brightness (Photographic) of 1898 Corona with the Law.

Brightness × (distance from Sun's centre)^6 = constant.

(The distances were measured in divisions of 13 to the Sun's radius. The brightnesses are expressed by powers of 2, zero representing Moon's brightness.)

Distance from Sun's centre in radii.	Typical brightness of corona alone.	Typical brightness with "glare" added.	Observed error of formula.						
			Plate.	N.	N.E.	E.	S.	S.W.	W.
1·08	+ 0·1	+0·1	I	+0·6	—	−0·1	+0·7	—	+0·4
1·15	− 0·4	−0·4	I	+0·6	−0·1	0·0	+0·4	−0·7	+0·4
1·23	− 1·0	−1·0	I	+0·2	—	−0·1	+0·2	−0·4	0·0
1·31	− 1·5	−1·5	I	+0·5	+0·1	+0·2	−0·2	−0·3	+0·1
1·38	− 2·0	−2·0	I	−0·4	—	0·0	0·0	0·0	+0·1
1·46	− 2·5	−2·4	I	0·0	+0·1	−0·5	+0·3	−0·1	−0·1
1·61	− 3·3	−3·1	I	−0·3	−0·5	−0·7	—	0·0	—
1·77	− 4·1	−3·8	I	—	−0·1	—	—	+0·2	—
1·92	− 4·9	−4·4	I	—	−0·1	—	—	+0·2	—
1·31	− 1·5	−1·5	II	+0·8	—	—	−0·1	—	—
1·38	− 2·0	−2·0	II	0·0	—	—	−0·3	—	+0·2
1·46	− 2·5	−2·4	II	−0·2	—	—	−0·5	—	−0·1
1·54	− 2·9	−2·8	II	−0·3	+0·5	+0·6	−0·3	—	−0·2
1·61	− 3·3	−3·1	II	−0·4	+0·1	+0·2	−0·3	+0·3	−0·2
1·77	− 4·1	−3·8	II	−0·2	−0·2	+0·1	−0·1	−0·1	−0·1
1·92	− 4·9	−4·4	II	—	−0·2	+0·1	—	+0·1	—
2·15	− 5·8	−5·1	II	+0·1	−0·3	+0·1	—	+0·2	—
2·54	− 7·2	−5·8	II	—	—	—	—	+0·3	—
1·46	− 2·5	−2·4	III	0·0	—	—	+0·1	—	—
1·61	− 3·3	−3·1	III	0·0	—	—	+0·1	—	0·0
1·77	− 4·1	−3·8	III	+0·1	+0·4	+0·2	+0·1	0·0	−0·1
1·92	− 4·9	−4·4	III	−0·1	+0·2	+0·2	+0·1	+0·1	−0·2
2·15	− 5·8	−5·1	III	−0·1	0·0	−0·1	+0·1	0·0	0·0
2·54	− 7·2	−5·8	III	+0·2	+0·2	+0·1	—	0·0	0·0
2·92	− 8·5	−6·1	III	—	+0·4	0·0	—	−0·1	—
1·92	− 4·9	−4·4	IV	+0·1	—	—	+0·3	—	—
2·08	− 5·5	−4·9	IV	+0·2	−0·4	—	+0 4	—	+0·4
2·23	− 6·1	−5·3	IV	+0·2	−0 2	0·0	+0·4	—	+0·2
2·38	− 6·7	−5·6	IV	—	−0.2	+0·1	—	0·0	+0·2
2·54	− 7·2	−5·8	IV	+0·2	−0·2	0·0	+0·5	0·0	+0·2
2·92	− 8·5	−6·1	IV	−0·1	−0·2	+0·1	+0·3	0·0	+0·3
3·31	− 9·6	−6·3	IV	—	−0·1	+0·1	+0 1	−0·1	0·0
3·69	−10·5	−6·3	IV	—	−0·2	0·0	—	−0·3	—
4·08	−11·4	−6·4	IV	—	−0·4	—	—	−0·3	—

15. Considering the irregularity of the coronal structure, we cannot perhaps expect better agreement with any simple law of brightness than is shown by these residuals; and the assumed law, whether it has

any physical significance or not, is, at any rate, a convenient method of expressing the facts. We may now turn to the measures previously given of the 1893 corona,[*] and see how they accord with this formula. On trial, it is found that a fair accordance can be secured if the constant correction for sky-glare be taken as $2^{-7 \cdot 8}$ instead of $2^{-6 \cdot 4}$, and the constants for the four radii measured be

N.	S.	E.	W.	Mean.
−0·1	+0·4	+0·5	+0·1	+0·23

16. With regard to the smaller value for sky-glare, if this depends on the general brightness of the corona itself, we may remark that the 1893 corona was generally fainter, according to the measures, than the 1898 corona, the mean constant for the former being + 0·23, and for the latter + 1·15. The difference is + 0·92, so that the 1898 corona was about twice as bright, and hence twice as bright a sky illumination is not unreasonable.

Table II.—Comparison of Observed Brightness (Photographic) of 1893 Corona with the Law.

Brightness × (distance from Sun's centre)^6 = constant.

(The distances are given in units of the Sun's radius. The brightnesses are expressed by powers of 2; zero representing the Moon's brightness.)

Distance from Sun's centre.	Typical brightness of corona alone.	With "glare" added.	Observed error of formula.			
			N.	S.	E.	W.
1·1	+0·2	+0·2	—	−0·9	—	—
1·2	−0·6	−0·6	−0·1	−0·4	—	—
1·3	−1·2	−1·2	—	−0·1	—	+0·1
1·4	−1·9	−1·9	+0·4	+0·4	−0·3	+0·3
1·5	−2·5	−2·5	+0·2	+0·4	—	+0·5
1·6	−3·0	−2·9	0·0	+0·3	—	—
1·7	−3·6	−3·5	−0·1	+0·4	—	+0·3
1·8	−4·1	−4·0	0·0	+0·2	+0·5	+0·1
1·9	−4·6	−4·4	−0·2	+0·1	—	0·0
2·0	−5·0	−4·8	−0·2	−0·1	—	—
2·1	−5·4	−5·2	−0·2	−0·2	—	−0·3
2·2	−5·8	−5·5	−0·1	−0·2	−0·2	−0·7
2·3	−6·2	−5·8	−0·3	−0·3	—	0·0
2·4	−6·6	−6·1	+0·2	−0·1	—	—
2·5	−7·0	−6·3	+0·1	0·0	—	0·0
2·6	−7·3	−6·5	+0·3	0·0	0·0	+0·1
2·7	−7·6	−6·7	—	+0·1	—	−0·1
2·8	−7·9	−6·8	+0·3	−0·1	—	—
2·9	−8·2	−7·0	—	−0·1	—	+0·1
3·0	−8·5	−7·1	+0·3	−0·1	0·0	+0·1

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[*] 'Roy. Soc. Proc.,' vol. 66, p. 403.

17. The discrepancies are again not large, and some of them may be due to the extrapolation which was necessary for the brighter parts of the corona, the standard squares not having been given a long-enough exposure (as stated in the former paper) to compare with the long exposure of 50 secs. to the corona. Measures on plates with a shorter exposure to the corona will perhaps allow of more accurate results near the sun's limb. Unfortunately no plate is available with an exposure shorter than 5 secs., but measures on this plate, so far as they have gone, indicate a closer accordance with the theoretical formula near the limb. Further measures are, however, required.

18. With the assumed law

$$\text{brightness} = Ar^{-6},$$

where r represents distance from the sun's limb in solar radii, the total brightness of the corona is

$$\int_1^\infty Ar^{-6} \times 2\pi r dr = \tfrac{1}{2}\pi A,$$

the total brightness of the full moon being represented by

$$\int_0^1 2\pi r dr = \pi.$$

Thus the ratio of the total brightness to that of the moon is $\frac{1}{2}$ A. In 1898 the value of A was approximately $2^{1\cdot15} = 2\cdot2$, and thus the whole corona was about equal to the full moon. In 1893 the value of A was $2^{0\cdot23} = 1\cdot2$; and the whole corona was thus about 0·6 of the full moon.

19. But we have omitted the constant illumination of the sky in this integral. If we include a portion of sky extending to distance R from the limb, and B be the value of the constant for "glare," which in 1893 was taken as $2^{-7\cdot8} = 0\cdot0046$, and in 1898 was $2^{-6\cdot4} = 0\cdot012$, then we must add to the above quantities

$$\frac{1}{\pi} B \int_1^R 2\pi r dr = B(R^2 - 1) \text{ full moon.}$$

It is not, however, easy to assign a definite value to R.

20. The integral brightness of the corona was measured in 1893 by the late Mr. James Forbes, jun.,* and found to be 1·1 full moon. We find $[0\cdot6 + B(R^2 - 1)]$ full moon.

If the two quantities be equated, we get

$$B(R^2 - 1) = 0\cdot5$$

or

$$R^2 = 0\cdot5/0\cdot0046$$

$$= 110$$

or

$$R = 10\cdot5.$$

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* 'Phil. Trans.,' A, 1896, p. 433.

[redacted]

Thus, if we suppose that Mr. Forbes measured the total light within a circular area 5° in diameter, which seems a fair supposition,* the two measures of total brightness agree.

On the same supposition, the value of B $(R^2 - 1)$ in 1898 would be 1·3 full moon, and the total brightness of the corona would appear as 1·1 + 1·3 = 2·4 full moon.

Summary.

(*a.*) The brightness of the corona of 1898 at a point distant *r* from the sun's *centre* expressed in solar radii may be approximately represented by the formula

$$\text{brightness} = Ar^{-6} + B,$$

where A and B are constants.

(*b.*) The first term may be considered as corona proper, while B may be taken as representing the constant illumination of the sky, or glare. In 1898 the value of B was $2^{-6\cdot4} = 0\cdot012$ moon, taking the brightness of the moon as 0·02 candle at 1 foot.

(*c.*) The constant A varies with the radius along which measures are made. In 1898 it varied from $2^{0\cdot6}$ moon to $2^{1\cdot9}$ moon, the mean being $2^{\cdot115}$ moon or 2·2 moon.

(*d.*) The same formula will fairly represent the 1893 corona, the mean value of A being $2^{0\cdot28} = 1\cdot2$, and the value of B $2^{-7\cdot8} = 0\cdot0046$.

(*e.*) The total brightness of the corona depends on the area of sky included. If a circular area 5° in diameter be included, the total brightness of the 1893 corona may be taken as 1·1 full moon, agreeing with the visual measures made, and that of 1898, on the same supposition, would be about 2·4 full moon.

"The Boiling Point of Liquid Hydrogen, determined by Hydrogen and Helium Gas Thermometers." By JAMES DEWAR, M.A., LL.D., F.R.S., Professor of Chemistry at the Royal Institution, and Jacksonian Professor, University of Cambridge. Received January 8,—Read February 7, 1901.

In a former paper† it was shown that a platinum-resistance thermometer gave for the boiling point of hydrogen −238°·4 C., or 34°·6

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* The dimensions of the box are not given, either here or in the previous paper to which we are referred; but on p. 369 of the 'Philosophical Transactions, A, 1889, there is a diagram of the box, from which it would appear that the angular aperture was not greater than 12°, judging by outside measurements.

† "On the Boiling Point of Liquid Hydrogen under Reduced Pressure," 'Roy. Soc. Proc.,' 1898 (vol. 64, p. 227).

absolute. As this value depended on an empirical law correlating temperature and resistance, which might break down at such an exceptional temperature, and was in any case deduced by a large extrapolation, it became necessary to have recourse to the gas thermometer.

In the present investigation the advantage claimed for the constant pressure gas thermometer over the constant volume thermometer is absent. The effect of high temperature combined with large increase of pressure does not occur in these experiments, where only very low temperatures and a maximum range of pressure of less than one atmosphere were encountered. At the same time, before dispensing with the effect of pressure upon the capacity of the reservoir of the thermometer, it was carefully estimated and found that it could not affect the volume of the reservoir by as much as 1/60,000th part. This being determined, a particular advantage results from the use of the constant volume form, because in its case it is unnecessary to know the actual volumes of the reservoir, and of the "outside" space. It is only necessary to know the ratio of these two volumes, and as this ratio appears only in the small terms of the calculation, it is not a serious factor in the estimation of such low temperatures.

Two constant volume thermometers (called No. I and No. II) were employed, in each of which the volume of the reservoir was about 40 c.c., and the ratio of the outside space to the volume of the reservoir was 1/50 and 1/115 respectively. A figure of the apparatus is given herewith, where A is the thermometric bulb covered with a vacuum vessel to hold the liquid hydrogen, and be exhausted when necessary; B is the manometric arrangement for adjusting the mercury at C to constant volume, and D is the barometer. The readings were made on a fixed scale by means of a telescope with cross-wires and level attached. A similar telescope was permanently fixed on the mark to which the volume had to be adjusted. As the observations had to be made quickly, it was found convenient to use both telescopes on the same massive stand and to read the barometer placed alongside simultaneously.

The formula of reduction used was that given by Chappuis in the 'Travaux et Mémoires du Bureau International des Poids et Mesures,' tom. vi. p. 53, namely,

$$\left(V_0 + \frac{v}{1 + \alpha t}\right) H_0 = \left(\frac{V_0(1 + \delta T) + \beta h}{1 + \alpha T} + \frac{v}{1 + \alpha t}\right) (H_0 + h) \ldots \quad (1),$$

where V_0 is volume of reservoir at 0° C,

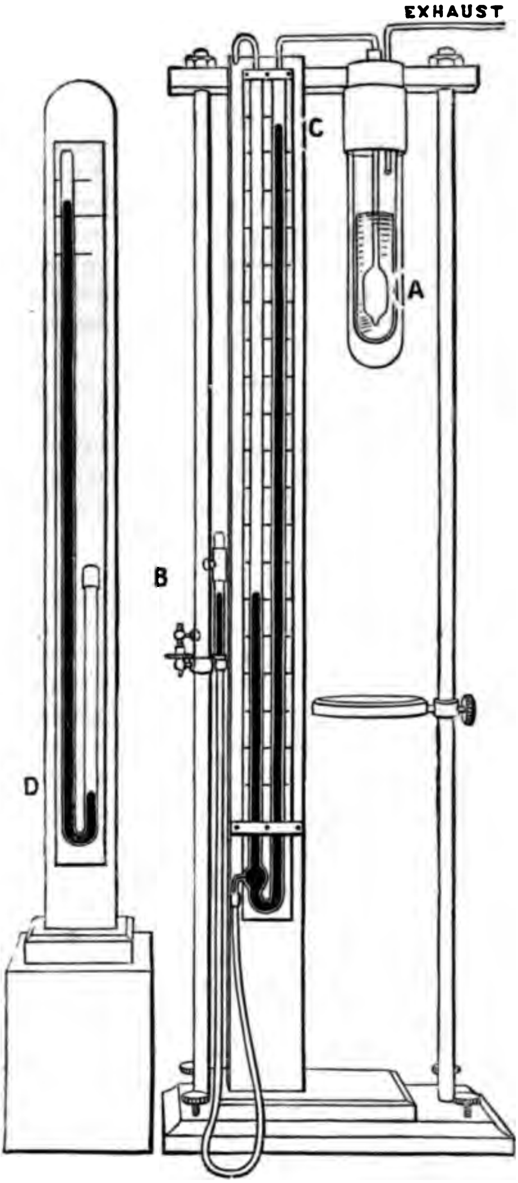
T, temperature of reservoir, measured from 0° C,

v, volume of "outside" space at the temperature of the room,

t, temperature of the room,

α, coefficient of expansion of the thermometric gas,

[redacted]



β, coefficient of alteration of volume of reservoir, due to change pressure,

δ, coefficient of expansion of substance of reservoir,

H_0, initial pressure (in these experiments always reduced to 0° C.

$H_0 + h$, pressure at temperature T, after all corrections have been made.

On putting $\beta = 0$ as already explained, equation (1), by algebraic transformation and without any approximation, was altered into the form

$$T = T_1 \frac{273 + t + x273}{273 + t - xT_1}, \text{(say)} = T_1\theta, \ldots\ldots\ldots \quad (2),$$

where

$$T_1 = \frac{P - P_0}{\alpha P_0 - \delta P} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3),$$

in which P_0 and P replace H_0 and $H_0 + h$, and $x = \frac{v}{V_0(1 + \alpha t)}$.

The gases used as thermometric substances were hydrogen, oxygen, helium, and carbonic acid. The values of α adopted in equation (3) were taken from Chappuis' memoir, and were 0·00366254 for the first three, and 0·00371634 for carbonic acid. The reciprocals of these coefficients are 273·035 and 269·083. The number "273" which appears in θ is so nearly equal to the reciprocal of the former value for α that it was allowed to remain for the first three gases; but in dealing with carbonic acid it was replaced by 269·083.

In these experiments T_1 is always negative, and numerically less than 273, so that the value of θ is always greater than unity; nevertheless it differs from it but slightly, its value being unity when $T_1 = -273°$ C., and rising to 1·02 when $T_1 = 0°$ C. in the case of thermometer No. I, where $x = 1/50$. It may be noted that when δ is neglected T_1 is the usual value given by Boyle's law; there is a convenience, therefore, in this form of Chappuis' formula for approximation, because T_1 can quickly be calculated, and the correcting factor θ can be applied later if desired.

In the first experiment (No. 1 of subjoined Table I) thermometer No. I was filled with electrolytic hydrogen. The initial pressure (the pressure at 0° C.) was almost three-eighths of an atmosphere, and was taken low in order to obviate any complication from condensation on the walls of the reservoir. Two other possible causes might abnormally reduce the pressure at very low temperatures; these were polymerisation and the presence as impurity of small quantities of gases liquefying above the boiling point of hydrogen. The measurement of the density of the gas at its boiling point showed that there was no polymerisation, and further proof of this was evident in the constancy of the value of the boiling point when different initial pressures were taken. To guard against the presence of gases with a higher boiling point than hydrogen, the electrolytic hydrogen was allowed to pass continuously for eighteen hours through the thermometric bulb before it was sealed off. It was further calculated that an impurity of oxygen necessary to reduce the boiling point of hydrogen by a degree would amount to 3 per cent., a

[redacted]

quantity too large to escape detection. This experiment gave the boiling point of oxygen as − 182°·2, and that of hydrogen as − 253°·0.

In the second experiment (No. 2) a new thermometer, No. II, was constructed with a much smaller value of x, and as a further protection against the presence of impurities, palladium hydrogen was employed as the source of the gas. A rod of palladium, weighing about 120 grammes, kindly placed at my disposal by Mr. George Matthey, F.R.S., was charged with hydrogen in the manner described in my paper "On the Absorption of Hydrogen by Palladium at High Temperatures and Pressures,"* and subsequently used as the source of supply to fill the thermometer. The initial pressure was slightly less than that in the first experiment; the corresponding results were − 182°·67 and − 253°·37.†

The new thermometer was filled afresh (No. 4) with palladium hydrogen at an initial pressure rather less than one atmosphere, and gave for the boiling point of hydrogen the temperature − 252°·8. This result is a confirmation of the absence of polymerisation.

The next step was to compare these results with the results of similar experiments made upon another gas whose boiling point fell within the range of easily determined temperatures; and as a further precaution the gas used in the thermometer was the vapour rising from the liquefied gas whose boiling point was to be determined. The gas first selected was oxygen (No. 5), and as an additional condition to be noted, the initial pressure was made slightly more than an atmosphere, so that it would be in a Van der Waal's "corresponding" state with the hydrogen in the first two experiments, namely, the initial pressure in each case was about 1/50 of the critical pressure. The critical pressure of oxygen was taken about 51 atmospheres, and that of the hydrogen about 18 atmospheres. There are good reasons for believing that the critical pressure of hydrogen is more likely to be about 11 or 12 atmospheres. In the event of the lower value being eventually found the more correct, the effect as between the oxygen thermometer and the hydrogen thermometer will be to make the boiling point of hydrogen a little too high. The result obtained from this experiment was to place the boiling point of oxygen at − 182°·29, thus corroborating in a satisfactory manner the reliability of the method of determining the boiling point of hydrogen.

The question still remained, How far is a gas thermometer to be trusted at temperatures in the neighbourhood of the boiling point of the gas with which it is filled? To answer this question the oxygen thermometer was used to determine the boiling point of liquid air (No. 7) in which a gold-resistance thermometer was simultaneously

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* 'Proc. Chem. Soc.,' 1897.

† This thermometer gave 99°·7 for the boiling point of water.

immersed. The gold thermometer had been previously tested and found to give correct indications of temperature down to temperatures not only well below the point in question, but lower than those obtainable by any other metal thermometer. In the result the oxygen thermometer gave – 189°·62, and the gold thermometer – 189°·68, as the temperature of that particular sample of air boiling at atmospheric pressure.

For another method of comparison this oxygen thermometer was partially discharged (No. 8) until its initial pressure was nearly the same as that in the first hydrogen thermometers. In this state it gave the boiling point of oxygen as – 182°·95, establishing again the reliability of the method. All the boiling points of the liquid gases were made on samples produced at different times.

As an extreme test of the method, I charged the thermometer No. II with carbonic acid (No. 11) at an initial pressure again a little less than one atmosphere, and used it to determine the boiling point of dry CO_2; the result was – 78°·22, which is the correct value.

Hence it appears that either a simple or a compound gas at an initial pressure somewhat less than one atmosphere, may be relied on to determine temperatures down to its own boiling point, in the constant volume gas thermometer.

Another thermometric substance at our disposal, as suitable for determining the boiling point of hydrogen as hydrogen had been in determining that of oxygen and other gases, is helium. The early experiments of Olszewski and my own later ones showed that pure helium is less condensible than hydrogen, and that the production of liquid or solid products by cooling Bath helium to the temperatures of boiling and solid hydrogen was only partial, and resulted from the presence of other gases undefined at the time the experiments were made. The mode of separating the helium from the gases given off by the King's Well at Bath is fully described in my paper on "The Liquefaction of Air and the Detection of Impurities."*

If the neon, present as impurity in the Bath helium which was used, should reach its saturation pressure about the boiling point of hydrogen, the values given by this thermometer for the boiling point of hydrogen would be too low. In order to avoid this, the crude helium extracted from the Bath gas was passed through a U-tube cooled by liquid hydrogen to condense out the known impurities—oxygen, nitrogen, and argon. In my paper "On the Application of Liquid Hydrogen to the production of High Vacua,"† it was shown that at the temperature of boiling hydrogen, oxygen, nitrogen and argon have no measurable tension of vapour, and that the only known gases uncondensed in air after such cooling were hydrogen, helium, and neon. This same neon material

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* 'Chem. Soc. Proc.,' 1897.

† 'Roy. Soc. Proc.,' 1898 (vol. 64, p. 231).

occurs in the gas derived from the Bath wells. A sample of helium prepared as above described, which had been passed over red-hot oxide of copper to remove any hydrogen, was found by Lord Rayleigh to have a refractivity of 0·132. The refractivity of Ramsay's pure helium being 0·1238, and that of neon 0·2345, it results that my helium contained some 7·4 per cent. of neon, according to the refractivity measurements. This would make the partial tension of the neon in the helium thermometer cooled in the liquid hydrogen to be about 4 mm., and this being taken as the saturation pressure the boiling point of neon is about 34° absolute. The initial pressure (No. 9) was taken rather less than an atmosphere, and the temperature of the boiling point of hydrogen was given by this thermometer as – 252°·68. A further observation (No. 10) was taken on another occasion with the same thermometer, and the value found was – 252°·84. The fact that the boiling point of hydrogen, as determined by the helium thermometer, is in substantial agreement with the results obtained by the use of hydrogen itself is a conclusive proof that no partial condensation of the neon had occurred.

Of the remaining experiments in Table I, (No. 3) was made in order to show the effect of a very small initial pressure, one-sixth of an atmosphere. The results were unsatisfactory, owing to the sticking of the long column of mercury giving uncertain pressure readings. In this case an error in the reading of a low pressure has six times as great an effect as if the initial pressure had been about an atmosphere. If the temperature deduced for the boiling point of oxygen is corrected, and the same factor of correction applied to the observed liquid hydrogen boiling point, then it becomes – 251°·4.

It is of particular moment to have some estimate of how far errors in the observed quantities employed in Chappuis' formula affect the final value of T.

In the case of an error in t, on differentiating equation (2) we get

$$dT = T_1 \frac{-x(273 + T_1)}{(273 + t - xT_1)^2} dt \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4).$$

If $x = 1/50$, $t = 13°$, $T_1 = -180°$; then $dT = 0·00339dt$, or it would need an alteration of 2½° in t to alter T by 1/100th of a degree at the boiling point of oxygen. In the same circumstances when $T_1 = -250$, $dT = 0·00136\ dt$, so that an alteration of between 7° and 8° in the value of t would only affect the boiling point of hydrogen by 1/100th of a degree.

From equation (4) the error in T varies with x very nearly. Thus for the second thermometer where $x = 1/115$, a variation of t to the extent of 6°, would only affect the boiling point of oxygen by 1/100th of a degree; and it would require an alteration of 17° in t to affect the boiling point of hydrogen to the same extent.

Table I.

	1	2	3	4	5	6	7	8	9	10	11
Thermometer $x = \frac{v_0}{V_0}$	No. I. $\frac{1}{80}$	No. II. $\frac{1}{115}$	No. II. $\frac{1}{115}$	No. II. $\frac{1}{115}$	No. I. $\frac{1}{80}$	No. I. $\frac{1}{80}$	No. I. $\frac{1}{80}$	No. I. $\frac{1}{80}$	No. II. $\frac{1}{115}$	No. II. $\frac{1}{115}$	No. II. $\frac{1}{115}$
Substance.	Electrolytic Hydrogen.	Palladium Hydrogen.	Palladium Hydrogen.	Palladium Hydrogen.	Oxygen.	Oxygen.	Oxygen.	Oxygen.	Helium (Bath).	Helium (Bath).	Carbonic Acid.
Barometer	760·6	764·4	759·5	770·5	772·5	756·0	766·0	753·5	765·0	770·0	759·0
Temperature of Room....	18°	13°	13°	21°	12°	13°·6	12°	13°·3	15°	15°	13°
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Pressures at 0° C.	286·6	269·8	127·0	739·0	806·0	806·0	807·0	290·5	728·0	728·0	619 0
B.P. of Carbonic Acid ..	204·3	193·6	91·0	—	—	—	—	—	—	—	441·0
„ Oxygen	97·0	90·2	43·0	—	272·5	269·0	—	97·5	—	—	—
„ Air	—	—	—	—	—	—	251·0	—	—	—	—
„ Hydrogen	21·5	19·7	10·7	55·5	—	—	—	—	55·0	54·6	—
„ Hydrogen Solid (30 to 40 mm.)........	—	14·4	8·2	—	—	—	—	—	—	—	—
*Calculated Temperatures.**											
B.P. of Carbonic Acid ..	—	− 77°·95	− 78°·24	—	—	—	—	—	—	—	−78°·22§
„ Oxygen	−182°·20	−182°·67	−181°·52	—	−182°·29	−183°·46	—	−182°·95	—	—	—
„ Air	—	—	—	—	—	—	−189°·62	—	—	—	—
„ Hydrogen	−253°·03	−253°·37	−250°·35†	−252·81	—	—	—	—	−252·68	−252°·84	—
„ Hydrogen Solid (30 to 40 mm.)........	—	−258°·66	−255°·67‡	—	—	—	—	—	—	—	—

* No value is attached to the second place of decimals.

‡ Corrected for Oxygen error (−257°·1).

† Corrected for Oxygen error − 251°·4.

§ Dry Carbonic Acid.

In the case of an error in P, a similar process gives

$$dT = \theta \frac{(\alpha - \delta)P}{(\alpha P_0 - \delta P)^2} \frac{273 + t}{273 + t - xT_1} dP \text{ .... } (5).$$

If $x = 1/50$, $t = 13°$, $P_0 = 760$ mm., $T_1 = -180°$; $dT = 0{\cdot}3563\, dP$, so that an error of 1 mm. in P would only alter the boiling point of oxygen by a third of a degree. In the same circumstances at $-250°$, $dT = 0{\cdot}3516\, dP$, which is practically the same result at the boiling point of hydrogen as at that of oxygen.

For the second thermometer, these two equations become

$$\text{at } -180°, \quad dT = 0{\cdot}3575\, dP,$$
$$\text{at } -250°, \quad dT = 0{\cdot}3548\, dP.$$

In each of the last four results if $P_0 = \frac{1}{n} \times 760$ mm. the formulæ become respectively

$$dT = n \times 0{\cdot}3563\, dP, \text{ and } dT = n \times 0{\cdot}3516\, dP,$$
$$dT = n \times 0{\cdot}3575\, dP, \text{ and } dT = n \times 0{\cdot}3548\, dP\,;$$

in other words, any error in reading P is magnified in its effect on T directly in proportion as P_0 is diminished. This affords some explanation of the weakness of the results in Experiment (No. 3).

In like manner, from an error in P_0, we get

$$dT = -\frac{P}{P_0} \frac{dT}{dP} dP_0 \text{ .... } (6).$$

Here if $x = 1/50$, $t = 13°$, $P_0 = 760$ mm., $T_1 = -180°$;

$$dT = -0{\cdot}1188\, dP_0,$$

or an error of 1 mm. in P_0 would only alter the boiling point of oxygen by a ninth of a degree; but with the same data at $-250°$, $dT = -0{\cdot}0264\, dP_0$, so that the boiling point of hydrogen would only be altered by a tenth of a degree for a change of 4 mm. on an initial pressure of about one atmosphere.

In this case also if $P_0 = \frac{1}{n} \times 760$ mm. we get similar results to those in the case of P, namely,

$$\text{For } x = 1/50, \; dT = -n \times 0{\cdot}1188\, dP_0 \text{ and } dT = -n \times 0{\cdot}0264\, dP_0.$$
$$\text{For } x = 1/115, \; dT = -n \times 0{\cdot}1192\, dP_0 \text{ and } dT = -n \times 0{\cdot}0266\, dP_0.$$

The general result of an error in either P_0 or P is, that the more reliable experiments are those in which the initial pressure is as high as possible. Hence Nos. 4, 9, 10 are in this respect the most reliable for hydrogen. Also, it is of much more importance that P should be accurate than that P_0 should be so; in fact, for hydrogen an error in P has 14 times as much effect as the same error in P_0.

We can verify these results from Table I. In Experiment (No. 2), where $P_0 = \frac{1}{3} \times 760$ nearly, we have two readings—one at the boiling point, the other in solid hydrogen,—namely, 19·7 mm. and 14·4 mm., whose difference is 5·3 mm. This corresponds to $dT = 3 \times 0{\cdot}3516(-5{\cdot}3)$ degrees, or 5°·59. The calculated temperatures for these pressures are $-253^\circ{\cdot}37$ and $-258^\circ{\cdot}66$, whose difference is 5°·29, a satisfactory agreement.

If we compare Experiments Nos. 4 and 9, in both of which the same value of α is used, we can pass from the former to the latter by the formula

$$dT = -0{\cdot}0266\, dP_0 + 0{\cdot}3548\, dP,$$

in which $dP_0 = -11$ mm. and $dP = -0{\cdot}5$ mm., whence $dT = 0^\circ{\cdot}152$ the observed result is $-252^\circ{\cdot}683 + 252^\circ{\cdot}806$ or 0°·123, which is also satisfactory and explains how so great a drop as 11 mm. in P_0 has, nevertheless, so slight an effect on the result.

An alteration in the value of x has but little relative effect on the results. As before we have

$$dT = T_1 \frac{(273 + t)(273 + T_1)}{(273 + t - xT_1)^2}\, dx \quad \ldots\ldots\ldots\ldots\ldots \quad (7).$$

If $x = 1/50$, $t = 13^\circ$, then

$$\text{at } T_1 = -180^\circ, \quad dT = -57{\cdot}085\, dx,$$
$$\text{at } T_1 = -250^\circ, \quad dT = -19{\cdot}4205\, dx,$$

and for the second thermometer ($x = 1/115$) in like circumstances,

and
$$dT = -57{\cdot}895\, dx.$$
$$dT = -19{\cdot}802\, dx.$$

For instance, if x were altered from 1/50 to 1/80 the result would be to raise the boiling point of oxygen by 0°·43 and that of hydrogen by 0°·15.

Finally, the alteration of α for any particular gas, being in any case small, affects the value of T practically only in its main factor T_1. To hundredths of a degree therefore the change in T is inversely proportional to the change in α, or, in other words, is directly proportional to the corresponding absolute zero.

For instance, in Experiment (No. 11) had we used the same value of α as for hydrogen the boiling point of dry CO_2 would have been $-79^\circ{\cdot}35$.

The following table shows what alterations would be required each of the thermometers, in the values of t, P, P_0, and x to alter boiling point of oxygen or that of hydrogen by 1/10 or 1/100 degree. The table is calculated for $t = 13°$; and in the cases of P P_0 the initial pressure is taken to be about $1/n$th of an atmosphere.

Table II.

	Thermometer No. 1.	Thermometer No. 2.	Alteratio of T.
t at B.P. of O ..	2½°	6°	$\frac{1}{100}$°
t at B.P. of H ..	7½°	17°	
P at B.P. of O ..	$\frac{0 \cdot 280}{n}$ mm.	$\frac{0 \cdot 280}{n}$ mm.	$\frac{1}{10}$°
P at B.P. of H ..	$\frac{0 \cdot 285}{n}$ mm.	$\frac{0 \cdot 282}{n}$ mm.	
P_0 at B.P. of O ..	$\frac{0 \cdot 842}{n}$ mm.	$\frac{0 \cdot 839}{n}$ mm.	$\frac{1}{10}$°
P_0 at B.P. of H ..	$\frac{3 \cdot 79}{n}$ mm.	$\frac{3 \cdot 76}{n}$ mm.	
x at B.P. of O ..	0·88 per cent.	2·00 per cent.	$\frac{1}{100}$°
x at B.P. of H ..	2·57 „	5·81 „	

Thus, for example, if the initial pressure in either thermometer v about half an atmosphere an error of 1/7 mm. in reading P would a T by a tenth of a degree.

If we take the average values given by these experiments as b the most probable, then the boiling point of oxygen is $-182°·5$ that of hydrogen is $-252°·5$, or $20°·5$ absolute. The temperat found for the boiling point of oxygen agrees with the mean result Wroblewski, Olszewski, and others. If the boiling point of oxyge raised to $-182°$, which is the highest value it can have; then an e addition to the hydrogen value must follow, making it then – or 21° absolute. In a future communication the temperature of s hydrogen will be discussed.

I am indebted to Mr. J. D. H. Dickson, M.A., of St. Peter's Coll Cambridge, for help in the theoretical discussion of the results, an Mr. Robert Lennox, F.C.S., for able assistance in the conduct of experiments.

February 14, 1901.

A. B. KEMPE, M.A., Treasurer and Vice-President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "Some Additional Notes on the Orientation of Greek Temples, being the Result of a Journey to Greece and Sicily, in April and May, 1900." By F. C. PENROSE, F.R.S.

II. "The Transmission of the *Trypanosoma Evansi* by Horse Flies, and other Experiments pointing to the Probable Identity of Surra of India and Nagana or Tsetse-fly Disease of Africa." By Dr. LEONARD ROGERS. Communicated by Major D. BRUCE, R.A.M.C., F.R.S.

III. "On the Influence of Ozone on the Vitality of some Pathogenic and other Bacteria." By Dr. A. RANSOME, F.R.S., and A. G. R. FOULERTON.

IV. "On the Functions of the Bile as a Solvent." By B. MOORE and W. H. PARKER. Communicated by Professor SCHÄFER, F.R.S.

V. "On the Application of the Kinetic Theory of Gases to the Electric, Magnetic, and Optical Properties of Diatomic Gases." By G. W. WALKER. Communicated by Professor RÜCKER, Sec. R.S.

VI. "Heredity, Differentiation, and other Conceptions of Biology: A Consideration of Professor Karl Pearson's Paper 'On the Principle of Homotyposis.'" By W. BATESON, F.R.S.

"On the Influence of Ozone on the Vitality of some Pathogenic and other Bacteria."

By ARTHUR RANSOME, M.D., F.R.C.P., F.R.S., and ALEXANDER G. R. FOULERTON, F.R.C.S. Received January 12,—Read February 14, 1901.

The influence of ozone on the vitality of bacteria is a matter which has received the attention of several investigators. But, on reviewing the records of the results which have been arrived at, it is obvious that such results have not always been consistent.

We determined, therefore, to investigate this question anew, in the hope of being able to come to a definite conclusion. The matter seemed to us to be one of considerable importance, since if ozone were possessed of the bactericidal properties which have been attributed to it by more than one investigator, the gas might prove of much value in solving one of the most unsatisfactory problems which have to be dealt with in the practice of modern sanitation, that is to say, the disinfection of rooms after the occurrence of infectious disease. Ozone can now be conveniently produced in large quantities, and, if efficient, would be admirably adapted to effect the purpose in view.

The question of the bactericidal action of ozone was especially brought into prominence by the classical work of Downes and Blunt, embodied in communications made to this Society in 1877 and 1878.[*] Working with impure cultures of bacteria, these investigators showed that direct sunlight in the presence of atmospheric air was capable in some cases of preventing in greater or less degree, or in other cases of absolutely inhibiting, the growth of the particular bacteria experimented with; and that not only might growth be inhibited, but that the bacteria themselves might be actually destroyed. Downes and Blunt further showed that so far as the destruction of bacteria is concerned the blue and violet rays of the spectrum are more effective than the red rays, that the interposition of a layer of water is sufficient to protect the bacteria to a certain extent, and that direct sunlight acting *in vacuo* may fail to destroy sporing bacteria.

Whilst this work of Downes and Blunt has been fully confirmed and amplified in certain directions by the work of others, no satisfactory explanation has yet been arrived at as to exactly how it is that bacteria are destroyed under these conditions. The explanation that the result is a direct effect of the sun's rays—of heat—has been shown to be untenable; and it has therefore been assumed that the destruction is effected by chemical rather than by physical action; that it results from an active oxidation of the substance of the bacteria by ozone, produced by the action of sunlight on atmospheric air. Others have regarded peroxide of hydrogen as the active agent.

Amongst the experiments which have been carried out in order to test this assumed bactericidal action of ozone, we may particularly mention those of Chapuis,[†] Sonntag[‡], and Ohlmüller.[§] Chapuis filtered air through cotton wool, and then exposed plugs of the wool with the contained bacteria to the action of ozone. The plugs were afterwards incubated in a nutrient wort solution, which remained sterile. Control plugs of the wool which had not been subjected to the action

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[*] 'Roy. Soc. Proc.,' vol. 26, p. 488; vol. 28, p. 199; vol. 40, p. 14.

[†] 'Bulletin de la Société Chimique,' 1881, Tome 35, p. 290.

[‡] 'Centralblatt für Bakteriologie.' Erste Abteilung, Band 8, p. 778, 1890.

[§] 'Arbeiten a. d. Kaiserl. Gesundheitsamte,' 1892, Band 8, p. 229.

of the ozone, gave rise to a free growth of bacteria, when incubated in the same medium. Sonntag and Ohlmüller's experiments, on the other hand, seemed to show that ozone in the dry state had little or no action on bacteria, but was capable of destroying them when passed through water containing them. Thus *B. anthracis*, suspended in distilled water, was destroyed after air containing 9·6 millegrammes of ozone per litre had been passed through the mixture for ten minutes. A sporing culture of the same bacillus was killed by passing air containing 15·2 milligrammes of ozone per litre through the water for ten minutes. If, however, organic matter, such as blood serum, were added to the water the results were different; and it seemed that under these latter conditions the most part of the ozone was expended in oxidation of the dead organic matter present, whilst the bacteria were little if at all affected.

Our experiments were planned with the view of ascertaining whether ozone applied in large quantities, either in a mixture with atmospheric air or with pure oxygen, has in reality a destructive influence on bacterial life, and especially whether it has any such influence under conditions which would enable it to be used for practical purposes of disinfection.

The experiments have included the testing of the action of ozone, (1) on the vitality of certain pathogenic and saprophytic bacteria, and (2) on the virulence of one pathogenic species. For the purposes of the latter test, we decided to test the action of the gas on *B. tuberculosis*, an organism which is known to be readily affected by the direct action of ordinary chemical agents, and one which numerous experiments would lead us to believe is very susceptible to the action of direct sunlight (Koch,* Ransome and Delepine,† and Jousset).‡

Experiment I.—In our first experiment, culture tubes with "sloped" surface of nutrient agar or gelatin were inoculated with various bacteria; a mixture of atmospheric air and ozone was passed continuously over the inoculated surface for a period of at least four hours, commencing twenty-four hours after the tubes were inoculated. The tubes were then incubated at appropriate temperatures, and the result compared with that obtained in control tubes which had been inoculated from the same stock cultures at the same time.

In detail the following was the procedure carried out:—The culture tubes were of the ordinary 15 × 2 cm. size, into the sides of which short pieces of 0·75 cm. calibre glass tubing had been blown in such a way that they opened into the lumen of the culture tubes about 3 cm. from the bottom and just above the lower level of the sloped nutrient

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* 'Ueber bacteriologische Forschung.' Introductory Address, Tenth International Medical Congress, August 4, 1890.

† 'Roy. Soc. Proc.,' vol. 56.

‡ 'Comptes Rendus de la Société de Biologie,' 1900, Tome 52, p. 884.

[redacted]

surface, and allowed the ozonised air to escape after passing over the bacteria. The culture tubes were closed at the upper end by a piece of cork through which passed a short length of the 0·75 cm. tubing, which formed the inlet for the ozonised air.

The inlet and outlet tubes were loosely plugged with cotton wool, and by means of them and short lengths of india-rubber tubing the culture tubes could be connected up in series, and sterile ozonised air drawn over the inoculated surfaces.

Such culture tubes were inoculated with the following bacteria:—

Glycerin-agar	tubes	(Nos. 1 to 6)	with	*Bacillus tuberculosis*.
,,	,,	(Nos. 7 and 8)	,,	*Bacillus mallei*.
Nutrient-agar	,,	(Nos. 9 and 10)	,,	*Bacillus diphtheriæ*.
,,	,,	(Nos. 11 ,, 12)	,,	*Bacillus anthracis* (sporing).
Nutrient-gelatin	,,	(Nos. 13 ,, 14)	,,	*Bacillus typhosus*.
,,	,,	(Nos. 15 ,, 16)	,,	*Micrococcus melitensis*.
,,	,,	(Nos. 17 ,, 18)	,,	*Micrococcus candicans*.

The tubes were then arranged in two series, those numbered 1 to 12 being connected up in one series and those numbered 13 to 18 in another. The two series of tubes were then placed in a room of about 900 cubic feet capacity and ozone was generated in the air of the room by means of four small "ozonisers," a 3-inch spark Ruhmkorff coil and an accumulator battery being used. The "ozonisers" were kept working for four hours, during the whole of which time ozonised air was slowly aspirated through the tubes. At the end of four hours the arrangement of the tubes was altered; a fresh series, including those numbered 3 to 12 and 15 to 18, being connected up, and pure oxygen charged with ozone was forced through the tubes for a period of thirty minutes. During this half-hour ozonised air was still being drawn through tubes 13 and 14. The culture tubes were then incubated, Nos. 1 to 12 at 37° C., and Nos. 13 to 18 at 22° C., the respective control tubes being incubated with them. The result of the experiment was that in the case of two out of the seven species tested, there seemed to have been some slight retardation of growth as the result of the exposure to the ozone; that is to say, in the case of one or both of the duplicate tubes containing *Bacillus mallei* and *Bacillus diphtheriæ*, the growth of the experimental cultures seemed at first to be rather slower than it was in the corresponding control tubes. But at the end of eight days' incubation all difference between the experimental and control tubes had disappeared, and growth was equal in both sets; and in further experiments this effect was not obvious. In the case of the other five species not the slightest effect could be observed as the result of the exposure. This experiment was carried out under conditions which, although they might approximate to those which would prevail in the actual use of ozone as an aerial disinfectant, were not adapted to test the action of ozone on bacteria, apart from an important disturbing factor. The bacteria were submitted to the action of ozone in the presence of a large amount of dead organic matter, and it was quite conceivable that such an amount of the ozone might have been decomposed in the oxidation of the dead organic matter that but little had been left to exert any action on the living bacteria.*

Experiment II.—In this experiment we endeavoured to test the action of ozone on the bacteria in the absence—so far as we could ensure the condition—of dead organic matter. The same culture tubes were used, but instead of inoculating agar or gelatin nutrient surfaces we inoculated small blocks of plaster of Paris from stock cultures of the various bacteria tested. These plaster of Paris blocks when inoculated were placed in the culture tubes, and the inlet and outlet tubes were plugged with fine Italian asbestos fibre instead of with cotton wool. And instead of passing the same current of ozone over a series of tubes in succession, we connected each tube separately with a main feeding pipe with lateral branches, the respective tubes being held in contact by pieces of india-rubber tubing. Thus each culture tube had a fresh supply of ozone. Ozone was generated as before, and passed over blocks inoculated from stock cultures of the following:—

1. *Staphylococcus pyogenes aureus.*
2. *Streptococcus pyogenes.*
3. *Micrococcus melitensis.*
4. *Bacillus mallei.*
5. *Bacillus diphtheriæ.*
6. *Bacillus anthracis* (from sporing culture).
7. *Bacillus typhosus.*
8. *Bacillus coli communis.*
9. *Bacillus pyocyaneus.*
10. *Bacillus pneumoniæ* (Friedlander).
11. *Bacillus prodigiosus.*
12. *Saccharomyces albicans.*

Duplicate tubes were inoculated with each organism, and a continuous current of air was pumped over the ozoniser, which was enclosed within a glass cylinder connected with the main feeding tube, and then through the culture tubes for a period of thirty minutes. The actual amount of ozone used was not estimated, but iodide of potassium and starch paper held over the outlet tubes gave a positive reaction within sixty seconds of the commencement of the experiment. The small plaster of Paris blocks were then shaken up in tubes containing 3 c.c. of nutrient broth, from the broth tubes loopfuls were transferred to other media, and the growth obtained after incubation compared with the growth on control tubes.

The results obtained on incubating the sub-cultures made it evident that none of the bacteria had been affected by the ozone in such a way as to impair either their capability of growth, or, in the case of the two

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* We are indebted to Mr. Bridge, chemist, of Bournemouth for assistance in the working of the ozonising apparatus used in carrying out this experiment.

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chromogenic bacteria, their function of pigment production. The pathogenic action of a broth sub-culture of *B. mallei*, after the ozonisation, was tested by intra-peritoneal inoculation of a male guinea-pig; an ordinary infection with characteristic lesions followed, the animal dying within forty-eight hours.

Experiment III.—We now decided to subject the bacteria to a rather more severe test than had been involved in the two preceding experiments. The ozone was produced by passing oxygen under pressure from a cylinder over a powerful "ozoniser," enclosed within a glass cylinder, and then into the main feeding tube, as in the previous experiment. The current used was an alternating one direct from the street main. Small pieces of porcelain were, after inoculation with the following bacteria, placed in the culture tubes:—

1. *Sarcina ventriculi.*
2. *Micrococcus melitensis.*
3. *Micrococcus candicans.*
4. *Bacillus mallei.*
5. *Bacillus diphtheriæ.*
6. *Bacillus anthracis* (from twenty-four hour old culture in broth, non-sporing).
7. *Bacillus anthracis* (from old sporing culture on potato).
8. *Bacillus typhosus.*
9. *Bacillus coli communis.*
10. *Bacillus pyocyaneus.*
11. *Bacillus pneumoniæ.*
12. *Bacillus prodigiosus.*

Duplicate tubes of each species were used for the experiment, the first attempt to carry out which resulted in failure, owing to the action of the ozone on the pieces of india-rubber tubing by which the branches of the main feeding tube and the inlets into the culture tubes were held in contact. Before the mixture of ozone and oxygen had been passed into the series of culture tubes for ninety seconds, every piece of india-rubber tubing was cut through, as if with a knife. The joints were, therefore, made with pieces of bored cork, and the experiment repeated. The mixture of ozone and oxygen was passed through the tubes at the rate of 1·5 litre per minute for a period of thirty minutes; the yield of ozone, as estimated by titration with $\frac{N}{10}$ iodide solution, amounted to 0·072 gramme per minute. The percentage amount of ozone was therefore about 2·4 by volume. At the end of thirty minutes the pieces of porcelain were dropped into tubes of nutrient broth and incubated. On comparison with the various controls it was obvious that the ozone had not affected the bacteria in such a way as to impair either their capability for growth, or, in the case of the chromogenic organisms, their power of producing pigment. The broth sub-culture of *B. anthracis* (non-sporing) after forty-eight hours' incubation at 37° C. was tested on a white mouse, and proved to be of normal virulence; 0·25 c.c. of the broth culture, injected into the peritoneal sac, killing the animal within twenty-four hours in typical fashion.*

Experiment IV.—Although it seemed to have been conclusively proved by the experiments of Ohlmüller, already referred to, that ozone was capable of considerable bactericidal action when the organisms were suspended in certain fluids, we determined to carry out a single experiment, using milk as the medium. We used milk because we considered that it would, as containing a large quantity of organic matter, test the bactericidal action of the gas severely.

Five flasks, each containing 125 c.c. of milk, were prepared as follows:—

Flask 1 contained sterilised milk which had been inoculated with a culture of *B. anthracis* (sporing).

Flask 2 contained sterilised milk which had been inoculated with a non-sporing culture of *B. anthracis*.

Flask 3 contained ordinary fresh unsterilised milk, to which a quantity of a broth culture of *B. prodigiosus* had been added.

Flask 4 contained ordinary fresh unsterilised milk.

Flask 5 contained a sample of commercial "sterilised" milk which had "gone bad" owing to the presence in pure culture of an anaerobic, sporing, butyric acid forming bacillus.

A current of oxygen containing the same proportion of ozone as that used in Experiment III was passed through the milk in each of the flasks for a period of twenty minutes at the rate of 1·5 litres per minute. Loopfuls of milk were then taken from each flask, transferred to various culture media, and incubated under both aerobic and anaerobic conditions; the flasks with the bulk of the milk still remaining in them were also incubated.

In the result, it was found that the contents of flasks 1, 2 and 5 were sterile of bacteria. The milk used for flasks 3 and 4 was taken from the same sample, and on incubation of the sub-cultures after ozonisation a growth of a mould-fungus was obtained from each flask; from flask 3 a very free growth of the mould was obtained, but neither *B. prodigiosus* or any other bacterium; from flask 4 a few colonies of a coccus were obtained in both aerobic and anaerobic cultures in addition to the mould which was present apparently in less quantity in the contents of flask 4 than it was in the contents of flask 3. In the case of the sub-cultures from flask 3, the growth of the mould was very rapid, and soon covered the surface of the medium, and so possibly checked the growth of the coccus which appeared on the sub-cultures from flask 4, in which the mould growth was less abundant.

A loopful of the milk used for flasks 3 and 4, taken before ozonisation and smeared over nutrient agar, gave, on incubation at 22° C.,

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* We are indebted to Mr. Wood Smith, F.I.C., for assistance in the working of the ozonising apparatus used in this experiment.

a large number of colonies of different bacteria; and it was apparent that the exposure to ozone had resulted in the destruction of a large majority of these, although complete sterilisation was not obtained as in the case of flasks 1, 2, and 5.

At the end of the experiment, the milk in flasks 1, 2, 3, and 4, although not changed in appearance, had acquired an extremely disagreeable taste and smell, which was in all probability at least partly due to the development of fatty acids. It seemed therefore possible that in the case of these milks, not only might the ozone have had a directly injurious action on the bacteria, but it might also have affected them indirectly by producing from the natural milk various bodies which might themselves also have to be considered as factors in the experiment.

The milk in flask 5 was in a late stage of decomposition and possessed of a most offensive odour; it was noticed that the offensiveness of this milk was considerably reduced after the passage of the ozone.

Experiment V.—Our next experiment was made in order to ascertain whether ozone had any influence on the virulence as apart from the mere vitality of *B. tuberculosis*, and was carried out in the following way:—Sputum rich in the specific bacillus was smeared over strips of filter-paper. These strips were then dried, and afterwards exposed for varying periods to the action of highly-ozonised air. The exposure was ensured by pinning out the strips on a board, which was hung about 6 feet from the same ozonising apparatus as that used in Experiment I, and in the same room. The apparatus was set at work two hours before the exposure of the sputum was commenced, and was continued without intermission throughout the experiment. When the exposure was commenced the air of the room was so highly charged with ozone as to be extremely unpleasant, and not respirable by anyone for more than a few minutes at a time. After undergoing exposures of the several durations given in the table below, the strips of infected paper were moistened, stretched out on glass, and the surface which had been smeared with the sputum was scraped off lightly with the edge of a knife. The scraping from each strip was collected in a cubic centimetre of sterilised normal saline solution, and doses of 0·2 c.c. of the emulsions thus obtained were injected under the skin of the inguinal fold in guinea-pigs. As controls, other guinea-pigs were similarly inoculated with some of the crude sputum, and also with the scrapings from an infected strip of paper which had not been previously ozonised. Fourteen animals in all were inoculated; the following table gives their weights and the nature of the emulsion used for each:—

[redacted]

Animal.	Weight.	Inoculated with—
	grammes.	
Guinea-pig I..	500	Small quantity of crude sputum.
„ II..	470	„ „ „
„ III..	390	Emulsion from filter-paper, not ozonised.
„ IV..	339	„ „ „ „
„ V..	420	„ „ „ ozonised ½ hour.
„ VI..	436	„ „ „ „ ½ „
„ VII..	450	„ „ „ „ 1 „
„ VIII..	455	„ „ „ „ 1 „
„ IX..	390	„ „ „ „ 2 hours.
„ X..	450	„ „ „ „ 2 „
„ XI..	370	„ „ „ „ 4 „
„ XII..	370	„ „ „ „ 4 „
„ XIII..	410	„ „ „ „ 8 „
„ XIV..	370	„ „ „ „ 8 „

The various animals were either allowed to die naturally or were killed with chloroform after definite signs of tubercular infection had developed. And it may at once be said that a severe infection occurred in all the animals; there was not the least indication that the ozonisation had exerted any effect whatever on the virulence of the bacilli. As examples, we may mention the following animals:—Guinea-pig No. I died on the twentieth day after inoculation, with a caseous abscess in the flank, infected mesenteric glands, and tubercles in the spleen; guinea-pig No. II was killed on the twenty-second day after inoculation, and was found to be in a similar condition; guinea-pig No. XI died on the twenty-second, and guinea-pig No. XIV on the twenty-third day, both being again in a similar stage. The presence of the specific bacillus in one or other of the internal lesions was proved in the case of every animal on the list.

Conclusions.

Our experiments have made it clear that ozone in the dry state, and in such strength as we used it, has no appreciable action on the vitality of the various bacteria experimented with, and, so far, our results are in accordance with those of Sonntag and Ohlmüller. Nor did a prolonged exposure to the action of ozone diminish in any way the pathogenic virulence of *B. tuberculosis* in sputum, as shown by Experiment V. Single experiments would also tend to show that ozone can have little, if any, effect on the pathogenic virulence of *B. mallei* and *B. anthracis*.

On the other hand, Experiment IV would appear to confirm the conclusion arrived at by Ohlmüller as to the bactericidal property of ozone when passed through a fluid medium containing bacteria in suspension.

A comparison of the inactivity of ozone as a disinfectant in the dry state with its action in the presence of water suggests a superficial resemblance with other gases, such as chlorine and sulphur dioxide. In the absence of further experiment, however, it would not be possible to press the analogy too closely.

In the dry state, and under the conditions in which it occurs in nature, ozone, then, is not capable of any injurious action on bacteria so far as can be judged from our experiments; and we conclude that any purifying action which ozone may have in the economy of nature is due to the direct chemical oxidation of putrescible organic matter, and that it does not in any way hinder the action of bacteria, which latter are, indeed, in their own way, working towards the same end as the ozone itself in resolving dead organic matter to simpler non-putrescible substances.

"On the Functions of the Bile as a Solvent." By BENJAMIN MOORE and WILLIAM H. PARKER.

Communicated by Professor SCHÄFER, F.R.S. Received January 24,—Read February 14, 1901.

The purpose of the biliary secretion and the uses of that fluid in digestion and otherwise have furnished much material for discussion to the physiological chemist, and the discussion has given rise to many ingenious but widely different theories.

The bile, unlike all the other digestive fluids which are secreted into the alimentary canal, has no specific action upon any of the three classes of food-stuffs. It contains small amounts of cholestearin and lecithin, and of other substances which are obviously to be regarded as excretory in character. It is necessary in the intestine for the complete absorption of the fats in normal amount, but even in its absence a considerable amount of fat can still be absorbed. The constituents which it contains in solution in largest quantity are the sodium salts of certain acids called the bile acids, and these bile salts are not excreted, but are reabsorbed, and undergo a circulation in the blood known as the circulation of the bile.

These few statements briefly summarise our experimental knowledge as to the action and physiological properties of the bile, and have given a basis to many theories.

It has been argued by some from the fact that bile contains no digestive enzyme, and from the presence in the fluid of certain constituents which are certainly excretory, that the bile is to be regarded purely as an excretion; but this view gives no explanation of the reabsorption of the bile salts, which are the most abundant constituent.

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By others the bile has been regarded as an anti-putrefactive, although it readily undergoes putrefaction itself. Others, without much experimental proof, have suggested that it stimulates the intestinal epithelium and increases peristalsis, but even if this be allowed it leaves much of the action of the bile untouched. While it is universally admitted that bile exhibits at most only unimportant traces of a digestive action on food-stuffs, some observers state that its presence favours and increases the activity of other digestive fluids upon carbohydrates, fats, or proteids, and see in this an important function of the bile.[*] On the other hand, it is stated by other experimenters that this aiding power of the added bile is no more than can be explained by the alteration in chemical reaction of the mixed fluid.[†]

With regard to the action of bile in favouring fat absorption, one view which has been held is that the bile alters the physical character of the intestinal epithelium when it wets it, and in some physical way makes the conditions more favourable for the taking up of emulsified fats. Since it is very probable, however, that all the fat is absorbed in some soluble form, and not as an emulsion, this theory of biliary activity falls to the ground.

It was first suggested by Altmann,[‡] mainly from histological observations, that bile aided fat absorption by dissolving the fatty acids set free from the neutral fats in the intestine. Marcet[§] had shown before this that bile dissolves free fatty acids to a clear solution, and later Moore and Rockwood[||] determined the solubilities of fatty acids in bile, and further demonstrated that in some classes of animals a certain amount of the fat was absorbed as dissolved free fatty acid.

The latter authors, while admitting that a considerable amount of absorption of fat as dissolved free fatty acid occurs in carnivora, and insisting upon the importance of bile as a solvent in this connection, showed from a consideration of the reaction of the intestinal contents during active fat absorption that in other species of animals practically all the fat was absorbed as dissolved soaps. Even in carnivora it was further shown that in addition to the absorption as free fatty acid dissolved by the bile, a considerable amount of absorption as dissolved soaps takes place.

The soaps formed in the intestine during the digestion of fat are chiefly sodium soaps. Now it has universally been taken for granted that these are easily soluble in water, and no one has considered any action of the bile as necessary to their solution in the intestinal con-

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[*] Rachford, 'Journ. of Physiology,' 1899, vol. 25, p. 165.

[†] Chittenden and Albro, 'Amer. Journ. of Physiol.,' 1898, vol. 1, p. 307.

[‡] 'Arch. f. Anat. u. Physiol.,' 1889, Anat. Abth. Supp. Bd., p. 86.

[§] 'Roy. Soc. Proc. Lond.,' vol. 9, 1868, p. 306.

[||] 'Roy. Soc. Proc.,' vol. 60, 1897, p. 438; 'Journ. of Physiol.,' vol. 21, 1897, p. 58. (In this paper the literature of the subject is given.)

tents. But the process of preparing the sodium soaps easily demonstrates that *the mixed sodium soaps prepared either from beef or mutton suet are only very sparingly soluble in water.* When the mixture obtained by boiling the fat is thrown into cold water, practically none dissolves, and the excess of alkali can easily be washed off in this way. An increase in the amount of oleate present raises the solubility in water, so that a mixture of soaps obtained from pig's fat cannot be separated in this way. When the mixed soaps derived from beef or mutton fat are boiled with water, they do dissolve to a greater extent; but the solution sets, on cooling, to a stiff jelly, even when it contains as little as 2 per cent. of the mixed soaps.

It occurred to us, therefore, that it would be desirable to make comparative quantitative experiments as to the solubilities *at body temperature* of such soaps in water and in bile respectively, in order to determine whether bile possessed any function as a solvent in soap absorption from the intestine. Opportunity was also taken to prepare and test the solubility quantitatively of the so-called "insoluble soaps" of calcium and magnesium, as well as of the separated and purified oleates, palmitates, and stearates of sodium, calcium, and magnesium.

Attention has previously been given to the solubility of the magnesium and calcium soaps, so far as we are aware, only in a qualitative fashion; and the unqualified statement has in consequence been made by Neumeister* that these soaps are dissolved in the intestine by the agency of the bile.

There is, in addition to the solvent action of bile upon the various fatty derivatives in the intestine, another point of view from which we may regard the bile as a solvent, and ascribe to it a very important function connected with the excretion into the intestine from the liver of substances insoluble in water. It is well known that the bile contains cholestearin and lecithin, and although these bodies are not present in large percentage, they occur in greater quantity in the bile than in any other fluid in the body, and further this is the only channel by which these important degradation-products of metabolism are removed from the body.

Although the presence of these substances in the bile has long been known, no one, so far as we are aware, has drawn any inferences as to why they are excreted by the bile rather than any other excretory channel, nor recognised the importance of the change in the physical properties of the bile, whereby it is adapted for carrying off these waste products to the intestine, and so acquires a specific function possessed by no other fluid in the body.

Both lecithin and cholestearin are insoluble in water, and hence cannot be thrown out of the body in simple aqueous solution. This fundamental fact suggests inquiries as to how these substances are

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* 'Lehrbuch der physiologischen Chemie,' Jena, 1897, p. 221.

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carried in solution to the liver cells to be there excreted, as to how they are preserved in solution in the bile, and as to the extent to which each of them is soluble in that fluid.

Experiments were accordingly arranged to test the powers of the bile salts as a solvent for these two substances, which taken in conjunction with the known facts as to the reabsorption and circulation in the blood of the bile salts cast a considerable light upon the questions above outlined, and furnish a rational explanation of the so-called "circulation of the bile."

It is, in our opinion, in this property of acting as a solvent for substances which are insoluble in water, that bile has its main if not its only function, both in excretion and absorption.

Any other properties which have been ascribed to the bile are of very minor importance compared to this one. It enables us in the first place to explain clearly the part played by bile in fat absorption, for our experiments show not only that the solubilities of the soaps are considerably increased, but, which is of more importance still, that they are dissolved by the bile in a different physical condition from that in which they are held in solution by water alone, as is shown by the altered physical properties of the solution. Further, free fatty acid could not be held in solution in the intestine in the absence of bile. Again, it is impossible to see how such substances as cholestearin and lecithin could be excreted in the absence of some vehicle conferring solubility upon them.

Experimental Methods.

The bile salts used in our experiments were prepared by a usual modification of Plattner's method from ox bile. The bile was concentrated to a syrup on a water-bath, mixed into a paste with animal charcoal, extracted with absolute alcohol, filtered, and ether added to commencing precipitation. On standing, the bile salts were obtained in crystalline spherules, and these were purified by dissolving in alcohol and reprecipitating with ether.

The mixed sodium soaps employed were obtained by saponifying beef suet. Much labour was expended on various attempts to prepare these in a pure form; such as obtaining the free fatty acids in ethereal solution and neutralising with alcoholic potash, or extracting the soaps with hot alcohol in a Soxhlet apparatus and cooling out from the alcohol. These methods have practical difficulties, however, on account of the varying solubilities of the constituent salts in the organic solvents. Accordingly, a simpler method was found to yield better results. The fat was first saponified by slight excess of caustic soda, and the mixture of soaps thrown into a large excess of cold water,*

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* Saturated solution of sodium chloride was at first used, but it was found that the mixed sodium soaps were so insoluble in *cold* water that no such saline

which dissolves out the surplus of alkali and inorganic salts. The soaps were next converted into free fatty acids by treatment with dilute hydrochloric acid, and the mixture of fatty acids was thoroughly washed by warming with water. The free acids were again converted into soaps by very slight excess of caustic soda, dissolved in boiling water, precipitated by cooling, washed with cold water, dried in a water bath, powdered, and kept in a glass-stoppered bottle.

The mixed calcium and magnesium soaps were prepared from these by precipitation from solution in hot water with calcium chloride and magnesium sulphate respectively, washing thoroughly with water, and drying on a water bath.

The pure oleic acid and oleates used were prepared from a sample of pure oleic acid by Merck.

The pure palmitic acid was obtained from bereberry tallow by repeated partial recrystallisation from alcohol until a constant and accurate melting point was obtained. The sodium soap was obtained by neutralising with caustic soda and recrystallising from hot alcohol; the magnesium and calcium soaps by precipitation of the sodium salt in hot aqueous solution by the appropriate salts, washing by decantation with cold water, and drying.

The pure stearic acid and stearates were similarly prepared from commercial stearin, and their purity tested by melting-point determinations for the free acid.

The lecithin used was prepared from yolk of egg by the following modification of the method of Hoppe-Seyler: The yolks were separated, beaten up into a common mass and extracted with five times their volume of 95 per cent. alcohol at a temperature of 50° to 60° C. for about two hours. The precipitated proteid and membrane was separated off by pressing through cheese cloth, the filtrate was allowed to cool to about 30° C. and separated from a certain amount of fatty oils which became pressed through along with the alcoholic extract. The alcoholic extract was evaporated down to a syrup at a temperature of about 60° C. on the water-bath, and then taken up in a small volume of absolute alcohol at a temperature of 40° to 50° C. This extract was next surrounded by a freezing mixture and kept at a temperature of − 5° to − 10° C. for some hours, which precipitates the greater part of the lecithin. This was removed by decantation and filtering through a chilled funnel, purified by again dissolving in

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precipitant is required. Not even any sodium oleate is dissolved by the cold water, as can be shown by first throwing into cold water, then removing the soap and saturating the water with sodium chloride, when scarcely a trace of a precipitate is obtained. Nor are acid soaps formed by this method of preparation, on account of dissociation of the alkali, for on incineration of the soaps and titration of the residue as sodium carbonate, we have obtained almost the theoretical yields required for neutral soaps.

a small volume of absolute alcohol, and once more cooling out of solution. The final product was dried in a desiccator over sulphuric acid for some days.

In the case of cholestearin the figures obtained for the solubility were so low, that pure cholestearin preparations were made from several sources in order to make certain of the result; but all the specimens gave a like result.

The cholestearin first used was prepared from a laboratory specimen by repeatedly recrystallising from ether and from hot alcohol. The second specimen was obtained by repeated recrystallisation from hot alcohol and ether of the residue after taking out the lecithin from the hot alcoholic extract of egg yolk by means of a small volume of absolute alcohol as above described. Large characteristic cholestearin crystals were easily obtained by this method in great abundance. A third specimen was similarly prepared from ox brain, and a fourth from human gallstones by the usual method of extraction.

Comparative determinations were made of the solubilities in distilled water, in 5 per cent. aqueous solution of bile salts, in 5 per cent. aqueous solution of bile salts *plus* 1 per cent. of lecithin, and occasionally in ox bile. Two methods were employed in carrying out the determinations, which were all made at a temperature as close to that of the human body as possible, viz., at 37° to 39° C.

In one method, an excess of the substance of which the solubility was to be determined was heated to a temperature of 50° to 60° C. with the solvent; the mixture was allowed to cool to the required temperature, and then filtered through paper in a funnel kept at body temperature by a warm jacket. It was afterwards tested that the filtrate became clear, when it was once more heated to body temperature.

The percentage dissolved is then estimated by determining the amount of dissolved substance in a given volume, say 5 c.c., of the filtered solution. This is done by evaporating to dryness, extracting the fatty acids with ether (in the case of the soaps, after first converting into free fatty acids by the action of a mineral acid), and weighing after evaporating off the solvent.

This method has some practical disadvantages which have precluded its use except in the case of the determination of the solubility of the sodium soaps in bile. In the first place, a considerable amount of both solvent and solute must be used in order to obtain a workable quantity of filtrate. It is also difficult to filter with some of the substances tested, and on extraction of the evaporated solution with ether it is often impossible to obtain a clear ethereal solution. This method has therefore only been carried out in the case of the sodium soaps and bile. Here it has been used to determine the *maximum* amount which can be taken up by the bile from such a naturally-occurring mixture of soaps as is obtained in the saponification of beef fat. When such a mixture is submitted to the solvent action of the bile it is found that more sodium oleate than palmitate or stearate is taken up, as is shown in the considerable reduction which is obtained in the melting point of the mixture of fatty acids dissolved and re-obtained from the bile as compared with the melting point of the fatty acids obtained from the mixed soaps before being acted upon by the bile. In fact, it is only when sodium oleate is also present that sodium palmitate and stearate are taken up by the bile in appreciable quantity. As a result of this, the figures obtained by this method, in the case of the mixed sodium soaps, must only be taken as indicating the maximum amount of soaps which the bile is capable of taking up from such a mixture at body temperature, and it must be remembered that the portion taken up has not the same composition as the mixture extracted, and that the solubility of the residue gradually decreases as the percentage of palmitate and stearate in it increase.*

The second method, which has chiefly been used in making the determinations, is to add the substance to be dissolved in small weighed portions at a time to a measured volume of the solvent contained in a test-tube and kept at body temperature by being immersed in a water bath provided with a thermostat. The mixture is stirred from time to time with a glass rod, and the substance to be dissolved is rubbed up with the solvent to hasten the process of solution. The amount added when solution ceases to be complete is noted, and from this a close approximation can be made to the percentage solubility. The approximation is the closer the smaller the amount of substance added each time, and the larger the volume of solvent which is taken. By using 10 c.c. of solvent and adding the substance in portions of 0·01 gramme at a time, it is thus possible to determine the solubility within one-tenth of a per cent. The method is somewhat laborious in making a first determination from the number of weighings, but in later determinations with the same solvent and solute it can be shortened by adding at once nearly the total quantity which it is known will be dissolved. Reliable results are obtained by this method in the case of determining the solubility of pure substances, but in a mixture of the soaps it gives a lower result than the total amount which the solvent will take up from the mixture, because the signal for stopping is here that point at which the maximum amount of the least soluble constituent of the mixture has been taken up. Thus a slight residue is obtained when even as little as 0·5 per cent. of mixed sodium soaps is added to bile at body temperature, and a somewhat heavier residue when water is

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* A similar result is seen when the mixed fatty acids or soaps obtained by saponifying any naturally occurring fat are treated with a solvent in which they are not exceedingly soluble, such as hot alcohol, a residue of insoluble stearic acid or stearate is finally obtained.

employed as the solvent; the amount of undissolved residue increases as the amount of mixed soaps added is increased, but it is obvious to the eye that a considerable amount of the later additions of soap are being dissolved, and, further, a determination of the melting point of the mixed fatty acids obtainable from the undissolved residue proves that this consists chiefly of palmitates and stearates.

This is interesting from the physiological point of view, since a similar separation must take place in the intestine, and the oleates be absorbed more readily and more rapidly than the palmitates and stearates.

RESULTS.

1. FREE FATTY ACIDS.—The mixed free fatty acids obtainable from beef suet are practically insoluble in distilled water at body temperature. When as little as 0·1 per cent. is added, the greater part remains undissolved in the form of melted globules; but, on cooling down, a faint opalescence in the fluid indicates a slight degree of solubility. A 5 per cent. solution of bile-salts dissolves 0·5 per cent. of the mixed acids, and a 5 per cent. solution of bile-salts *plus* 1 per cent. of lecithin dissolves 0·7 per cent. The effect of the lecithin in increasing the solubility is clearly seen by heating simultaneously in two test-tubes, one containing bile-salts alone, and the other bile-salts *plus* lecithin, 0·5 per cent. of the fatty acids. The tube containing the lecithin clears first, and on cooling the two tubes a heavy precipitate is obtained in the case of the bile-salts only, and scarcely any precipitate in the solution containing lecithin in addition.

Oleic acid has the following solubilities:—Distilled water less than 0·1 per cent.; bile-salt solution, 0·5 per cent.; bile-salt *plus* lecithin solution, 4 per cent.*

Palmitic acid, in distilled water, less than 0·1 per cent.; in bile-salt solution, 0·1 per cent.; in bile-salt *plus* lecithin solution, 0·6 per cent.

Stearic acid, in distilled water, less than 0·1 per cent.; in bile-salt solution, less than 0·1 per cent.; in bile-salt *plus* lecithin solution, 0·2 per cent.

2. SODIUM SOAPS.—The mixed sodium soaps of beef suet, tested by the supersaturation method, yield to distilled water 2·23 per cent., and to ox bile (sp. gr. 1027) 3·69 per cent. The solubilities in the other solvents of the mixed soaps was not determined, because the constituents, for the reasons assigned above, are not taken up in proportionate quantities, and hence the figures have little value as quantitative results.

The above figures consequently give merely the maximum uptake of

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* The bile-salt solutions employed invariably contained 5 per cent. of the mixed bile-salts of ox bile, and the bile salt *plus* lecithin solutions 1 per cent. of lecithin in addition.

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soaps by bile from such a naturally occurring mixture, and do not mean that a mixture of soaps of unaltered composition is taken up to the extent indicated.

Of much more importance physiologically than the increase in *amount* of soap taken up, due to the presence of the bile salts, is the obvious physical change in character of the solution. After filtration in each case from the excess of undissolved soap, a difference is observable even at body temperature between the two solutions. The solution of slightly over 2 per cent. of soaps in distilled water is opalescent like a starch or dilute glycogen solution, while that of over 3 per cent. of the same soaps in bile is limpid and clear. On allowing the two solutions to cool to the temperature of the room, the physical differences become much more marked, for the more dilute distilled water solution sets into a stiff jelly so that the containing flask can be turned upside down without causing any alteration in the shape of the jelly, while the solution in bile remains quite limpid, and only a small part of the dissolved soaps passes out of solution *as a finely granular precipitate*. The formation of a jelly on cooling, in the case of the distilled water solution only, is not due to the fact that a larger quantity of soaps passes out of solution here on cooling; for no matter at what temperature higher than that of the body bile be saturated with the mixture of soaps, and hence no matter how much soap passes out of solution on cooling, it never forms a jelly, but always a precipitate and a clear supernatant fluid.

Now the formation of a viscid solution and ultimately of a jelly is one of the general properties of colloidal solutions, and hence the above-described experimental difference in behaviour probably indicates that soaps in solution in distilled water are in a more colloidal condition, and accordingly in a less diffusible and absorbable condition, than when dissolved in the presence of bile-salts.

Sodium oleate has the following solubilities—in distilled water, 5·0 per cent.; in bile-salt solution, 7·6 per cent.; in bile-salt *plus* lecithin solution, 11·6 per cent.

Sodium palmitate, in distilled water, 0·2 per cent.; in bile-salt solution, 1·0 per cent.; in bile-salt *plus* lecithin solution, 2·4 per cent.

Sodium stearate, in distilled water, 0·1 per cent.; in bile-salt solution, 0·2 per cent.; in bile-salt *plus* lecithin, 0·7 per cent.

3. Calcium and Magnesium Soaps.—The usual statement that the "insoluble soaps" of calcium and magnesium are soluble in bile receives considerable modification when tested quantitatively, for the experiment shows that these soaps are only very sparingly soluble in bile. Neither the mixed calcium or magnesium soaps derived from beef suet nor their constituent salts, viz., the respective oleates, palmitates, or stearates, are at all soluble in distilled water, that is to say, the solubility in each case lies much below 0·1 per cent., which we

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have taken as the lowest practicable limit in making our determinations. The solubility of the mixed calcium or magnesium soaps in bile is difficult to accurately determine on account of the undissolved residue of palmitate and stearate left behind. When even as little as 0·1 per cent. of either mixture is added to ox bile a residue is obtained. The magnesium soaps are somewhat more soluble than the calcium soaps, but in both cases the solubility is very low. In the case of the mixed calcium soaps, apparently none is taken up into the solution after 0·2 per cent. has been added; and in the case of the mixed magnesium soaps the same result is attained after the addition of about 0·4 per cent. Similar results are obtained in the case of the mixed soaps with bile-salt solution alone, and with bile-salt *plus* lecithin. A bile-salt solution (5 per cent.) ceases to dissolve more when 0·1 per cent. of mixed calcium soaps has been added or 0·2 per cent. of mixed magnesium soaps; and the figures are almost doubled when 1 per cent. of lecithin is dissolved in addition in the bile-salt solution used.

When the solubilities of the separated soaps in bile-salt, or in bile-salt *plus* lecithin, solutions are tested, it is found that the solubilities are only considerable in the case of the oleates; and here again it is seen that the magnesium salts are more soluble than the calcium salts.

Calcium oleate, in bile-salt solution, 0·2 per cent.; in bile-salt *plus* lecithin solution, 1·4 per cent.

Calcium palmitate, in bile-salt solution, less than 0·1 per cent.; in bile-salt *plus* lecithin solution, 0·9 per cent.

Calcium stearate, in bile-salt solution, less than 0·1 per cent.; in bile salt *plus* lecithin solution, 0·4 per cent.

Magnesium oleate, in bile-salt solution, 3·2 per cent.; in bile-salt *plus* lecithin, 8·2 per cent.

Magnesium palmitate, in bile-salt solution, 0·2 per cent.; in bile-salt *plus* lecithin, 1·2 per cent.

Magnesium stearate, in bile-salt solution, less than 0·1 per cent.; in bile-salt *plus* lecithin solution, 1·0 per cent.

The physiological importance of the solubilities of the calcium and magnesium soaps in bile has, in our opinion, been much overrated. Although the figures above given show that the solubilities of the mixed soaps of calcium or magnesium are very low, and hence that the usual statement that these bodies are soluble must be modified, a point of more physiological import is that the percentage of such soaps formed in the intestine during digestion of fat must be very small under normal condition, and hence their solution by the bile is of no great physiological moment. Such solubilities as are quoted above, low though they be, are in any case more than sufficient to account for the absorption of such minimal amounts of calcium or magnesium soaps as may be formed during fat digestion.

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4. Lecithin.—The power which aqueous solutions of bile-salts possess of taking up a large quantity of lecithin into *clear* solution at body temperature is very interesting from the point of view of the re-absorption of the bile-salts, as is also the fact that in presence of lecithin the solvent power is greatly increased for other fatty substances, such as the free fatty acids and soaps, as is shown by the foregoing figures.

Pure lecithin is practically insoluble in water, the addition of as little as 0·1 per cent. causes an opalescence, and further additions give rise, as is well known, to a kind of emulsion. But when lecithin is added to a 5 per cent. solution of bile-salts,* the appearances observed are quite different.

The lecithin dissolves to a clear brown-coloured solution, and the amount taken up is surprising; thus a 5 per cent. solution takes up no less than 7 per cent. of lecithin at a temperature of 37° C. On cooling, part of the lecithin is thrown out of solution as a finely suspended precipitate or emulsion, which glistens with a silky lustre when the test-tube containing it is shaken so as to set the fluid in motion. At ordinary room temperatures of 15° to 20° C., a considerable amount of lecithin, 4 to 5 per cent., is, however, still retained in solution.

The power of lecithin in increasing the solubilities of the fatty acids and soaps, explains in great part why lower solubilities are obtained in experimenting with pure bile-salt solutions, than with bile. The lecithin naturally occurring in bile thus increases the solvent power of that fluid in the intestine for fatty acids and soaps.

5. Cholestearin.—After the high solubility obtained for lecithin, we were much surprised at the excessively low solubility obtained for cholestearin, and proceeded as above described to make preparations of pure cholestearin from several different sources. The experimental results obtained were however uniform; in all cases it was found that while cholestearin is appreciably more soluble in bile-salt solutions than in water, in which it appears to be absolutely insoluble, yet the degree of solubility is very low. Thus, in several experiments with ox bile, we were unable to dissolve 0·1 per cent. of cholestearin additional, and as far as we could judge most samples of bile are practically saturated with cholestearin. A 5 per cent. solution of bile-salts dissolves about 0·1 per cent. of cholestearin, and the amount is not very appreciably increased by the simultaneous presence of lecithin; at any rate, the amount dissolved by 5 per cent. of bile-salts *plus* 1 per cent. of lecithin does not exceed 0·15 per cent.

This exceedingly low solubility of cholestearin in bile furnishes an interesting experimental explanation of a well-known clinical fact,

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* The same results are obtained when lecithin is added to bile; thus a sample of ox bile dissolved 6 per cent. at 36° C. This shows that bile is not nearly saturated with lecithin under normal conditions of its secretion.

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viz., that gallstones so often consist of almost pure cholestearin. On account of the low solubility of cholestearin, the bile (the excretory agent for this substance) must, even under normal conditions, be almost saturated with it. Hence anything which either diminishes the amount of bile-salts in circulation or increases the amount of cholestearin in the circulation, such, for example, as increased metabolic changes in the nervous tissues, may cause a supersaturation of the bile with cholestearin, and a deposition of that substance. Such a deposition would occur most commonly in the gall bladder where the supersaturated bile is stored for a time, and where absorption of water and probably of bile-salts also occurs, lowering the solvent power of the contained bile. When precipitation from solution does take place, as is well known under such conditions, the deposition will occur most readily around any nidus of foreign material, such as an epithelial cell.

In such conditions, it is obviously the supersaturation of the bile with cholestearin which is the primary predisposing factor to gallstone formation, and not the presence of the epithelial cell. When a stone is once started, like a crystal already formed in a solution, its surface is a favourable situation for continued deposit, and so the stone continues to increase in size. The ringed appearance of the cross-section is probably due to alternations in the rapidity of growth, the bile being more saturated with cholestearin at some periods than at others. Lecithin and the other constituents of the bile, with the exception of the bile pigments, being very soluble are not represented in the composition of gallstones.

CONCLUSIONS.

1. Bile has a dual function as a solvent: (*a*) it acts as a solvent for lecithin and cholestearin, and hence aids in the excretion of those otherwise insoluble bodies by the liver cells, and in their carriage to the intestine; (*b*) it acts as a solvent in the intestine for both free fatty acids and soaps, conferring their entire solubility on the former, and largely increasing the solubility of the latter.

2. These solvent properties of the bile are chiefly due to the bile salts; but in the case of the fatty acids and soaps the amount dissolved is greatly increased by the simultaneous presence of lecithin.

3. These solvent actions of the bile salts explain the utility of the reabsorption of the bile-salts and their circulation through the liver, so that they may be used over and over again as solvent agents. In absorption, the bile salts carry the soaps of fatty acids into the columnar cells; in the liver, they are absorbed by the liver cells, carry the excretory lecithin and cholestearin with them, and are passed into the bile canaliculi holding these substances in solution; in the bile, the lecithin and cholestearin are carried in solution to the intestine; and in the intestine, the soaps and fatty acids are dissolved and rendered capable of

[redacted]

being taken in along with the bile-salts by the columnar cells, while the lecithin and cholestearin which are incapable of absorption are precipitated as the bile-salts are absorbed.

4. Lecithin possesses a high solubility in the bile, and cholestearin a very low solubility. The low solubility of cholestearin furnishes an explanation of the fact that gallstones are composed almost entirely of this substance.

5. The sodium soaps possess only a low solubility in water, the palmitate and stearate being practically insoluble; but the solubility is increased by the presence of bile-salts, and especially in the presence of lecithin; further, the character of the solution is different in the two cases, being less colloidal when in bile-salt solution.

6. Even in bile or bile-salt solution the calcium and magnesium soaps have a low solubility, but of the two the magnesium soaps are the more soluble.

7. These results cast some light on the relative functions of the pancreatic juice and bile in fat digestion and absorption. The enzyme of the pancreatic juice splits up the neutral fats, forming free fatty acids, which are largely converted into soaps by the alkali present; while the bile gives solubility to the fatty acids and soaps so produced. Now it is well known that the fat-absorbing power is impaired but not completely destroyed by the absence of either one secretion, but is practically lost when both secretions are absent. These facts can probably be best explained as follows:—(*a*) In the absence of the pancreatic ferment, since the bile has no action upon neutral fats, and these are insoluble, only that portion can be absorbed which is free in the fat when ingested, or is set free in the stomach, or by bacterial action in the intestine. Since bacterial action is at a minimum in the small intestine, the fat in great part is not set free until the large intestine is reached, when the bile salts have all been reabsorbed, and hence cannot assist in solution. Accordingly, in the absence of the pancreatic secretion, a large percentage of the fat appears as fatty acids in the fæces. (*b*) In the absence of the bile, although the fat is decomposed high up in the intestine and converted into fatty acids and soaps, the absorption is slow because the solvent action of the bile is wanting, and hence only a fraction is absorbed, and the remainder passes on chiefly as fatty acid to be thrown out in the fæces. When both pancreatic secretion and bile are absent, in the first place only a small amount is decomposed in the small intestine, and in the second place there is nothing to confer solubility on this small portion, with the result that absorption falls almost to zero.

"On the Application of the Kinetic Theory of Gases to the Electric, Magnetic, and Optical Properties of Diatomic Gases." By GEORGE W. WALKER, B.A., A.R.C.Sc., Fellow of Trinity College, Cambridge, Sir Isaac Newton Research Student. Communicated by Professor RÜCKER, Sec. R.S. Received January 23,—Read February 14, 1901.

(Abstract.)

The aim of this paper is to apply the method of "The Boltzmann-Maxwell Kinetic Theory of Gases" to the electric, magnetic, and optical properties of gases. For the sake of simplicity the molecule is supposed to consist of two atoms, so that the results apply to gases such as Hydrogen or Oxygen. Several of the results indicate, however, qualitatively what we might expect for more complex molecules.

One of the atoms is supposed to have a positive electric charge and the other an equal negative charge, and the force in play between the two atoms is taken as the ordinary electrostatic force.

It is contended that the molecules may be classified into three types—(1) that in which the two atoms rotate in contact; (2) that in which the two atoms revolve in elliptic orbits about their C.G., but not in contact; (3) that in which the two atoms move in hyperbolic orbits for the short time during which they influence each other appreciably. They may thus be regarded as practically free.

The first portion of the paper is concerned with calculations respecting the relative proportions of these three sets; and although a quite complete solution is not obtained, the results indicate certain important features, and may prepare the way for a more complete investigation.

It is next shown that such a system will exhibit magnetic properties, and the *coefficient of magnetic susceptibility* is calculated. The formula obtained shows a close agreement with Professor Quincke's experiments on this question.

The system will also exhibit electrical properties. *The dielectric constant* is calculated. The formula differs essentially from other theories of electric susceptibility, *e.g.*, Boltzmann's, in the *important dependence on temperature.* A note at the end of the paper, giving some recent experimental results by Herr Karl Baedecker, shows how closely the theory agrees with his experimental observations of the temperature effect.

The electrical conductivity is calculated as depending on the number of free atoms present. Reference is also made to a paper by the author, communicated to the Physical Society of London, in which it is shown how the formation of striæ in a vacuum tube may be accounted for.

The optical properties are next considered, and the amount of *refraction produced by free atoms and molecules* calculated. The calculations on the free atoms are of interest, inasmuch as it is shown that they *accelerate the velocity* with which waves are transmitted. With regard to the molecules, it is shown that the *optical control may be regarded as due to* $\bar{\omega}^2$, the mean value of ω^2 for the molecules, where ω is the angular velocity of rotation of the two atoms about their common C.G. Dispersion is also accounted for, and *depends essentially on the distribution law of velocities.* The effects of radiation from the molecules are also considered in the course of the work.

The *rate of rotation of the plane of polarisation in a magnetic field* is also calculated, and the sign of the rotation shown to depend on which atom has the larger mass. If the masses are equal no rotation is produced. The work borders in some ways with Professor W. Voigt's investigations.

The formulæ obtained are applied to the case of oxygen to obtain estimates of e/m_1 and e/m_2, e being the charge and m_1 and m_2 the masses of the two atoms. An estimate of $\bar{\omega}$, and hence of $2r_0$, the sum of the radii of the two atoms, is also obtained. *The value of* e/m_1 *agrees closely numerically with this ratio obtained from electrolytic considerations, while the value of* e/m_2 *agrees closely with the value obtained from considerations of the Zeeman effect.*

February 21, 1901.

Sir WILLIAM HUGGINS, K.C.B., D.C.L., President, followed by The LORD LISTER, F.R.C.S., D.C.L., Vice-President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "An Attempt to Estimate the Vitality of Seeds by an Electrical Method." By Dr. A. D. WALLER, F.R.S.

II. "On a New Manometer, and on the Law of the Pressure of Gases between 1·5 and 0·01 Millimetres of Mercury." By LORD RAYLEIGH, F.R.S.

III. "An Investigation of the Spectra of Flames resulting from Operations in the Open-hearth and 'Basic' Bessemer Processes." By Professor W. N. HARTLEY, F.R.S., and HUGH RAMAGE.

IV. "The Mineral Constituents of Dust and Soot from various Sources." By Professor W. N. HARTLEY, F.R.S., and HUGH RAMAGE.

V. "Notes on the Spark Spectra of Silicon as rendered by Silicates." By Professor W. N. HARTLEY, F.R.S.

VI. "On the Conductivity of Gases under the Becquerel Rays." By the Hon. R. J. STRUTT, M.A., Fellow of Trinity College, Cambridge. Communicated by LORD RAYLEIGH, F.R.S.

"An Attempt to Estimate the Vitality of Seeds by an Electrical Method." By AUGUSTUS D. WALLER, M.D., F.R.S. Received January 28,—Read February 21, 1901.

The present observations form part of an extensive series of experiments by which I am engaged in verifying whether or no "blaze currents"[*] may be utilised as a sign and measure of vitality.

An inquiry of this scope necessitates superficial examination of many varieties of animal and vegetable matter, and the closer study of certain favourable test-cases.

I have selected as such a test-case, the "vitality" of seeds, and have chosen for my purpose beans (*Phaseolus*) which are anatomically convenient and practically easy to obtain of known age.

But before entering upon the results in this particular test-case, I think it advisable to preface those results by a brief indication of the principle involved in all such experiments.

The method of investigation is similar to that adopted in the case of the frog's eyeball,[*] the complications of the principle and a tentative explanation of such complications is reserved for future discussion in a more comprehensive memoir.

By "blaze current" (the term which I was led to adopt by the study of retinal effects) I mean to denote the galvanometrical token of an explosive change locally excited in living matter. An unequivocal blaze current electrically excited is in the same direction as the exciting current, *i.e.*, it cannot be a polarisation counter-current. (An equivocal blaze current, in the contrary direction to the exciting current, *i.e.*, not at first sight distinguishable from a polarisation counter-effect, also exists, but is not taken into consideration in this communication.)

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[*] A. D. W.—"On the 'Blaze Currents' of the Frog's Eyeball," 'Roy. Soc. Proc.,' vol. 67, p. 439, and 'Phil. Trans.,' 1901.

Although the theoretical explanation of these currents is not now in question, it may here be remarked that the unequivocal or homodrome blaze current is probably of local post-anodic origin (the previously anodic spot being now strongly electro-positive to the previously kathodic spot), while the equivocal or heterodrome blaze current is probably of local post-kathodic origin (the previously kathodic spot being now strongly electro-positive to the previously anodic spot).

The presence of an unequivocal or homodrome blaze current is in my experience proof positive that the object under examination is alive. Absence of the effect is strong presumptive evidence that the object is "dead," or rather not-living. It may be in that paradoxical state of immobility which we characterise as latent life, and which we may not characterise as the living state, inasmuch as no sign of life is manifested, nor as dead, inasmuch as the living state can be resumed. An object in this dormant state exhibits no "blaze current" or other sign of life. And although it has capacity of life, and cannot therefore be classed in the category of "dead" things, it is not actually living, and must therefore logically be classed in the more extensive category of not-living things.

Limiting ourselves to the unequivocal blaze current as the criterion between the living and not-living states, we may formulate the following practical rule for a summary interrogation of any given object:—

If the after-currents aroused by single induced currents of both directions are in the same direction, the object investigated is alive.

Practically, by reason of the fact that most objects of experiment are not physiologically homogeneous, this rule finds frequent application, inasmuch, as there is a favourable and an unfavourable direction of response, which occurs in the former direction, whether the excitation happen to be in the former or in the latter (*e.g.*, electrical organs, eyeball, skin, injured tissues animal and vegetable).

In the case of objects that are physiologically homogeneous or nearly so, the after-currents to both directions of exciting current may be homodrome, *i.e.*, of the nature of unequivocal blaze currents. In such case it generally happens that the two opposite reactions are more or less unequal, by reason of imperfect physiological homogeneity of the mass of matter under investigation. It rarely happens that the physiological homogeneity is such that the two unequivocal blaze currents are quite equal and opposite.

So that the diagnosis of any suitable object as to its state of life or not-life rests upon the three following types of response:—

1. Both after-currents aroused by single induction shocks (or by condenser discharges) of both directions are homodrome to the exciting currents. From which it is to be inferred that the object is living.
2. Both after-currents are in the same direction. The object is living.
3. Both after-currents are in the polarisation direction. The object is not-living.

Direction of exciting current	−	+
	←—— - −	———→
Direction of after-current (1)	←—— -	———→
" " (2)ᵃ	←—— -	←———
" " (2)ᵇ	———→	———→
" " (3)	——→	←——

The three cases are indicated as above, and it should be stated that in addition to the test of direction, electromotive force (which on my plan of investigation can always be approximately ascertained) serves to make the diagnosis easy in the great majority of instances. The electromotive value in the case of an ordinary blaze current greatly exceeds that of an ordinary polarisation-current (*e.g.*, the former on vigorous seeds may reach 0·1 volt, while on the same seeds the polarisation-current similarly observed, was between 0·0005 and 0·001 volt). It is only in the case of weak or moribund seeds that there is any room for uncertainty in the answer, by reason of a weak blaze current in conflict with the weak polarisation-current. But the vitality of such seeds, although we may be unable to assert that it has fallen to the zero level, is insufficient for germination, and as tested in the incubator at 25° such seeds have to be registered as dead.

The principal points of the preceding statements may be illustrated by the following experiment, which I give as being typical; the expressions "positive" and "negative" signify that the currents respectively pass upwards from B to A, or downwards from A to B, through the seed.

Typical Experiment.—A freshly shelled out and unbruised bean set up laterally* between unpolarisable electrodes gives—

1. Blaze current in the positive direction in response to an induc-

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* I have given this typical experiment only to represent main facts without details concerning differences according to strength of excitation, interval between successive excitations, temporary abolition by excessive excitation, recovery of capccity for reponse after injury, &c., &c. These and other points will be dealt with in a more detailed and comprehensive account of the phenomena. It should, however, be remarked at this stage that the lateral position of a bean, so that an exciting current traverses both cotyledons normally, is chosen as being the least asymmetrical and by reason of the situation of the embryo less liable to involve physiological inequality than a longitudinal disposition. The comparison of effects on the embryo proper and on the detached cotyledons shows that although all parts of the seed give the blaze effect, the latter is greater in the embryo than in the cotyledons at the outset of germination, and that in an abortive germination it disappears from the embryo sooner than from the cotyledons; *e.g.*—

Cot. 1.	Radicle.	Cot. 2.
0·0050	0·0625	0·0020
nil	0·0180	0·0015
0·0060	0·0170	0·0040

The plumule gave generally a smaller effect than the corresponding radicle. The peeled-off testa gave no blaze whatever, and was evidently dead; its polarisation counter-currents were relatively considerable. For these and other reasons I prefer to test the isolated radicle rather than the entire seed.

FIG. 1.

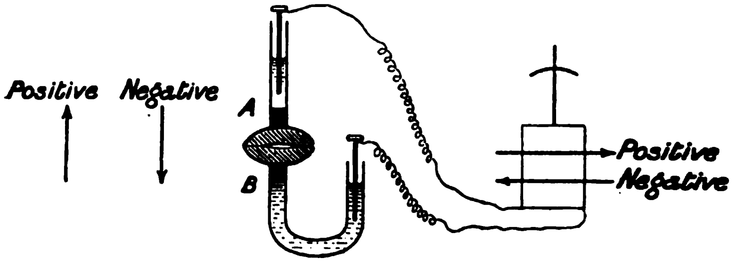
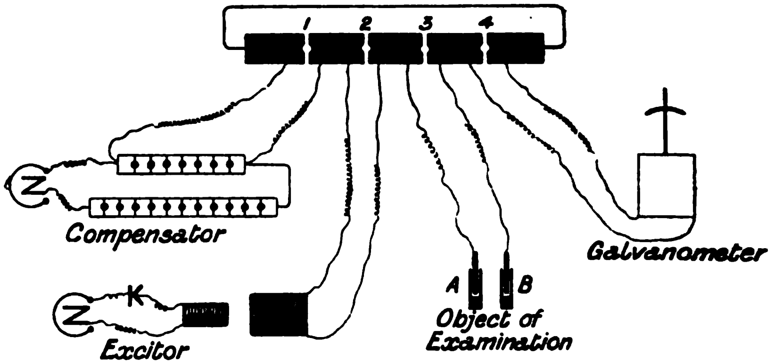


FIG. 2.



To a keyboard having four plugs and plug-holes 1, 2, 3, 4 are connected—

1. A compensator to balance any accidental current in circuit and to measure E.M.F. of reaction.
2. An induction coil to supply the stimulus, preferably a single break shock, the make being cut out.
3. The object under examination.
4. A galvanometer.

The procedure is as follows:—

With 3 and 4 unplugged any current that may be present in the object is shown by the galvanometer. Such current is balanced by manipulation of the compensator unplugged at 1. When exact compensation is obtained the galvanometer can be plugged and unplugged at 4 without any deflection from zero.

With the galvanometer plugged at 4 a single induction shock is now sent through the object (with 1, 2, and 3 unplugged). Immediately afterwards the galvanometer is unplugged, and the deflection (caused by the after-current) is noted.

The E.M.F. causing it is approximately estimated by comparison with the deflection by a known E.M.F. from the compensator.

tion shock in the positive direction; and in the negative direction in response to an induction shock in the negative direction.

2. The same bean after removal of a horizontal slice from its under

surface B (giving therefore current of injury of positive direction) gives blaze currents in the negative direction in response to an induction shock in the positive direction (= an equivocal blaze in the polarisation direction) and to an induction shock in the negative direction (= an unequivocal blaze in the homodrome direction). If the bean is horizontally sliced at the upper surface A instead of at the lower surface B, the current of injury is negative and the blaze currents positive in response to both directions of excitation.

3. A boiled bean gives no blaze currents in either direction but only small polarisation counter-currents, in the positive direction after a negative current and in the negative direction after a positive current.

The next obvious point to be tested is the effect of anæsthetics upon the response. The results depend upon strength of excitation employed, and duration of anæsthetisation. *Cæteris paribus*, the strong effect of a strong stimulus is far more refractory to the action of an anæsthetic than the smaller effect of a weaker stimulus, and in the former case the suppression is apt to be incomplete, or when complete to be definitive. To obtain temporary suppression it is necessary to choose a sufficient but not too strong exciting current, and to anæsthetise by ether rather than by chloroform.

In a preceding paragraph it has been mentioned that a fresh vigorous seed gives a large blaze current, whereas a stale or moribund seed gives little or no response. The next step was obviously to compare similar seeds submitted to various enfeebling modifications, as well as different crops of similar seeds, the electrical tests being controlled by parallel germination tests.

The first and most readily effected comparison is that between the reactions of fresh seeds and of the same seeds killed by boiling. The result of this comparison is unmistakable and invariable. Fresh seeds, giving unequivocal blaze currents with an E.M.F. of 0·01 to 0·10 volt, give no blaze currents whatever after they have been boiled, but only polarisation counter-current with an E.M.F. of 0·0005 to 0·0020 volt. The seeds upon which I have made this test have been leguminous seeds, such as shelled beans and peas boiled in water, and the kernels of stoned fruits such as cherries, plums, and peaches boiled in their protected state.*

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* The reaction is abolished at a temperature considerably below that of boiling water; *e.g.*, at a temperature of between 40° and 50° of a warm moist chamber. Miss S. C. M. Sowton has carefully investigated this point and that relating to the effect of anæsthetics, by aid of photographic records, which are in fact indispensable in connection with these two points. It is also abolished by congelation (at − 3° to − 5°), which causes a sudden large electromotive effect at this point. On recovery of normal temperature no blaze can be obtained, and on recongelation there is no electromotive effect at the critical temperature.

My attention at this early stage of the inquiry has been chiefly directed to the deterioration of seeds with age and to the comparison *inter se* of sets of seeds of certificated years by means of the germination test and of the blaze test used quantitatively.

I selected beans as being of suitable bulk and readily obtainable, and I have to thank Messrs. Sutton for supplying me with many different samples of known dates. After a considerable number of trials upon entire seeds variously orientated between the electrodes, soaked in water of various temperatures for various periods, and upon the several isolated parts of seeds, I fixed upon the following procedure as conveniently yielding series of numerical results comparable *inter se*.

The "dry" beans are first soaked in water for twelve hours in an incubator adjusted at 25° C., then laid upon moist flannel and replaced in the incubator for examination during the next day. Each bean was then peeled and split, and the radicle was carefully broken off and placed between the clay pads of the electrodes (fig. 1) so that the uninjured apex was in contact with the upper electrode A, and the fractured base with the lower electrode B. With this position we have a "positive" current of injury from B to A, and have to expect a "negative blaze" current from A to B in response to excitation. In order that the response shall be "unequivocal," the exciting current is taken of negative direction. To ensure maximal effect a strong current is taken, viz., a break induction shock at 10,000 units of Berne coil. And inasmuch as a current of such strength repeated for a second time shortly after a first trial produces little or no effect, and even when repeated after a considerable interval a much smaller effect than at its first application, it is necessary to take for the purpose of numerical comparison exclusively the values obtained at first trials. To this end it may be necessary to shunt the galvanometer to such an extent that the blaze effect to be expected from the first excitation shall give a deflection within the scale; a second trial when the first trial has given a deflection off scale, is of no value whatever.

By adoption of uniform conditions on these lines, comparisons may profitably be made between different series of results. But at this early stage of the inquiry, not knowing what conditions it might be advisable to select, I have been forced to vary them in tentative directions, by variation of strength of excitation,* of length of soakage, and

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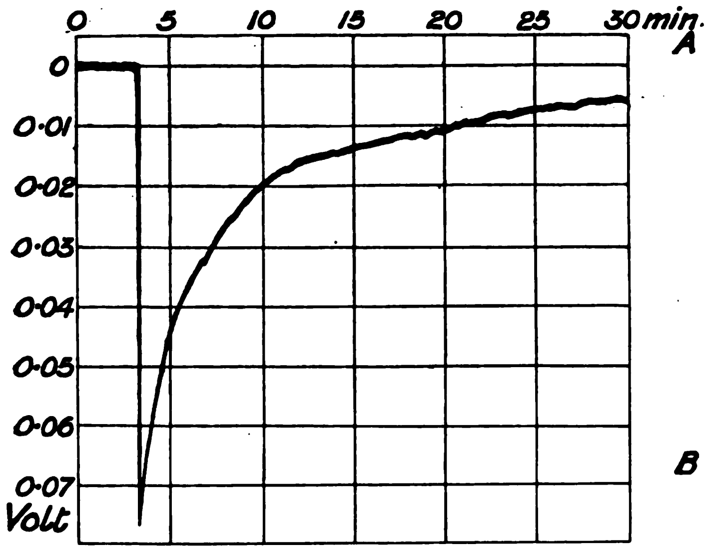
* To avoid exhaustion by strong currents, and to obtain a regularly repeated series of effects, I find that condenser discharges are more suitable than induction shocks. The discharge of 1 microfarad charged by two Leclanché cells (= about ·40 ergs) usually gives a convenient normal effect upon which to investigate the effects of temperature variations, and of anæsthetic vapours.

I also find it preferable to use the radicle some hours after it has been broken off, by which time its current of injury has subsided, and blaze currents are obtainable in both directions.

of interval between soakage and examination. These departures from strict uniformity, while affording necessary information, restrict legitimate comparisons to data within each particular table; comparisons from table to table may not be safely made.

FIG. 3.



Photographic record of an unequivocal blaze current of the radicle of a bean (1900 crop). Excitation by a strong break induction shock in the A to B or negative direction. Homodrome response of 0·075 volt.

With regard to the germination tests, they have been carried out for the most part upon similar lots taken from the same parcels as those from which other seeds were taken to be electrically tested as described above. This latter required each seed to be broken up and rendered unfit for germination. I think that the parallel pair of tests made upon twin lots of different individual seeds is nearly as conclusive as if both tests had been made upon the same individual seeds—*vide*, *e.g.*, Table I. Nevertheless, to meet the criticism that this proof is not conclusive, I have obtained three series of data in which the electrical and germination tests were carried out upon the same individual beans. In all three series I previously determined the coefficient of each intact seed by the blaze test; the germination test was subsequently carried out in one series at Kew under the supervision of Sir W. Thiselton-Dyer (Table VII); in a second series at Chelsea under the supervision of Professor Farmer (Table VIII); and in the third series by myself in my own laboratory (Table IX). But I find it far less satisfactory to make the electrical test upon an entire seed with unknown local bruises received during its fresh state or in course of preparation, than upon a previously protected portion of the seed with an obvious injured end, as in the case of the radicle freshly exposed by separation of the cotyledons, and nipped off at its base immediately* before an observation is made. Moreover, in the former case the current-density is smaller, the blaze effects are relatively less considerable, and the polarisation counter-effects relatively more considerable. And, finally, irregularities due to irregular distribution of water† are more liable to occur in the comparatively large mass of an entire seed than in the comparatively small mass of its removed radicle.

Table I.—Comparison between Radicles of Bean Embryos of the years 1860 and 1899. In each case the seeds were soaked in water at room temperature (15° to 18°) for 24 hours before experiment.

N.B.—In these and all subsequent experiments the radicles were disposed as described in the text, with uninjured apex to electrode A and fractured base to electrode B (fig. 1). Excitation is by a single break induction shock of a Berne coil, fed by two Leclanché cells, 10,000 units, negative direction from A to B. The blaze current is in the same (negative) direction, *i.e.*, is unequivocal.

The galvanometer was shunted to such an extent that $\frac{1}{100}$th volt gave a deflection of 4 cm. of scale. At this degree of sensitiveness polarisation currents are practically illegible.

Seed.	1860.	Seed.	1899.
No. 1	0	No. 11........	−0·0750
„ 2	0	„ 12........	−0·0400
„ 3	0	„ 13........	−0·0700
„ 4	0	„ 14........	−0·0600
„ 5	0	„ 15........	−0·0350
„ 6	0	„ 16........	−0·0350
„ 7	0	„ 17........	−0·0100
„ 8	0	„ 18........	−0·0175
„ 9	0	„ 19........	−0·0200
„ 10	0	„ 20........	−0·0075
Average blaze..	0	..	−0·03700
Germination ..	0 per cent.	..	100 per cent.

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* Or some hours previously (*vide* note on p. 84), although in such case the radicle has appeared to be more rapidly exhausted by repeated stimulation.

† Beans soaked unequally (at the end of twenty-four hours) give blaze currents from more soaked to less soaked portions and not *vice versâ*. A bean that is left for several days in water becomes water-logged and finally decomposes. Such a "drowned" bean will not germinate nor give any blaze whatever. A half-drowned bean gives blaze only towards the drowned (or more soaked) half.

Seed.	1899 (after three days in water).	Seed.	1899 (after four weeks soaking in water, *i.e.*, rotting).
No. 21........	−0·0300	No. 31........	0
„ 22........	−0·0150	„ 32........	0
„ 23........	−0·0200	„ 33........	0
„ 24........	−0·0200	„ 34........	0
„ 25........	−0·0250	„ 35........	0
„ 26........	−0·0100	„ 36........	0
„ 27........	−0·0100	„ 37........	0
„ 28........	−0·0250	„ 38........	0
„ 29........	−0·0175	„ 39........	0
„ 30........	−0·0200	„ 40........	0
Average	−0·01925	..	0

Remarks.—The seeds of 1860 gave no blaze currents, nor any sign of germination. All those of 1899 gave blaze currents and germinated vigorously. In consequence of prolonged immersion under water, other seeds of 1899 became waterlogged, and finally gave no blaze current nor sign of germination.

Four weeks is not a minimum time. I have found beans to be without exception completely drowned at the end of 5 days' immersion in water at 25°, and this period has probably not been a minimum. The shortest time of soakage after which I have observed the blaze has been one hour.

Table II.—Comparison between Beans of the years 1895 to 1899. Forty-eight hours' soakage at room temperature. Averages of 10 seeds of each year. Germination test not made.

	1895.	1896.	1897.	1898.	1899.
Weight of 10 seeds—	grammes.				
Before soaking...	6·2	5·8	6·2	3·3	4·8
After soaking....	13·9	7·6	12·5	6·4	10·5
Average blaze..	0·0014	0·0036	0·0043	0·0052	0·0170

Table III.—Do., do. Time of soakage not noted (? 36 hours). October 15.

Average blaze	0·0008	0·0027	0·0031	0·0035	0·0086

Table IV.—Do., do., but a different series.

Average blaze	0·0030	0·0028	0·0033	0·0240	0·0260

Table V.—Another series of three years (dates not known with certainty).

	1896 ?	1897 ?	1899.
Average of 10 observations—			
On entire seeds	0·0002*	—	0·0014 (irregular)
On separated radicles.....	0·0007*	0·0028	0·0056 (regular)
Germination value	55 per cent.	75 per cent.	90 per cent.

Table VI.—Beans (radicles only) of two years, 1895 and 1900.

	1895. Soaked for 3—5 hours.	1900. Soaked for 3—5 hours.	1900. Soaked for 12 hours.
Average of 10 observations ..	0·0016 irregular	0·0120	0·0510†
Germination value	.. "weak"	100 per cent. "strong"	100 per cent. "strong"

Table VII.—Twelve Intact Beans of 1895, soaked in water at 24° for 12 hours, then laid on wet flannel in incubator for a further 12 hours at 24°, measured electrically on December 17, and forwarded to Kew for independent test by germination. I have to thank Sir W. Thiselton-Dyer for the account of their subsequent behaviour.

	Blaze reactions.	Subsequent behaviour at Kew.	
		Date of germination.	Condition.
Bean No. 1	0·0050	December 28	Weak.‡
" 2	0·0025	Failed	
" 3	0·0175	December 22	Strong.
" 4	0·0125	December 27	Moderate.
" 5	0	Failed	
" 6	0·0100	December 22	Strong.
" 7	0	Failed	
" 8	0·0100	December 25	Strong.
" 9	0	Failed	
" 10	0·0050	December 31	Weak.‡
" 11	0·0100	December 24	Strong.
" 12	0·0100	December 24	Strong.

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* The responses were small and irregular, and in the case of the entire seeds the arithmetical mean of the series of 10 is of wrong—*i.e.*, of polarisation-direction. The electrical resistance of all the radicles was tested and found to be within the limits of 100,000 and 200,000 ohms.

† The average value obtained from 20 entire beans was 0·0040.

The maximum value observed on the radicles of 1900 was 0·1200.

‡ *Those* marked weak are not likely to get beyond the cotyledon stage.

Table VIII.—Intact Beans of 1895 and of 1900, tested Electrically by Dr. Bullot, and subsequently forwarded to Professor Farmer at Chelsea for an independently Germination Test.

1895.	Accidental current.	Electrical response.		Germination.
		Exc. +.	Exc. −.	
No. 1	−0·0018	−0·0003	+0·0017	None.
,, 2	−0·0023	−0·0012	−0·0021	,,
,, 3	−0·0004	+0·0004	+0·0003	,,
,, 4	−0·0014	−0·0002	+0·0003	,,
,, 5	−0·0077	+0·0008	+0·0022	,,
,, 6*	−0·0022	−0·0001	+0·0002	,,
,, 7*	−0·0030	−0·0002	+0·0002	,,
,, 8	+0·0009	+0·0038	−0·0045	,,
,, 9	−0·0100	+0·0011	+0·0070	,,
,, 10	−0·0020	+0·0005	−0·0038	,,
1900.				
No. 11	+0·0010	+0·0125	−0·0075	Yes.
,, 12*	+0·0005	0	0	No.
,, 13	−0·0120	+0·0065	+0·0020	Yes.
,, 14	−0·0205	+0·0013	+0·0100	,,
,, 15	+0·0025	−0·0040	−0·0125	,,
,, 16	−0·0070	−0·0010	+0·0046	No.
,, 17	−0·0105	+0·0060	+0·0024	Yes.
,, 18	−0·0025	+0·0056	−0.0050	No.
,, 19	−0·0067	+0·0012	+0·0044	Yes.
,, 20*	−0·0025	−0·0003	+0·0003	No.

With regard to the second series Professor Farmer remarks that he does not attach much value to it, since the seeds were kept cool at first and otherwise more might have germinated. Nos. 14 and 18, according to the blaze test, should have germinated, but did not do so. A seed giving blaze may fail to germinate, but I have as yet met with only one case of a seed giving no blaze, and subsequently germinating (No. 4 of Table X).

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* Nos. 6, 7, 12, and 20 had been previously boiled.

Table IX.—Intact Beans of 1895 and of 1900 tested Electrically and subsequently by Germination Results.

1895.	Electrical response.		Germination.
	Exc. 10,000 +.	Exc. 10,000 −.	
No. 1	−0·0009	−0·0010	None.
,, 2	+0·0002	+0·0006	,,
,, 3	−0·0004	−0·0003	,,
,, 4	0	+0·0010	,,
,, 5	−0·0007	−0·0002	,,
,, 6	+0·0007	+0·0015	,,
,, 7	0	+0·0008	,,
,, 8	−0·0008	−0·0010	,,
,, 9	−0·0006	+0·0003	,,
,, 10	0	+0·0014	,,
1900.			
No. 1	+0·0054	−0·0020	Yes.
,, 2	+0·0021	−0·0030	,,
,, 3	+0·0032	−0·0022	,,
,, 4	+0·0042	−0·0015	,,
,, 5	+0·0025	−0·0010	,,
,, 6	+0·0008	−0·0042	,,
,, 7	−0·0008	+0·0004	No.
,, 8	+0·0004	−0·0006	Yes.
,, 9	+0·0165	−0·0104	,,
,, 10	+0·0025	−0·0015	,,

In my hands and in those of Professor Farmer the germination (in earth) of this 1895 sample was nil. The electrical response was throughout small and irregular. A further test of germination made on moist flannel in the incubator at 25° gave 40 per cent. as the proportion of seeds exhibiting any sign of activity.

The second series of this table gave a very striking and satisfactory result. Of the ten seeds all but the seventh had given clear electrical signs. They were planted in two regular rows and left undisturbed in a greenhouse for one month. At the end of this time the box contained two rows of nine vigorous plants with a gap opposite the number 7.

Table X.—Beans of 1900 crop (*Phaseolus ?*) soaked in water for 12 hours, then incubated for 12 hours. Tested electrically (+ Br. 10000) on January 28. Incubated on flannel and observed on January 31 and on February 4, when they were again tested electrically.

	January 28. Blaze.	January 31. Germin.	February 4. Radicle.	Blaze.
No., 1	> +0·0050 volt.	Yes	Large	+0·0124
,, 2	0	No	None	−0·0002
,, 3	+0·0035 ,,	Yes	Small	−0·0023
,, 4	−0·0002 ,,	No (App. Feb. 2)	Mod.	+0·0006
,, 5	+0·0018 ,,	Yes	Mod.	−0·0006
,, 6	> +0·0050 ,,	Yes	Large	+0·0050
,, 7	−0·0005 ,,	No	None	−0·0002
,, 8	−0 ,,	No	None	0
,, 9	> +0·0050 ,,	Yes	Large	> +0·0100
,, 10	> +0·0050 ,,	Yes	Large	+0·0080

CONCLUSION.

The physiological character of the blaze reaction is proved (1) by the influence of raised temperature; (2) by its general parallelism with germination tests; (3) by the influence of lowered temperature; (4) by the influence of anæsthetics; (5) by the influence of strong electrical currents; (6) by the absence of blaze and failure of germination in the case of water-logged seeds. In every instance a bean giving no blaze, gave subsequently no sign of germination.

There has been throughout these first observations a general, but not faultless, correspondence, as regards magnitude, between the blaze reaction and the germinative activity. The correspondence is such as to make good the principal fact that the blaze reaction is a sign of life, and that its magnitude is some measure of what we designate as "vitality." The defects of correspondence may have been due to irregularities in the results of the blaze test, or of the germination test, or of both tests. As regards great differences of vitality, both tests are obviously and in every case concordant, both replying by an indubitable "yes" or "no" to the question whether there is blaze and germination. As regards the lower degrees and the smaller differences of vitality, the chances of disagreement between the two tests are obviously greater. As regards the electrical test, it is more difficult to take the measure upon the entire seed than upon its isolated radicle. As regards the germination test, it is not always easy to ensure identical and optimum conditions.

Fresh and vigorous seeds manifest a large blaze response (0·0500 volt or more), and germinate strongly. Older and less vigorous seeds mani-

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fest a smaller blaze (0·0100 volt or less), and a less active germination. Still older seeds, incapable of germination under even the most favourable conditions, manifest still smaller blaze (0·0010 volt or less), and finally none at all, or the small counter-effect due to polarisation (0·0005 volt more or less).

The series of communications, of which the present communication is the 12th, is as follows:—

1. "On the Retinal Currents of the Frog's Eye, Excited by Light and Excited Electrically," 'Roy. Soc. Proc.,' vol. 66, p. 327, March 29, 1900; 'Phil. Trans.,' p. 123, 1900.
2. "Action Électromotrice de la Substance Végétale consécutive à l'Excitation Lumineuse," 'Comptes Rendus de la Société de Biologie,' p. 342. March 31, 1900.
3. "The Electrical Effects of Light upon Green Leaves," 'Roy. Soc. Proc.,' vol. 67, p. 129, June 14, 1900.
4. "Four Observations concerning the Electrical Effects of Light upon Green Leaves," 'Physiol. Soc. Proc.,' June 30, 1900.
5. "Le Dernier Signe de Vie," 'Comptes Rendus de l'Académie des Sciences,' September 3, 1900.
6. "On the Excitability of Nerve: its last Sign of Life," 'Proceedings of the Neurological Society,' October 25, 1900; "Brain," p. 542.
7. "The Eyeball as an Electrical Organ," 'Physiol. Soc. Proc.,' November 10, 1900.
8. "On the 'Blaze Currents' of the Frog's Eyeball," 'Roy. Soc. Proc.,' vol. 67, p. 439, December 6, 1900; 'Phil. Trans.,' 1901.
9. "The Frog's Skin as an Electrical Organ," 'Physiol. Soc. Proc.,' December 8, 1900.
10. "Action Électromotrice des Feuilles Vertes sous l'Influence des Lumières Rouge, Bleue et Verte," 'Comptes Rendus de la Société de Biologie,' December 22, 1900.
11. "Le Premier Signe de Vie," 'Comptes Rendus de l'Académie des Sciences,' December 24, 1900.

"On a New Manometer, and on the Law of the Pressure of Gases between 1·5 and 0·01 Millimetres of Mercury." By LORD RAYLEIGH, F.R.S. Received January 15,—Read February 21, 1901.

(Abstract.)

The new manometer, charged with mercury, is capable of measuring small pressures to an accuracy of 1/2000 mm. of mercury. This may be compared with the ordinary manometer, read with the aid of a cathetometer, which is capable, according to Amagat, of an accuracy of 1/100 mm. at most.

With this instrument the behaviour of nitrogen, hydrogen, and

oxygen gases between the pressures mentioned has been investigated. The results confirm the applicability of Boyle's law. In the case of oxygen nothing has been seen of the anomalies encountered by Bohr, especially in the neighbourhood of a pressure of 0·7 mm.

"An Investigation of the Spectra of Flames resulting from Operations in the Open-hearth and 'Basic' Bessemer Processes."

By W. N. HARTLEY, F.R.S., Royal College of Science, Dublin, and HUGH RAMAGE, A.R.C.Sc.I., St. John's College, Cambridge.

Received November 15, 1900,—Read February 21, 1901.

(Abstract.)

Three papers on "Flame Spectra," by one of the authors, were published in the 'Philosophical Transactions' for 1894. Parts I and II, "Flame Spectra at High Temperatures," and Part III, "The Spectroscopic Phenomena and Thermochemistry of the Bessemer Process." The results in the last of these papers had reference to the phenomena observed in the flames of the "acid" Bessemer process; the present paper deals mainly with an investigation of the Thomas-Gilchrist or "basic" process.

The Cleveland district of Yorkshire was chosen as the principal centre; owing to the interest taken in the work by Mr. Arthur Cooper, Past President of the Iron and Steel Institute, and in consequence of the courtesy and attention shown us, the North Eastern Steel Company's works at Middlesbrough were selected.

It was found necessary at the outset to have three observers at work simultaneously, and the authors were voluntarily and ably assisted by Mr. E. V. Clark, A.R.S.M. Photographs of the plant and the flames, at different periods of the blow, were secured by means of a small Anschütz camera and Goertz lens; eye observations were made with a small direct-vision spectroscope; photographs of spectra were taken with the spectrograph described in 'Philosophical Transactions,' A, vol. 185, p. 1047, and the times of the exposures, &c., were observed and recorded in a note-book. This work was not accomplished without some difficulty, which was occasioned by the large quantity of lime dust blown into the air.

The spectroscopic results were quite different from those previously obtained, as the continuous spectrum was much stronger. Many lines and bands new to the Bessemer flame spectra have been observed in addition to the spectra of the common alkali metals, iron, and manganese. Thus rubidium, cæsium, calcium, copper, silver, and gallium have been identified. The crude iron, the ores, limestone,

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lime, slags, flue dust, and the finished steel have all been analysed, and their constituent elements have been traced all through the process of manufacture.

While no indication was obtained of the amount of phosphorus in the metal during the process of "blowing," some insight into the chemistry of the process has been obtained. The greatest interest, however, is attached to the knowledge it has given us of flame spectra under variations of temperature, and of the wide distribution of many of the rarer elements in minute proportions in ores and common minerals.*

Comparison of Spectra from Open-hearth and Cupola Furnaces.

Early in 1895, by kind permission of Mr. F. W. Webb, the flame over the hearth of a Siemens' open hearth steel furnace in Crewe works was examined spectroscopically, but no lines of metals except sodium were detected. The continuous spectrum of the light emitted by the walls was very strong, and extended to wave-length 3470. Observations were also made at this time on the spectra of the flame above the charge in a cupola. While the blast was turned on the flame was bluish, and lines of sodium, lithium, and potassium were observed. When the blast was stopped, the flame became smaller and whiter, and the lines of the above elements became stronger; the ends of the two strongest bands of manganese were also seen.

Description of the "Blow" and "Over Blow" in the Basic Bessemer Process.

The converter is first charged with about two tons of lime in lumps, and then with twelve tons of fluid "mixer metal," a mixture of metal coming direct from the blast furnace, and molten pig iron from the cupolas. The blast is turned on and the vessel rotated into a nearly vertical position.

The "blow" may be divided into three stages. The first stage ends when the flame drops, indicating that the carbon has been burnt. The second stage ends when the vessel is turned down for a sample of metal to be taken out and the slag poured off. More lime is then added and the blow is continued for a few seconds longer to complete the removal of the phosphorus; this forms the third stage. The average duration of the first stage was twelve minutes and twenty seconds, and of the second stage, five and a half minutes.

The blow began with the expulsion of a large quantity of lime dust, which hid everything from view for a minute or two and covered

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* 'Roy. Soc. Proc.,' vol. 60, pp. 35 and 393; 'Chem. Soc. Trans.,' 1897, pp. 533 and 547.

[redacted]

the instruments and observers. A flame was visible at the mouth of the converter as soon as the cloud of dust had cleared away; this had a yellow or yellowish-red colour. The flame grew rapidly in length and remained clear as in the "acid" process, until it dropped and the second stage began. In this stage the flame was very short, and a large quantity of fume was expelled from the vessel; the flame grew longer and the quantity of fume increased as the "blow" proceeded.

Twenty-six plates of spectra were photographed; some of these were very sharp and gave a complete record of substances present in the flame at intervals of one minute throughout the blow. Careful measurements of the best spectra have been made, and the wavelengths of the lines and bands recorded. The others, not measured in detail, have been compared with these, but no lines or bands occur in them which do not also occur in the best plates. A plate of spectra was usually taken by giving the same time of exposure to each spectrum of the series until the flame dropped; two further exposures were then made on the flame of the over-blow. The spectra increase in intensity as the blow proceeds in the first stage, and this can only result from a corresponding increase in the temperature of the bath of metal and of the flame.

Much detail was lost in many of the spectra, by the interference of the light reflected from a large quantity of white dust and smoke in the air in the neighbourhood of the converters. The converter nearest the observers was the only one of the four from which delicate detail was obtainable, and this was only secured by working in the evening when the sun was very low, or after it had set.

Considerable difficulty was experienced in the identification of some of the lines and bands. This was due partly to the comparatively small dispersion in the less refrangible portion of the green and red rays, by which lines and the sharp edges of bands were almost indistinguishable on the strong continuous spectrum. In other cases, lines were present which had not been observed in flame spectra before, some due to uncommon elements, and others were relatively much stronger than a study of the oxyhydrogen flame and other spectra of the same metals led us to expect.

Conclusions.

(1.) *Line spectra are not observed in the open-hearth furnace.* This is attributed mainly to the fact that the atmosphere of the furnace is oxidising, and under these conditions, as Gouy has shown,* only sodium gives a spectrum approaching in intensity that which it gives in a reducing flame. The D lines were observed by eye observation, but did not appear on the photographs.

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* 'Phil. Mag.,' vol. 2, 1877, p. 156.

(2.) *The phenomena of the "basic" Bessemer blow differ considerably from those of the "acid" process.*

First, a flame is visible from the commencement of blowing, or as soon as the cloud of lime dust has dispersed. We conclude that the immediate production of this flame is caused by carbonaceous matter in the lining of the vessel, that its luminosity is due partly to the volatilisation of the alkalies, and to the incandescence of lime dust carried out by the blast.

Secondly, volatilisation of metal occurs largely at an early period in the blow, and is due to the difference in composition of the metal blown, chiefly to the smaller quantity of silicon. There is practically no distinct period when silicious slags are formed in the "basic" process, and metals are volatilised readily in the reducing atmosphere, rich in carbon monoxide.

Thirdly, a very large amount of fume is formed towards the close of the second period. This arises from the oxidation of metal and of phosphorus in the iron phosphide being productive of a high temperature, but little or no carbon remaining. The flame is comparatively short, and the metallic vapours carried up are burnt by the blast.

Fourthly, the "over-blow" is characterised by a very powerful illumination from what appears to be a brilliant yellow flame: a dense fume is produced at this time composed of oxidised metallic vapours, chiefly iron. These particles are undoubtedly of very minute dimensions, as is proved by the fact that they scatter the light which falls on them, and the cloud casts a brown shadow, and, on a still day, ascends to a great height. The spectrum is continuous, but does not extend beyond wave-length 4000. This indicates that the source of light is at a comparatively low temperature, approaching that of a yellowish-white heat. We conclude, therefore, that the light emanates from a torrent of very small particles, liquid or solid, at a yellowish-white heat. The "flame" can have but little reducing power at this stage, and this, together with its low temperature, accounts for the very feeble lines of lithium, sodium, potassium, and manganese seen in the photographs, or by eye observations.

Fifthly, the spectra of flames from the first stage of the "basic" process differ from those of the "acid" process in several particulars. The manganese bands are relatively feeble, and lines of elements, not usually associated with Bessemer metal, are present. Both the charges of metal and of "basic" material contribute to these. Lithium, sodium, potassium, rubidium, and cæsium have been traced mainly to the lime; manganese, copper, silver and gallium to the metal. Other metals, such as vanadium and titanium, are not in evidence, because they do not yield flame spectra; they, together with chromium, pass into the slag in an oxidised state.

(3.) *Differences in the intensity of metallic lines.* The intensity of the lines of any metal varies with the amount of the metal in the charge, but in some cases variations of intensity occur among the lines of one metal as observed in the spectra photographed at Crewe in 1893; especially is this the case with some lines in the visible spectrum of iron.

These variations are due to changes in temperature; as the temperature of the flame rises, some lines fade almost away, others become stronger. The changes are more marked in the arc spectrum and still more in the spark spectrum of iron.

Lines of potassium and the edges of manganese bands are shown to have been intensified by the proximity of iron lines in some cases, but this is doubtless a result of low dispersion. The two violet rubidium lines nearly coincide with two lines of iron.[*]

A new line of potassium with variable intensity. This line, wave-length approximately 4642, varies in intensity within somewhat wide limits. In a given flame its brilliancy is increased by diminishing the quantity of metallic vapour in the flame: this does not appear to lepend altogether on the weakening of the continuous spectrum; it is probably due, in part at least, to the increased freedom of motion permitted to the molecules of the metal.

"The Mineral Constituents of Dust and Soot from various Sources."

By W. N. HARTLEY, F.R.S., Royal College of Science, Dublin, and HUGH RAMAGE, A.R.C.So.I., St. John's College, Cambridge.

Received November 20, 1900—Read February 21, 1901.

Baron Nordenskjöld has described three different kinds of dust rhich were collected by him.[†] Of two of these, one consisted of liatomaceæ and another of a silicious and apparently felspathic sand: oth were found on ice in the Arctic regions. The third variety was uite different and appeared to be of cosmic origin. He observed that ome sand collected at the end of a five or six days' continuous fall ras mingled with a large quantity of sooty-looking particles, consistng of a material rich in carbon. It appeared to be similar to the ust which fell, with a shower of meteorites, at Hessle near Upsala the beginning of the year 1869. As in this particular instance it ight be supposed that the railways and houses of Stockholm had ontributed some of this matter to the atmosphere, and that the snow ad carried it down, he requested his brother, who then resided in a esert district of Finland, to give his attention to the subject, with

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[*] 'Roy. Dublin Soc. Proc.,' vol. 8 (N.S.), Part VI, p. 705.

[†] 'Comptes Rendus,' vol. 78, p. 236.

the result that he collected a similar powder. The snow gathered in the latitude of 80° N. in an expedition to Spitzbergen, and that collected from floating ice in the Arctic regions and on the glaciers of Greenland, leaves, after it has melted, a greyish residue, which consists largely of diatomaceæ, but mixed with these organisms there were also particles of a carbonaceous dust of considerable size, which on analysis were found to contain metallic iron, cobalt, and nickel, also silicon, carbon, and phosphorus. The origin of this mineral matter was at first doubtful. Two of its constituents, cobalt and nickel, were believed to be of very uncommon occurrence in terrestrial matter, while on the other hand they are elements invariably associated with the metallic iron of meteorites, the nickel being more particularly in large proportion. If we suppose that this dust is discharged from the mouth of a distant volcano, or that it may be sand carried up by a whirlwind, we have yet to explain the peculiarities in its composition which render it similar to that of meteorites.

Nordenskjöld arrived at the conclusion that it was meteoric matter which had descended upon the earth in a shower similar to that which occurred near Upsala. By the facts which he had collected it appears to have been proved that cosmic dust is falling imperceptibly and continually. It seems that this view is either generally not accepted, or that the facts are not commonly known.

Very little is really known about the composition of atmospheric dust, notwithstanding that searching investigations were made by Pasteur and Angus Smith, aided by the microscope, and later by Liveing and Dewar by the aid of the spectroscope.

Professor O'Reilly, M.R.I.A., supplied us with small quantities of a material concerning the nature of which he was desirous of obtaining information. On inspection it appeared to be of an unusual character for mere town dust, and accordingly we submitted it to a spectrographic analysis, and determined the principal metallic elements which enter into its composition. The following specimens in particular have been examined with care :—

(I.) Solid matter which fell in or with hail in a hail-storm on Wednesday, April 14, 1897, and was collected by Professor O'Reilly at a window facing the large open space of Stephen's Green, at the Royal College of Science, Dublin. It contained iron, sodium, lead, copper, silver, calcium, potassium, nickel, manganese a trace; gallium and cobalt gave doubtful indications.

(II.) Solid matter from hail and sleet collected by Professor O'Reilly from a window-sill of the Royal College of Science, Dublin, during a very heavy shower, from 2.30 till 3 o'clock, in the afternoon of March 28, 1896.

Total weight of the dust 0·1018 gramme, of which 0·08 gramme was burnt in the oxyhydrogen flame. The colour of the dust was steel

[redacted]

grey and it was magnetic. It contained iron, copper, and sodium, lead, calcium, potassium, manganese, nickel, silver, thallium a trace, gallium and rubidium a trace, doubtful.

(III.) Pumice from Krakatoa eruption 1883; from Professor O'Reilly. By decomposing the silicate with ammonium fluoride and sulphuric acid, and precipitating the solution with ammonia, the following bases were separated: iron, copper, silver, sodium, nickel, potassium, rubidium, manganese, gallium, and indium a trace.*

The salt separated by filtration and evaporation of the filtrate contained sodium, potassium, calcium, copper, silver, strontium, nickel a trace, rubidium, and manganese. With the very notable exceptions of strontium, nickel, and cobalt we have found these constituents in ninety-seven irons, ores and associated minerals.† On the other hand, in the examination of six meteoric irons, we have found the same elements invariably associated with nickel and cobalt, the last-named being always in much smaller proportion than the nickel.‡ Had it been possible to operate on larger quantities, we quite expect that cobalt would have been found in this dust, but the small amount of 8 centigrams is insufficient for such a purpose, even in the case of most meteoric irons. It is rather a striking fact that in the dust No. 2 there is a trace of thallium. This is rather suggestive of its being probably pyrites flue dust, a substance which might occur in hail or rain in a neighbourhood where sulphuric acid is manufactured. It might possibly come from an admixture of soot yielded by a coal containing thalliferous pyrites.

There are three vitriol works within 2 or 3 miles of the College, but after taking all the facts into consideration, we are not able to admit this source as a probable means of contamination, for as will be seen from analyses to be presented, there is one notable constituent we have found in flue dust which is absent from the samples I and II, namely, indium.

In 1897, in order to push this inquiry somewhat further, dust was collected in porcelain dishes placed upon a grass plot in the garden of a residence just on the outskirts of Dublin§ during a period from the 15th November to the 15th December. A considerable fall of a carbonaceous-looking matter occurred on the 16th and 17th of November; some of the particles were 2 or 3 mm. in diameter, and had a steel grey appearance rather like hard coke or graphite. These particles all sank in the rain-water which collected on the 17th or 18th, while a large number of sooty particles floated; as the dish became over-filled, the sooty matter was automatically washed away

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* 'Trans. Chem. Soc.,' vol. 79, p. 61, 1901.

† Nickel was found in twenty-three. 'Trans. Chem. Soc.,' vol. 71, p. 533, 1897.

‡ 'Sci. Proc. Dublin Soc.,' New Series, vol. 8.

§ At the back of my house and remote from any factory chimneys.—W. N. H.

and only the heavier particles remained. The contents of the dishes were poured into glass cylinders, and after the heavier particles had been deposited the water was removed by decantation.

Subsequently it became interesting to ascertain what substances are to be found in ordinary soot and flue dust—dust from volcanic eruptions, &c. We have tabulated the results and arranged together those substances which we know to have the same origin.

The specimens of soot required no preliminary treatment before being burnt, and the analysis of each is given in the tabular statement only, but the different kinds of volcanic dust and flue dust were dissolved and the silica removed, after which the bases were separated into groups, and the spectra of these groups were photographed; each spectrum receives a detailed description preceding the tabulated statement.

Flue Dust.

Plate 386.—Dust from the flue of Crewe gasworks. May 28, 1899. The silica was removed from 1 gramme by treatment with ammonium fluoride.

Spectrum 1.—The insoluble residue contained—
Ca, Sr, Na, Pb, Fe, Cu, Ag, K.

„ 2.—The precipitate yielded by sulphuretted hydrogen—
Pb, Cu, Ag, Ca, Na, Fe, K.

„ 3.—The ammonium hydrate precipitate—
Fe, Ga, Cu, Ag, Pb, In, Ni trace,
Ca, Na, K.

„ 4.—The ammonium sulphide precipitate—
Mn, Na, K, Cu, Ag, Ni, Fe.

„ 5.—The less soluble sulphates—
Ca, Sr, Cu, Na, K.

„ 6.—Magnesia and the alkalies—
Na, K, Ca, Sr, Ni, Rb trace.

Plate 388. Spectra 4 and 7.—Insoluble residue after treating the dust with hydrochloric acid—
Fe, Ga, Na, K, Ca, Cu, Ag, Ni, Mn.

Plate 347.—Flue dust from Cleveland iron furnaces.
Spectrum 1.—Samuelson's samples, No. 6—
Na, K, Ca, Fe, Rb, Pb, Mn;
traces of Cu, Ag, Ni, Ga, Tl.

Spectrum 2.—Flue dust from basic iron furnace. Samuelson's No. 9—

Na, K, Ca, Fe, Rb, Pb, Mn;
traces of Cu, Ag, Ni, Tl, Ga, In, Cs, Sr.

„ 3.—Flue dust, Gjers, Mills, and Co.—

Na, K, Ca, Fe, Rb, Pb, Mn;
traces of Cu, Ag, Ni, K, Ga, In.

Plate 354.
Spectrum 4.—Flue dust, Gjers, Mills, and Co.—

Fe, Ca, Cu, Mn, Na, K, Pb, Rb;
traces of Ni, Tl, Ag.

Plate 325. 1.—Flue dust from Nicholson's copper smelting works, Hunslet, Leeds—

Na, Cu, Pb, Tl, Ag, In, Fe, K,
Ca, Ga, Rb.

Plate 312.—Iron pyrites from coal—

Fe, Cu, Tl, Pb, Ag, and possibly a trace of gallium.

Volcanic Dust.

Specimens received from Professor J. P. O'Reilly.

Plate 311.—*Te Ariki.* After complete solution of the substance the heavy metals were precipitated with ammonia and the filtrate with ammonium oxalate, after which the solution containing magnesia and the alkalies was examined.

Spectrum 1.—The ammonia precipitate—

Fe, Ca, Pb, Na, K trace, Ga trace, Cu trace.

„ 2.—The ammonium oxalate precipitate—

Ca, Sr, Mn, traces of Na, K, Pb, Fe, and Ag.

„ 3.—Magnesia and the alkalies—

Na, K, MgO, Mn, Rb, Cu;
Ni the merest trace.

Taurunga.

Plate 311.
Spectrum 4.—The ammonia precipitate—

The constituents are similar to No. 1.

„ 5.—Ammonium oxalate precipitate.
Similar to No. 2.

„ 6.—Magnesia and the alkalies—
Similar to No. 3.

[redacted]

Le Hape-o-Toru.

Plate 312.

Spectrum 1.—The ammonia precipitate—
Similar to Nos. 1 and 4.
„ 2.—The oxalates—
Similar to Nos. 2 and 5, but the silver was not so strong.
„ 3.—Magnesia and the alkalies—
Similar to Nos. 3 and 6.

It is necessary to explain that the symbol for magnesium and the alkaline earth metals refers generally to the oxides. With magnesium, in fact, this is always so, since the bands of the oxide magnesia alone are visible. In the case of calcium, the blue line 4226 is photographed when only a small quantity is present, but the bands of calcium oxide are the chief feature of the spectrum when the base is in larger proportion. Where the symbol is printed in italics it indicates a trace of the substance, and where followed by a note of interrogation it is not quite certain if even a trace is present, as, for instance, where only one of two rubidium lines is seen, there being two iron lines occupying almost the same positions; or where one of the gallium lines is barely visible, and the second is enveloped by manganese lines. The relative strength of the lines, as seen by comparing the different spectra, is, in some instances, indicated on the tabulated statement by suffixes, the number 1 indicating the weakest line and 10 the strongest.

The difference in the number of the iron lines is a measure of the quantity of iron present as metal or otherwise, and a comparison of the strength of the lines also indicates the relative quantity of substances. The results in many cases are quantitative, inasmuch as the same weight of material was taken.

On the Nature of Dust from the Clouds.

The principal characteristic of dust which has fallen directly from the clouds or collected by hail, snow, sleet, or rain, is its regularity in composition—each specimen appears to contain the same proportions of iron, nickel, calcium, copper, potassium, and sodium. The proportion of carbonaceous matter must be small, otherwise a diminution in the proportion of the metals present would render the metallic lines weaker. There is a very considerable difference between the dust from sleet, snow, and hail suddenly precipitated, the difference being in the proportion of lead, which, in the dust from sleet, is much larger than in the other specimens, though dust from hail and one quantity collected from rain contain more than is found in any other specimens

The Composition of Dust from Various Sources.

	Sodium.	Potassium.	Rubidium.	Cæsium.	Copper.	Silver.	Magnesium.	Calcium.	Strontium.	Aluminium.	Gallium.	Indium.	Thallium.	Iron.	Nickel.	Cobalt.	Manganese.	Chromium.	Lead.
Dust from sleet, fell 28th March, 1896	Na	K	Rb?	..	Cu	Ag	..	Ca	..	..	Ga	..	*Tl*	Fe	Ni	..	Mn	..	Pb
Dust from hail, fell 14th April, 1897	Na	K	..	..	Cu	Ag	..	Ca	..	..	Ga?	..	..	Fe	Ni	..	*Mn*		Pb
Dust from the clouds, fell 16th and 17th November, 1897	Na	K	..	..	Cu	Ag	..	Ca	..	..	Ga	..	*Tl*	Fe	Ni	..	Mn	*Cr*	Pb
Dust from rain, 13th to 15th November, 1897	Na	K	..	..	Cu	Ag	..	Ca	*Sr*	..	*Ga*	..	*Tl*	Fe	Ni	..	*Mn*		Pb
Volcanic dust from New Zealand—																			
(1.) Te Ariki	Na	K	Rb	..	Cu	*Ag*	MgO	Ca	Sr	..	*Ga*	..	..	Fe	*Ni*	..	Mn		Pb
(2.) Tauranga	Na	K	Rb	..	Cu	*Ag*	MgO	Ca	Sr	..	*Ga*	..	..	Fe	*Ni*	..	Mn		Pb
(3.) Te Hope-O-Toroa	Na	K	Rb	..	Cu	*Ag*	MgO	Ca	Sr	..	*Ga*	..	..	Fe	*Ni*	..	Mn		Pb
Pumice from Krakatoa	Na	K	Rb	..	Cu	Ag	..	Ca	Sr	..	Ga	*In*	..	Fe	Ni	..	Mn		Pb
Lead chloride from crater of Vesuvius	Na	K	Rb	..	Cu	..	..	..	..	..	..	..	Tl	Fe	..	..	..		Pb
Soot from chimneys—																			
(1.) A bedroom chimney	Na_9	K_4	*Rb?*	..	Cu_2	..	..	Ca_7	Sr_1	..	Ga_1	..	Tl_1	Fe_8	Ni_1	..	Mn_1		Pb_4
(2.) A kitchen chimney	Na_4	..	..	..	..	..	..	Ca_3	..	..	..	..	..	Fe_2					

The Composition of Dust from Various Sources—*continued.*

	Sodium.	Potassium.	Rubidium.	Cæsium.	Copper.	Silver.	Magnesium.	Calcium.	Strontium.	Aluminium.	Gallium.	Indium.	Thallium.	Iron.	Nickel.	Cobalt.	Manganese.	Chromium.	Lead.	Zinc.	Cadmium.	Tin.
Soot from chimneys—*continued.*																						
(3.) A laundry chimney	Na_9	K_4	*Rb ?*	.	Cu_4	Ag_1	..	Ca_7	Sr_1	..	Ga_2	..	Tl_2	Fe_9	Ni_3	..	Mn_3	Cr_1	Pb_6			
(4.) Assay laboratory fusion furnace	Na_9	K_8	*Rb ?*	..	Cu_4	Ag_4	..	Ca_2	..	..	Ga_3	..	Tl_3	Fe_7	Ni_3	..	Mn_1	..	Pb_9			
(5.) Assay laboratory gas muffle ...	Na_7	K_3	..	..	Cu_3	Ag_2	..	Ca_3	..	..	*Ga ?*	..	Tl_1	Fe_7	..	..	Mn_1	..	Pb_8			
(6.) Heating apparatus furnace ..	Na_9	K_4	*Rb ?*	..	Cu_3	..	..	Ca_9	Sr_2	..	*Ga ?*	..	Tl_1	Fe_9	Ni_1	..	Mn_6	..	Pb_8			
Flue dust*—																						
(1.) Gasworks, Crewe	Na	K	*Rb*	..	Cu	Ag	..	Ca	Sr	..	Ga	In	..	Fe	Ni	..	Mn	..	Pb			
(2.) Boyd's chemical works, Dublin..	Na	K	..	..	Cu	Ag	..	Ca	..	..	..	In	Tl	Fe	..	..	..	..	Pb			
(3.) Nicholson's copper works, Leeds, 0·5 grm.	Na	K	Rb	..	Cu	Ag	..	Ca	..	..	Ga	In	Tl	Fe	..	..	..	..	Pb			
Do. do. 20 grms.†	Na	K	Rb	*Cs*	Cu	Ag	..	Ca	Sr	Al	Ga	In	Tl	Fe	Ni	*Co*	Mn	Cr	Pb	Zn	Cd	Sn
(4.) Ferro-manganese furnace, Pittsburg, U.S.A. ..	Na	K	Rb	..	Cu	..	..	Ca	..	..	..	..	Tl	Fe	Ni	..	Mn	..	Pb			
(5.) Ferro manganese furnace	Na	K	Rb	*Cs*	Cu	Ag	..	Ca	..	..	Ga	*In*	Tl	Fe	..	..	Mn	..	Pb			

* Lithium was found in all these dusts.

† Bismuth was found in this dust.

The Composition of Dust from Various Sources—*continued.*

	Sodium.	Potassium.	Rubidium.	Cæsium.	Copper.	Silver.	Magnesium.	Calcium.	Strontium.	Aluminium.	Gallium.	Indium.	Thallium.	Iron.	Nickel.	Cobalt.	Manganese.	Chromium.	Lead.
Flue dust—*continued.*																			
(6.) Cleveland iron furnace, Samuelson, Middlesbrough	Na	K	Rb	..	*Cu*	*Ag*	..	Ca	..	..	*Ga*	..	*Tl*	Fe	*Ni*	..	Mn	..	Pb
(7.) Cleveland iron furnace	Na	K	Rb	..	*Cu*	*Ag*	..	Ca	..	..	*Ga*	*In*	*Tl*	Fe	*Ni*	..	Mn	..	Pb
(8.) "Basic iron" furnace..........	Na	K	Rb	*Cs*	*Cu*	*Ag*	..	Ca	Sr	..	*Ga*	*In*	*Tl*	Fe	*Ni*	..	Mn	..	Pb
(9.) South Wales iron furnace	Na	K	Rb	..	*Cu*	*Ag*	..	Ca	..	..	*Ga*	*In*	..	Fe	..	..	..	..	Pb
Examples of Well-known Meteorites.																			
Meteoric stone, Alfianello............	Na	K	..	..	Cu	Ag	MgO	Ca	..	..	*Ga*	..	..	Fe	Ni	..	Mn	Cr	Pb
Meteoric stone, Pultush	Na	K	..	..	Cu	Ag	MgO	Ca	..	..	..	..	..	Fe	Ni	..	Mn	Cr	Pb
Meteoric stone, Mocs................	Na	K	..	..	Cu	Ag	MgO	Ca	*Sr*	..	..	..	..	Fe	Ni	..	Mn	Cr	Pb
Siderolite, Atacama.................	Na	K	..	..	Cu	Ag	..	Ca	..	..	..	..	..	Fe	Ni	..	Mn	Cr	Pb

with such an origin. The only meteorite which contains as much lead as this is the siderolite from Atacama.

Of Volcanic Dust.

If we examine the spectra of specimens of volcanic dust it is noticeable that the heavy metals are, without exception, in comparatively small proportions—lead and iron, for example—while lime, magnesia, and the alkalies are the chief basic constituents. The spectra of the heavy metals, the alkaline earths, and the magnesia with the alkalies appear on separate photographs.

Of Soot from different Chimneys.

The nature of soot from different sources is characterised by the small proportion of iron in most specimens and of metals precipitated as hydroxides; its large proportion of lime and the greater variability in the proportions of its different constituents distinguishes it from other kinds of dust collected from the clouds or in the open air. It was certainly unexpected when nickel, calcium, manganese, copper, and silver were found to be constant constituents of soot from different chimneys and flues. The proportions of lead, silver, and copper are much larger in the soot from the assaying furnace and the laundry chimney.

To illustrate the differences observable in dust and soot of various kinds, a list is appended of the wave-lengths of the iron lines observed in the spectra from soot obtained from the laundry, laboratory, kitchen, and bedroom chimneys. A second list gives the wave-lengths of lines belonging to other elements and observed in other substances as well as dust and soot.

It will be seen that there is an extraordinary difference between the kitchen and the laundry soot, which is probably caused by a higher temperature and more complete combustion of the fuel in the laundry fire.

Flue Dust.

In flue dust from different sources the chief characteristics are the presence of lead, silver, and copper in larger proportions than in other varieties of dust or of coal ashes which have also been examined. Nickel and manganese also are in larger proportions. But the most striking feature is the quantity of rubidium, gallium, indium, and thallium in all samples examined.

It is evident now that we can state with absolute certainty whether two kinds of dust have the same composition or in what constituents they differ substantially.

When dust is collected in the open air it is liable to become mixed

The Lines of Iron observed in different kinds of Soot.

Laundry.	Laboratory.	Kitchen.	Bedroom.	
5893·0				
4404·9				
4383·7	4383·7			
25·9				
08·0				
4289·8				
16·3	4216·0			The two rubidium lines 4215·8 and 4202·4 almost coincide with two iron lines 4216·3 and 4202·1.
02·1				
4144·0	4144·0			
32·2				
4063·7				
45·9				
3930·4	3930·4		3930·4	
28·0	28·0		28·0	
23·0	23·0		23·0	
20·4	20·4		20·4	
06·6	06·6		06·6	
3899·9	3899·9		3899·9	
95·8	95·8		95·8	
86·4	86·4	3886·4 Extremely feeble	86·4	
75·7	78·7		78·7	
72·6	72·6			
65·6				
60·0	60·0	3860·0 Very feeble	3860·0	
56·5	56·5		56·5	
50·1	50·1			
40·5	40·5			
34·3	34·3			
26·0	26·0		3826·0	
24·5	24·5	3824·5 Barely visible	24·5	
20·5	20·5		20·5	
15·9	15·9			
13·1	13·1			
3799·6	3799·6			
98·6	98·6			
95·1				
88·0	88·0			
49·6	49·6	3749·6	3749·6	
45·7	45·7	45·7	45·7	
35·0	35·0	35·0	35·0	
33·4	33·4	33·4	33·4	
27·7	27·7			
22·6	22·6	3722·6	3722·6	
20·0	20·0	20·0	20·0	
09·3	09·3	The six last lines are very feeble	09·3	
05·7	05·7		05·7	
3687·6	3687·6		3687·6	
80·0	80·0			
77·8	77·8		3677·8	
47·9	47·9			
31·6	31·6			
18·9	18·9			
3585·5	3585·5			
81·3	81·3			
70·2	70·2			

Wave-lengths of other Lines than Iron in Spectra from various kinds of Dust and Soot, and in Meteorites.

	Sodium.	*Calcium.*	*Chromium.*
D lines.	5896·1 5890·2 Mean 5893·0 3303·1 3302·5 Mean 3302·3	4226·9 A line.	4289·9 4274·6 4254·4 A triplet. 3605·3 3593·7 3578·8 A triplet.
	Potassium.	*Calcium Oxide.*	*Manganese.*
	5805·0 4047·4 4044·0 Mean 4045·7	5598·0 to 5485·0 A strong band. 6253·0 to 6116·0 A band. 6075·0 to about 5985·0 A weaker band.	4034·5 4033·2 4031·0 Lines which often appear like one broad line.
	Lithium.	*Magnesium Oxide.*	*Copper.*
	4602·3 3232·7	3929·0 to 3856·0 A band, strong, diffuse. 3834·0 to about 3805·0 A band, strong, diffuse.	3273·6 3247·0
	Cæsium.	*Strontium.*	*Silver.*
	4557·0	4607·0	3383·5 3282·1
	Rubidium.	*Lead.*	*Nickel.*
	4215·7 4202·4	4057·6 3682·9 3639·2	3618·5 3609·8 3571·2 3461·0 3433·0 The lines observed are near the positions of such as are here indicated, and are probably identical with them. There is also a line 3525, the only one observed in Cleveland pig iron. It does not appear in these analyses.
	Thallium.		
	5349·6 3775·6		
	Gallium.		
	4172·2 4033·0		
	Indium.		
	4511·0 4102·0		

Some of the lines were measured with a micrometer and the wave-lengths deduced from a curve on an enlarged scale drawn from Rowland's measurements of iron lines in the solar spectrum.

with other dust and soot, and we cannot be certain whether it comes from only one source or not, but soot, as a rule, can be separated by washing it away from the heavier matter. The occurrence of nickel in soot and flue dust was certainly unexpected. It is probably disseminated in extremely minute traces in coal, and its concentration in soot is owing to the conditions in a coal fire being favourable to the formation of nickel tetra-carbonyl and its subsequent decomposition

[redacted]

Conclusions.

(1.) The presence of nickel, as shown by the examination of soot, is not positive evidence that the dust from the clouds comes from other than a terrestrial source.

(2) The dust which fell on the 16th and 17th of November, 1897, with its regularity in composition and its similarity to meteorites, being magnetic, also its comparative freedom from extraneous matter, exhibits properties which are quite in favour of its cosmic origin. Moreover, its composition is totally unlike that of volcanic dust and flue dust from various chemical and metallurgical works. This dust for the most part fell on a perfectly calm fine night, and there was no rain for twenty-four hours or more afterwards.

We beg to draw attention once more to the very wide distribution of gallium in minute proportions; it occurs in all aluminous minerals, flue dust of very different kinds, soot and atmospheric dust, also in a great variety of iron ores. Bauxite contains it in larger proportion than any other mineral, but the quantity even in this substance is very small. We have hopes of finding it concentrated in some mineral, as thallium, cæsium, germanium, and indium are. Indium and thallium, the other members of the same group of elements, are found in blende and pyrites, and accordingly we might expect gallium to occur in a concentrated state in a sulphide, arsenide, or similar compound. Judging, however, from its analogy with aluminium, there does not seem to be much probability of this.

"Notes on the Spark Spectrum of Silicon as rendered by Silicates." By W. N. Hartley, F.R.S. Received November 19, 1900—Read February 21, 1901.

The interesting account by Mr. Lunt* of his identification of three lines of silicon, corresponding with three unknown lines in the spectra of certain fixed stars, contains the following remarks:—

"It is a curious fact that Hartley and Adeney, and Eder and Valenta, who alone give us any extended list of lines due to silicon, appear not to have examined the spectrum of this element in the region of the three rays here considered. Their published wave-lengths show only lines in the extreme ultra-violet, and the majority of them are quite outside the region which can be examined by the McClean star spectroscope."

There is an inaccuracy here, and a similar mistake as to authorship occurs in the paper of Eder and Valenta. Silicon was not one of the sixteen elements whose spark spectra were investigated by Hartley

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* 'Roy. Soc. Proc.,' vol. 66, p. 44.

and Adeney,[*] because it was found to be practically a non-conductor of electricity, and no uninterrupted stream of sparks could be obtained from it. A prior publication,[†] "On Line Spectra of Boron and Silicon," by me, gives descriptions and wave-lengths of lines characteristic of these elements which were observed in solutions of borates and silicates.[‡]

Having some of the spectra photographed in 1883, I find upon examination of the plates that they were closely investigated at that time. They show no trace of any line of silicon less refrangible than 2881·0 (Ångström's unit).

There is a line at the less refrangible extremity of the spectrum which, to judge from its position, is yellow or yellowish-green in colour; but it certainly does not belong to silicon, because solutions of a silicate, and of hydrofluosilicic acid containing 1 per cent., 0·1 per cent., 0·01 per cent., and 0·001 per cent. of silicon, show this line to be stronger in the spectrum given by 0·01 per cent. than in any other of the photographs. It has every appearance of and no doubt is the well-known pair of sodium lines with a mean wave-length of 5893. A concentrated solution of sodium silicate gave no stronger indication of this line, and only a feeble representation of the strongest sodium line 3301. This may be accounted for by the remarkable fact referred to in the original paper, that the lines of the metal in borates and silicates seem to be suppressed when the spectra of boron and silicon appear with greatest intensity, but if the quantity of the borate or silicate in the solution is diminished, the sodium lines gain in strength.

There is, however, a line near a very strong air line seen in the spectrum of a 1 per cent. solution. It continues to increase in length and intensity in other spectra as the proportion of silica diminishes; otherwise it would not be noticeable because it is extremely short, feeble, and enveloped in air lines when photographed from a 1 per cent. solution. A solution equivalent to 0·001 per cent. of silicon yields a spectrum in which this line is about one-fourth of the length of the air lines, and of the seven carbon lines in other parts of the spectrum.

It is in fact the least refrangible carbon line from the graphite electrodes 4266·3 (Hartley and Adeney), and is visible and of normal strength and length on photograph No. 10 in the 'Journal of the Chemical Society,' vol. 41, p. 90, 1882. It is one of those lines which is occasionally absent from the carbon spectrum, and it is somewhat

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[*] 'Phil. Trans.,' 1884, Part 1, p. 63.

[†] 'Roy. Soc. Proc.,' 1883, vol. 35, p. 301.

[‡] For a list of these lines, see also Watts's 'Index of Spectra,' p. 127, 1889. In Appendix E, p. 21 of the Index, the same list of lines is headed H. and A., which is erroneous.

lengthened when the electrodes are wet.* It is doubtless a carbon line, for Deslandres† gives its wave-length as 4267 (Rowland's unit), and he used carbon purified in Moissan's electric furnace. The least refrangible of the silicon lines on my plates is at wave-length 2881·0, and it corresponds with a line in the arc spectrum 2881·1 (Liveing and Dewar).

There is a group of air lines‡ 4446·02, 4432·58, 4425·90, 4415·51, and 4413·60, then come 4628·95 and 4674·2, but there is no trace of any silicon lines between 4573 and 4553 where Mr. Lunt found three.

Mr. Lunt used a powerfully disruptive discharge, and that apparently is sufficient to account for the difference in the spectrum which he obtained. I have always employed very simple apparatus, but it happens that when investigating the coefficient of extinction of the various rays of silicon a second series of experiments was made with a more powerful coil and jar. It was found that when all the lines had become very short, and the weaker lines had nearly disappeared, they could be reproduced to a great extent from the same solution by increasing the capacity of the Leyden jar or condenser, but as only extremely dilute solutions of silicates were used, the lines obtained by Mr. Lunt from the solid silicates did not appear.

I give here the normal length of the six lines in the characteristic

Silicon Lines.

A. Strength of solution, or per cent. of silicon.
B. Length of the lines in hundredths of an inch.

Description of lines.	Wave-lengths. (Rowland's unit.)	A, 1·0. B.	A, 0·1. B.	A, 0·01. B.	A, 0·001. B.
Strongest but one of the group	2506·8	20	10	10·0	9
A weaker line	2514·0	20	12	10·0	8
Strongest and longest	2515·9	20	15	10·0	10
The weakest lines of the group	2518·9	20	9	7·5	7
	2523·9	20	10	7·5	7
	2528·6	20	10	7·5	7
An isolated line weak and thin	2631·8	17	6	2·0	Barely visible
Very strong line	2881·5	22	14	10·0	9

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* 'Phil. Trans.,' 1884, Part I, p. 49.

† 'Comptes Rendus,' 1895, vol. 120, p. 1259.

‡ These wave-lengths are copied from the original numbers written upon the 16-inch enlargements of the spectra referred to as being published in the 'Journal of the Chemical Society.' The values are according to Ångström's unit, and are doubtless not so accurate as numbers more recently determined.

group as they are seen when a 1 per cent. solution and graphite electrodes are used, and of two isolated lines which are less refrangible; with them are compared the lines photographed from other more dilute solutions. The sodium line λ 3301 appears as a long line in the 1 per cent. solution and becomes shorter as the quantity of substance is reduced.

Observations were carried as far as a solution containing 0·000001 per cent. of silicon, the two strongest lines being still visible, but as the photographs of these more dilute solutions have been damaged by being kept so long a time in the atmosphere of the chemical laboratory, they are not now available for similar measurements.

As the sodium lines are suppressed when the silicon lines are strong, the two carbon lines are also reduced very much in length and strength. This is very easily observed on account of the close proximity of the silicon lines, the wave-lengths of the two carbon lines being 2508·7 and 2511·6 (Hartley and Adeney). In the more dilute solution, these lines are observed to be lengthened until they become of the normal dimensions of 20/100ths of an inch. It thus appears more than probable that the suppression of the sodium does not result from any chemical action within the spark discharge, such as might be supposed to occur if the sodium were dissociated from the compound, and being in contact with a silicate were to liberate silicon, or to combine with silicon directly, and in presence of water give rise to the formation of silicon hydride.

The suppression of much of the sodium spectrum, and the shortening and weakening of the carbon lines, is more likely to be a purely physical phenomenon than the result of any chemical reaction in the spark.

"Some Additional Notes on the Orientation of Greek Temples, being the Result of a Journey to Greece and Sicily in April and May, 1900." By F. C. Penrose, M.A., F.R.S.

Received January 17,—Read February 14, 1901.

(Abstract.)

The paper contains notes on two examples from Greece and four from Sicily—of these, three are of the nature of amplification and correction, and three are fresh cases.

(1.) To the second head belongs a rude and archaic shrine in the Isle of Delos; not improbably the most ancient existing example of a religious structure on Greek soil. It exhibits the usual stellar connection with its orientation and an approximate date conformable with its remote antiquity (1530 B.C.).

[redacted]

(2.) Some further observations on the Temple of Apollo, at Delphi, of which the recent complete clearance of the site admitted of measurement with greater exactness than before.

(3.) At Syracuse I found that the architecture of the temple which has been erroneously attributed to Diana,* was of a character much too archaic for the date assigned to it in that paper, which had been derived from the orientation of the axis; but that when taken from the northern limit of the eastern opening the date would be quite consistent both with architecture and the history of the town.

(4.) This led to a re-examination of the other Syracusan examples and an error was discovered, altering the orientation of the temple attributed to Minerva, and its derived date, from 815 to 550 B.C., to its great advantage in every respect.

(5.) The most interesting example, however, is from another Sicilian temple lately unearthed at Selinus. Of this temple I found the orientation of the eastern axis to be 30° 22′ north amplitude, which at once suggests a solar temple arranged for the summer solstice, which for a level site and for the date in question, should be 30° 35′. But the temple's site is near the bottom of a valley; and the sun would have to gain an altitude of rather more than two and a half degrees before it could shine into the temple; and then the amplitude required would be 28° 17′. Thus apart from what may be derived from the plan of the temple itself, the orientation theory would seem to show to a disadvantage. At the same time the peculiarities of the plan of the temple would be difficult to explain without the orientation theory.

Presumably the angle upon which the lines of the temple were set out was taken from data obtained on some platform which had a level horizon, and the building was considerably advanced before the actual solstice came round and showed the error that had been made.

To meet the difficulty a *naos* was constructed within the flank walls, but hugging the northern one; so that the first beam of sunrise coming through the centre of the eastern aperture, at the local amplitude of + 28° 17′ E., might shine in centrally upon the statue of the deity: and for this a pedestal was provided a little northwards of the centre of the niche which had been previously formed for it. We may notice also that the angle of the Propylæa is so placed as to keep exactly clear of the point of sunrise (see figure, next page).

(6.) An argument is drawn from the orientation of the foundations of a small temple lately discovered, adjoining the famous theatre at Taormina, that the theatre itself was that of the city of Naxos, which occupied the sea-coast at about 800 feet immediately below it; and not the work of the much later town of Tauromenium, from which Taormina derives its name.

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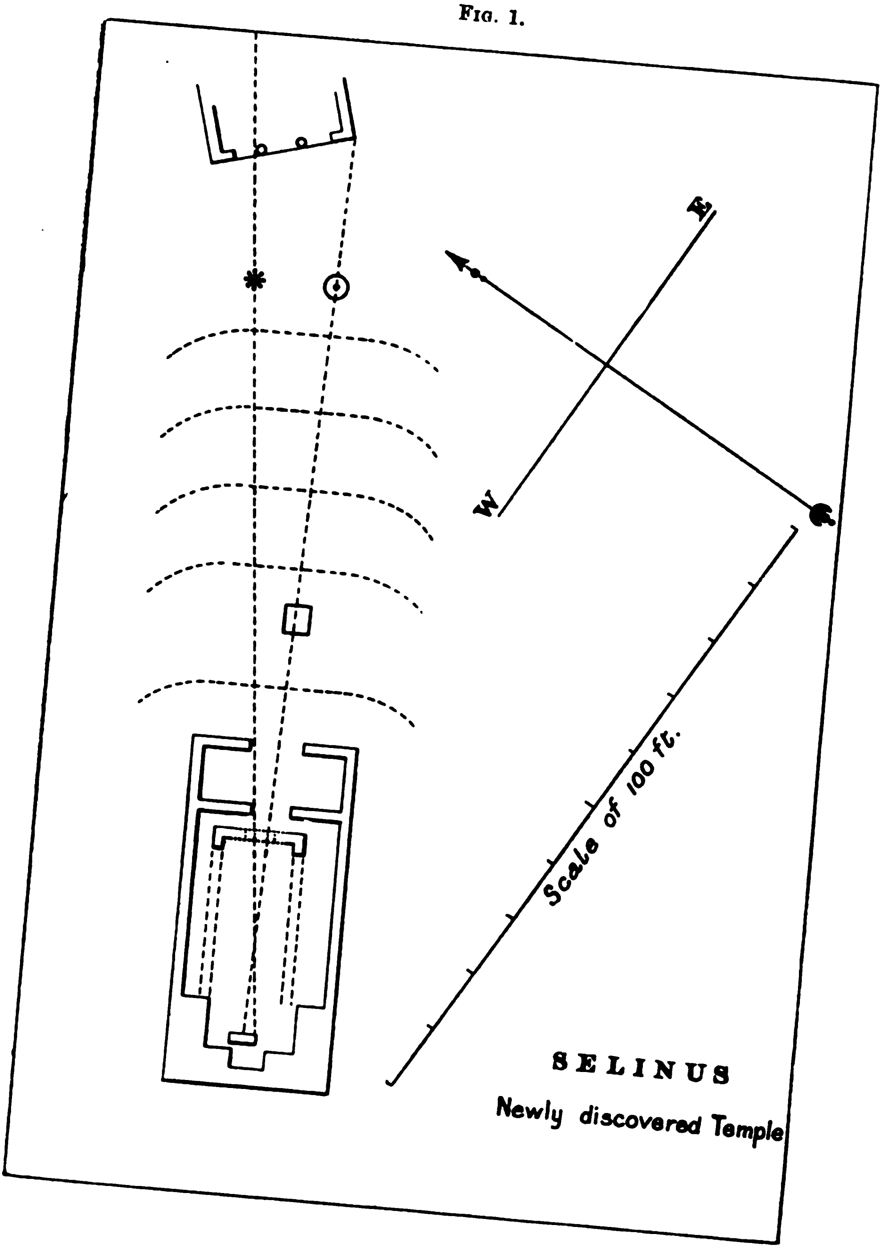
* 'Phil. Trans.,' A, vol. 190, 1897, p. 39.

FIG. 1.



February 28, 1901.

Mr. W. H. M. CHRISTIE, Vice-President, Astronomer Royal, in the Chair.

The Secretary reported that on Saturday, February 23, the President, accompanied by the Treasurer, the Senior Secretary, the Foreign Secretary, Lord Lister, Lord Kelvin, and Sir Joseph Hooker, Past Presidents, and Mr. Christie, Vice-President, had proceeded to St. James's Palace, and, being admitted to the presence of the Throne, had the honour of presenting to His Gracious Majesty an Address of Condolence and of Homage, and that His Majesty had made a gracious reply.

The Address and Royal Reply are as follows :—

To the King's Most Excellent Majesty.

The Humble Address of the President, Council, and Fellows of the Royal Society of London for Promoting Natural Knowledge.

Most Gracious Sovereign,

We, Your Majesty's most dutiful and loyal subjects, the President, Council, and Fellows of the Royal Society of London for Promoting Natural Knowledge, humbly beg leave to offer our deepest and most heartfelt sympathy with Your Majesty in the great sorrow which has befallen You in the death of Your beloved Mother, our late Sovereign Lady the Queen. Your Majesty's loss is our loss also : a loss not only to ourselves, not only to all Your Majesty's subjects throughout the Empire, but to the whole world. During Your beloved Mother's wise and beneficent reign, under Her thoughtful fostering care, that natural knowledge which the Society was founded by one of Your ancestors to promote has been promoted to an extent, and in ways, never known before ; and we feel sure that not in our time only, but in the years to come, to the story of the advance of Science in the past century will be most closely linked the memory of the goodness, the wisdom, the peerless worth of the august and beloved Lady, whose death has now plunged us into the deepest grief.

While thus uttering words of sorrow, we ask leave, Sire, at the same time, to lay at Your Majesty's feet our unfeigned and heartfelt congratulation upon Your Majesty's accession to the Throne of Your ancestors, to reign over a people to whom, happily, Your Majesty is nostranger, but who have, by many experiences, learnt to recognise Your great worth, and have been led to the sure hope, that, under Your gracious rule, the Nation will continue to hold the proud position which it has gained under the guidance of Your beloved Mother.

That Your Majesty's reign may be long, happy, and glorious, and that You may ever rule in the hearts as well as over the persons of a loving, dutiful, and grateful people, is the earnest wish and ardent prayer of

Your Majesty's loyal and dutiful Subjects,
THE PRESIDENT, COUNCIL, AND FELLOWS
OF THE ROYAL SOCIETY OF LONDON.

HIS MAJESTY'S GRACIOUS REPLY.

"I am much gratified by the warm expression of your loyalty and affection, of your profound sympathy with our present grief, and of your loving appreciation of the goodness and great qualities of my dearly beloved mother.

"I thank you for your dutiful good wishes, and I share your hope that my reign also may be blessed by a continuous growth of my people in enlightenment, refinement, and power for good. The intellectual attainments and energies which your Society so conspicuously represents are among the most precious possessions of the nation as aids in securing those high ends, and I remember with gratification the close connection of the Society with its Royal Founder and my other predecessors on this Throne, and the fact that I am a Fellow, as was also my dear Father.

"You may feel assured of my constant interest in and protection of your work, and in token of my goodwill I shall be pleased to inscribe my name as Patron in the Charter Book."

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "The New Star in Perseus.—Preliminary Note." By Sir NORMAN LOCKYER, K.C.B., F.R.S.

II. "On the Structure and Affinities of Fossil Plants from the Palæozoic Rocks. IV.—The Seed-like Fructification of *Lepidocarpon*, a Genus of Lycopodiaceous Cones from the Carboniferous Formation." By Dr. D. H. SCOTT, F.R.S.

III. "A Preliminary Account of the Development of the Free-swimming Nauplius of *Leptodon hyalina* (Lillj.)." By Dr. E. WARREN.

[redacted]

IV. "On the Result of Chilling Copper-Tin Alloys." By C. T. Heycock, F.R.S., and F. H. Neville, F.R.S.

V. "On the Theory of Consistence of Logical Class-frequencies, and its Geometrical Representation." By G. Udny Yule.

"On the Structure and Affinities of Fossil Plants from the Palæozoic Rocks. IV. The Seed-like Fructification of *Lepidocarpon*, a Genus of Lycopodiaceous Cones from the Carboniferous Formation." By D. H. Scott, M.A., Ph.D., F.R.S., Hon. Keeper of the Jodrell Laboratory, Royal Gardens, Kew.

Received February 19,—Read February 28, 1901.

(Abstract.)

A short account of the new genus *Lepidocarpon* has been given in a note communicated to the Royal Society last August*; the present paper contains a full, illustrated description of the fossils in question, together with a discussion of their morphology and affinities.

The strobilus of *Lepidocarpon Lomaxi*, the Coal-measure species, is, in its earlier condition, in all respects that of a *Lepidostrobus*, of the type of *L. Oldhamius.*

In each megasporangium, however, a single megaspore or embryo-sac alone came to perfection, filling almost the whole sporangial cavity, but accompanied by the remains of its abortive sister-cells. An integument ultimately grew up from the sporophyll, completely enclosing the megasporangium, and leaving only a narrow slit-like opening, or micropyle, along the top. As shown in specially favourable specimens, both of *Lepidocarpon Lomaxi*, and of *L. Wildianum*, the more ancient Burntisland form, the functional megaspore became filled by a large-celled prothallus, resembling that of the recent *Isoëtes* or *Selaginella.* The whole body, consisting of the sporophyll, bearing the integumented megasporangium and its contents, became detached from the strobilus, and in this isolated condition is identical with the "seed" described by Williamson under the name of *Cardiocarpon anomalum*, which, however, proves to be totally distinct from the Cordaitean seed so named by Carruthers.

The seed-like organs of *Lepidocarpon* are regarded by the author as presenting close analogies with true seeds, but as differing too widely from the seeds of any known Spermophyta to afford any proof of affinity. The case appears rather to be one of parallel or convergent development, and not to indicate any genetic connection between the Lycopods and the Gymnosperms, or other Phanerogams.

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* "Note on the Occurrence of a Seed-like Fructification in certain Palæozoic Lycopods," 'Roy. Soc. Proc.,' vol. 67, p. 306.

"On the Theory of Consistence of Logical Class-frequencies and its Geometrical Representation."

By G. UDNY YULE, formerly Assistant Professor of Applied Mathematics in University College, London. Communicated by Professor K. PEARSON, F.R.S. Received February 9,—Read February 28, 1901.

(Abstract.)

The memoir deals with the theory of the conditions to which a series of logical class-frequencies is subject if the series is to be self-consistent; *i.e.*, if the class-frequencies are to be such as might be observed within one and the same logical universe.

The theory has been dealt with to a limited extent by De Morgan, in his 'Formal Logic' ("On the Numerically Definite Syllogism") and by Boole, in the 'Laws of Thought' (in the chapter entitled "Of Statistical Conditions").

In the present memoir the first section deals with the theory of consistence, by a simple method, up to class-frequencies in five attributes, and a general formula is then obtained, giving the conditions for any case. In the second part of the paper some illustrations are given of the geometrical representations of the conditions obtained in Part I.

In the case of three second-order frequencies (AB), (AC), and (BC), the complete conditions of consistence may be represented by a tetrahedron with its edges truncated. The first-order frequencies are treated as constant, (AB), (AC), (BC) as co-ordinates, and the limits to (BC), for example, are given by the points in which the line drawn through the point (AB) (AC) parallel to the (BC)-axis cuts the surface. The general form of the surface depends on the value of the first-order frequencies. If

$$(A)/(U) = (B)/(U) = (C)/(U) = \tfrac{1}{2}$$

(U) being the total frequency, the edges are not truncated and the "congruence-surface" becomes a simple equilateral tetrahedron. The limits given to (BC) in terms of (AB) and (AC) in this case are shown to correspond to the limits to the correlation coefficient r_{23} in terms of r_{12} and r_{13} in the case of normal correlation. The congruence-surface shows very clearly the nature of the approximation towards the syllogism, as conditions of the "universal" type (all A's are B, or no A's are B) are approached. One or two illustrations are also given of congruence-surfaces for third-order frequencies, the first- and second-order frequencies being both treated as constants.

In the third part of the paper some numerical examples, and sketches of congruence-surfaces for actual cases, are given, in further illustration of the theory.

[redacted]

"The New Star in Perseus.—Preliminary Note."

By Sir NORMAN LOCKYER, K.C.B., F.R.S.

Received and Read February 28, 1901.

Dr. Copeland was kind enough to inform me by telegram on the afternoon of February 22, of the discovery by Dr. Anderson of a new star in the Milky Way in Perseus on the early morning of that day. It was stated that its position was R.A. 3^h 24^m 25^s and Declination $+43° 34'$, its magnitude 2·7, and colour of a bluish-white. Later in the evening this information was corroborated by another telegram from the "Centralstelle" at Kiel.

Owing to cloudy weather, no photographs could be obtained at Kensington until the evening of the 25th. Momentary glimpses of the star on the evening of the 22nd, between the hours of 6 and 7.30 P.M., indicated that the Nova had considerably brightened since the time of its discovery, as it was estimated as a little brighter than a 1st magnitude star; no satisfactory observations of the spectrum could be made. Another glimpse on the early morning (1.30 A.M.) of Monday (25th) showed that the star was still of about the 1st magnitude.

Professor Pickering reports that the Nova was dimmer than an 11th magnitude star on February 19. On the 23rd it was as bright as Capella. The star, therefore, was then at least 10,000 times brighter than it was four days previously, and ranks as the brightest new star recorded since that which appeared in the year 1604.

Since the 25th the brightness has diminished slightly, and on the evening of the 27th was estimated between the 1st and 2nd magnitude (1·7). If this reduction of brilliancy continues at the same rate, the new star will evidently be shorter lived than those to which it has most closely approximated in luminous intensity at the maximum, and less time will be available for studying the spectral changes which may be anticipated. I may state that Tycho's Nova (1572) was visible for nearly 1½ years, and Kepler's (1604) for about the same period.

It is interesting to note that the star was described by Dr. Anderson as being of a bluish-white colour at the time of discovery. Since it has diminished in brightness this has changed, and on the night of February 27, a reddish tinge was observed.

The sky on Monday evening was by no means free from clouds, but ten very satisfactory photographs were secured with the three instruments in regular use for stellar spectra. Edwards's isochromatic plates were used, as it was considered desirable to secure a record of the green part of the spectrum.

Although there has not been time for a complete discussion of these photographs, it may be stated that the spectrum contains numerous dark lines, several of which are associated with bright bands on the

less refrangible side. Further, the spectrum, as a whole, g
resembles that of Nova Aurigæ.

(A). Spectrum of Nova Persei.
(B). " " α Persei, photographed on the same plate.
Taken with a 30-inch common reflector and a two-prism slit spectroscope.

One of the chief features of the principal bright lines is their width, amounting to 30 tenth-metres, and each is accompanied by line of considerable breadth on its more refrangible side. A comp spectrum of γ Orionis, photographed alongside that of the Nova of the plates, indicates that the middle portions of the bright lines are not far from their normal positions; those of the dark ones, however, are displaced by some 15 tenth-metres towards the violet, thus indicating a differential movement of something like 700 miles a second.

Movements more rapid and disturbances more violent than those observed in Nova Aurigæ are therefore indicated; both by the greater displacement of the dark lines relatively to those that are bright and the greater breadth of the bright and dark lines.

The comparison of spectra shows us that we are dealing with two swarms, one of which, the less dense, gives us broad bright lines and is almost at rest with reference to the line of sight; the denser swarm, indicated by the dark lines, is in most rapid movement in the line of sight towards the earth.

An interesting feature of the spectrum is the presence of fine dark lines down the middle of each of the bright lines of hydrogen and calcium; these are most probably reversals, and if this be so, they will be of great service for accurate determination of the wave-lengths of the other bright lines. The dark hydrogen line $H\gamma$, and perhaps $H\beta$ and $H\delta$, are also possibly reversed.

Eye observations showed among the chief lines a group of four in the green; one probably $H\beta$, the others near $\lambda\lambda$ 492, 501, and 517; a bright line at or near D, and a brilliant red line probably corresponding to $H\alpha$. Each of these was accompanied by a dark broad line on its more refrangible side. Other lines of less brightness were observed both in the green and red.

It at first seemed probable that two of the bright lines in the green ($\lambda\lambda$ 492 and 501) might be due to asterium, while that in the orange was perhaps the helium line D_3. Subsequent investigation, however, suggested as an alternative origin that these lines might be the enhanced lines of iron at λ 4924·1 and 5018·6, which are very nearly in the same positions as the asterium lines. This view was tested by inquiring whether other prominent enhanced lines of iron so strongly visible in the spectrum of α Cygni were present.

A comparison with the spectrum of this star photographed with the same instruments suggested that many lines between F and *h* in the Nova probably correspond with lines in α Cygni. Certainty could not be arrived at in consequence of the great breadth of the lines in the Nova.

Hence, as the Nova bore some resemblance to both Nova Aurigæ and α Cygni, a reference was suggested to the lines recorded in the spectrum of Nova Aurigæ which were observed when the light of that star was on the wane, and when the lines were thinned enough to be easily measurable. I may also add that these observations were made before the work on enhanced lines was undertaken.

The importance of this reference was strengthened by the consideration that with such a tremendous outburst we should expect the original invisible swarm to have been (very rapidly) advanced to a considerable condensation at the locus of impact, and therefore to resemble some "star" which had (slowly) arrived at a position pretty high up on the ascending temperature curve in the ordinary course of evolution on the meteoritic hypothesis.

A comparison of the bright lines recorded by Campbell[*] and Vogel[†] in the spectrum of Nova Aurigæ with the strongest lines of α Cygni—a very detailed record of the spectrum of which star has been recently compiled here—shows that there is a close agreement between the two sets of lines. These strong α Cygni lines are almost without exception the representatives of "enhanced" lines of some of the metals, chiefly Fe, Ti, Cr, Ni, Ca, Sr, and Sc. If we exclude the lines of hydrogen from those which were recorded in the spectrum of Nova Aurigæ, there remain forty-four lines for comparison. Thirty of these, or about 70 per cent., agree approximately in position with either strong isolated lines or groups of lines in the spectrum of α Cygni.

It may be assumed that, taking into consideration the broad nature of the Nova lines, if there be any genuine connection between them and the lines of α Cygni, any close groups of separately distinguishable lines in the latter spectrum would be thrown together in the Nova spectrum, and appear as broad bands. A good instance of this appears in Campbell's list. He records a band extending from λλ 4534 to 4501. In the spectrum of α Cygni there is a strong line at each of the positions given, and between them there occurs a strong quartet of lines. The former are well enhanced lines of titanium, and the latter of iron. It seems extremely likely, therefore, that the six lines thrown together produce the apparently continuous band observed by Campbell.

If the stage of α Cygni has really been reached, the following considerations come in:—

In the orderly condensation of swarms, according to the meteoritic hypothesis, the earlier stages are—

Ascending temperature. ↑	Cygnian	Dark lines, corresponding chiefly with the enhanced lines of various metals.
	Polarian	Dark lines, comprising both arc and enhanced lines of various metals.
	Aldebarian	Dark lines, chiefly corresponding to those which appear in the arc spectra of various metals.
	Antarian	Mixed bright and dark flutings and dark lines. Bright lines of hydrogen in those stars which are variable.
	Nebula	Bright lines.

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[*] 'Ast.-Phys. Jour.,' vol. xi, p. 807, 1892.

[†] 'Ast.-Phys. Jour.,' vol. xii, p. 912, 1893.

In the case of new stars, after the maximum of luminosity has been reached, however high they ascend, short of the apex of the temperature curve, this order must be reversed, and hence we should expect to find the spectrum varying in accordance with the foregoing sequence, but in the reverse order.

In Nova Coronæ (1866), according to the observations of Sir William Huggins and Dr. Miller, the absorption spectrum was very similar to that of α Orionis, which is a star of the Antarian group, so that the temperature attained was relatively low; this indeed is demonstrated by the fact that at present it shines faintly as an Antarian star, and doubtless did so before the collision. The collision, therefore, probably did not take Nova Coronæ very much above its initial stage of temperature, and when the disturbance was over it simply reverted to its old conditions.

The spectrum of Nova Cygni (1876) was not photographed, and as special attention was given by most observers to the bright lines, there is no satisfactory record of the absorption spectrum.

This now appears as a nebula, and doubtless it was a nebula to begin with, as Nova Coronæ was a star to begin with.

In Nova Aurigæ (1892), as we have seen, the comparison with α Cygni indicates that the Cygnian (a higher) stage was reached, and in the final stages its spectrum corresponded with that of the planetary nebulæ, that is, a stage lower than that reached by Nova Coronæ. The intermediate stages, however, were not observed, possibly because the star was never very brilliant, and partly because of the difficulty of observing closely grouped lines, such as occur in the Polarian and Aldebarian stages when they are rendered broad by such disturbances as those which were obviously present in the Nova.

The observed maximum magnitude in the case of a new star will evidently depend upon the distance and size of the colliding masses, as well as upon the temperature produced by the collision. It is not remarkable, therefore, that there is no apparent relation between the greatest brightness and the temperature indicated by the spectra. Nova Coronæ, with its relatively low temperature, shone for a time as a 2nd magnitude star, while Nova Aurigæ, with a much higher temperature, scarcely surpassed a star of the 5th magnitude.

I now return to Nova Persei. If the idea that in the present Nova the swarm which gives the dark line spectrum resembles α Cygni be confirmed; as its temperature is reduced we may expect it to pass successively through some or all of the stages of temperature represented by stars of the Polarian, Aldebarian, and Antarian groups, enhanced lines being first replaced by arc lines, and then by flutings. Whether it remains at one of these stages or undergoes a further backwardation into a nebula will be a point of the highest interest.

If, like Nova Aurigæ, the present Nova should end as a nebula, it will furnish a most convincing proof of the fundamental metallic nature of nebulæ.

In conclusion, I wish to express my thanks to Dr. W. J. S. Lockyer and Mr. F. E. Baxandall, of the Solar Physics Observatory, and to Mr. A. Fowler, of the Royal College of Science, who have greatly assisted me in preparing the present note, and who, with the addition of Mr. Butler, of the Solar Physics Observatory, secured the excellent set of photographs and eye observations on the night of the 25th, from which the new knowledge has been derived.

The preparation of the slides I owe to Sapper J. P. Wilkie.

March 7, 1901.

Sir WILLIAM HUGGINS, K.C.B., D.C.L., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

In pursuance of the Statutes, the names of Candidates for election into the Society were read as follows:—

Adeney, Walter Ernest, D.Sc.
Alcock, Alfred William, Major, I.M.S.
Allen, Alfred Henry, F.C.S.
Ardagh, Sir John, Major-General, R.E.
Ballance, Charles Alfred, F.R.C.S.
Binnie, Sir Alexander Richardson, M.I.C.E.
Bourne, Gilbert C., M.A.
Bovey, Professor Henry T., M.A.
Boyce, Professor Rubert.
Bridge, Professor Thomas William, M.A.
Brown, Adrian John, F.C.S.
Brown, John.
Bruce, John Mitchell, M.D.
Budge, Ernest A. Wallis, D.Litt.
Callaway, Charles, D.Sc.
Cardew, Philip, Major, R.E.
Chattaway, Frederick Daniel, M.A.
Clowes, Frank, D.Sc.
Copeman, Sydney Monckton, M.D.
Corfield, Professor William Henry, M.D.
Crookshank, Professor Edgar March, M.B.
Darwin, Horace, M.A.
Davison, Charles, D.Sc.
Dendy, Professor Arthur, D.Sc.
Dixon, Professor Alfred Cardew, M.A.
Dixon, Professor Augustus Edward, F.C.S.
Dyson, Frank Watson, M.A.
Evans, Arthur John, M.A.
Feilden, Colonel Henry Wemyss.
Galloway, Professor William, F.G.S.
Goodrich, Edwin S.
Gray, Professor Thomas, B.Sc.
Gregory, Professor J. W., D.Sc.

Hamilton, Professor David James, M.D.
Hardy, William Bate, M.A.
Harker, Alfred, M.A.
Harmer, Frederic William, F.G.S.
Hiern, William Philip, M.A.
Hills, Edmond Herbert, Captain, R.E.
Hopkinson, Edward, M.A.
Jackson, Henry Bradwardine, Captain, R.N.
Jukes-Browne, Alfred John, F.G.S.
Kidston, Robert, F.G.S.
Knott, Cargill Gilston, D.Sc.
Letts, Edmund Albert, D.Sc.
Lewis, Sir William Thomas, Bart., M.Inst.C.E.
MacArthur, John Stewart, F.C.S.
Macdonald, Hector Munro, M.A.
Maclean, Magnus, D.Sc.
MacMunn, Charles Alexander, M.D.
Mallock, Henry Reginald Arnulph.
Mance, Sir Henry C., C.I.E.
Mansergh, James, M.Inst.C.E.
Martin, Professor Charles James, M.B.
Masson, Professor Orme, M.A.
Mather, Thomas.
Matthey, Edward, F.C.S.
Maunder, Edward Walter, F.R.A.S.
Meyrick, Edward, B.A.
Michell, John Henry, M.A.
Mill, Hugh Robert, D.Sc.
Newall, Hugh Frank, M.A.
Notter, James Lane, Surg. Lieut.-Col., M.D.
Oliver, John Ryder, Major-General (late R.A.), C.M.G.
Parsons, Frederick Gymer, F.R.C.S.
Payne, Joseph Frank, M.D.
Perkin, Arthur George.
Pope, William Jackson.
Rose, Thomas Kirke, D.Sc.
Ross, Ronald, Major, M.R.C.S.
Russell, James Samuel Risien, M.D.
Salomons, Sir David, Bart., M.A.
Saunders, Edward.
Schlich, Professor William, C.I.E.
Sidgreaves, Rev. Walter, S.J., F.R.A.S.
Smith, Fred., Lieut.-Col.
Smith, James Lorrain, M.D.
Smithells, Professor Arthur, B.Sc.
Stead, John Edward, F.C.S.
Strahan, Aubrey, M.A.
Swinburne, James.
Swinton, Alan Archibald Campbell, Assoc. M.Inst.C.E.
Symington, Prof. Johnson, M.D.
Tarleton, Professor Francis Alexander, Sc.D.
Tatham, John F. W., F.R.C.P.
Thomas, Michael Rogers Oldfield, F.Z.S.
Wager, Harold, F.L.S.
Walker, James, M.A.
Waterhouse, James, Maj.-Gen.
Watkin, Colonel, R.A., C.B.
Watson, William, B.Sc.
Whetham, William C. D., M.A.
White, William Hale, M.D.
Whitehead, Alfred North, M.A.
Willey, Arthur, D.Sc.
Woodhead, Professor German Sims, M.D.
Woodward, Arthur Smith, F.G.S.

The following Papers were read:—

I. "Further Observations on Nova Persei." By Sir Norman Lockyer, K.C.B., F.R.S.

II. "Some Physical Properties of Nitric Acid Solutions." By V. H. Veley, F.R.S., and J. J. Manley.

[redacted]

III. "The Anatomy of Symmetrical Double Monstrosities in the Trout." By Dr. J. F. Gemmill. Communicated by Professor Cleland, F.R.S.

IV. "Preliminary Communication on the Œstrous Cycle and the Formation of the Corpus Luteum in the Sheep." By F. H. A. Marshall. Communicated by Professor J. C. Ewart, F.R.S.

V. "On the Composition and Variations of the Pelvic Plexus in *Acanthias vulgaris.*" By R. C. Punnett. Communicated by Dr. Gadow, F.R.S.

VI. "On the Heat dissipated by a Platinum Surface at High Temperatures. IV.—High-Pressure Gases." By J. E. Petavel. Communicated by Professor Schuster, F.R.S.

"On the Conductivity of Gases under the Becquerel Rays." By the Hon. R. J. Strutt, Fellow of Trinity College, Cambridge. Communicated by Lord Rayleigh, F.R.S. Received December 15, 1900,—Read February 21, 1901.

(Abstract)

This paper gives an account of experiments on the relative conductivities of gases under the action of Becquerel radiation from various radio-active bodies.

It is first explained that in order to determine the constants fundamentally involved, the following conditions must be complied with:—

(1.) The E.M.F. applied to the conducting gas must be great enough to consume all the ions produced by the rays.

(2.) The pressure of the gas must be low enough to prevent any appreciable fraction of the radiation being absorbed by it.

If this is not so, then the layers of gas nearer the radio-active surface are exposed to stronger radiation than those further from it. The effective strength of the radiation will thus depend on the absorbing power of the gas at the particular pressure, and the observed ratio of the conductivities of two gases at the same pressure will not represent the ratio of their conductivities under radiation of a given strength.

The criterion applied to test whether the absorption was appreciable, was to examine the conductivity at different pressures. The range was ascertained within which the law of approximate proportionality to the pressure held good. In the experiments, care was taken to keep the pressure well within that range.

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The kinds of radiation employed are there enumerated. They include,

(1.) The most penetrating kind of radiation, from radium—that deflectable by the magnet.

(2.) The easily absorbed kind of radiation from radium, which is not so deflectable.

(3.) and (4.) The radiation from two different samples of polonium.

(5.) The radiation from uranium salt.

The method of measurement is then described. It was in outline as follows:—

The layer of the radio-active body was placed at the bottom of a shallow brass box containing the gas under investigation. In this box and parallel to its flat top was a disc electrode, carried by a brass rod passing, air-tight, through an insulating ebonite stopper. The outside of the box was maintained at a high potential by a battery of small storage cells, and the current through the gas measured by the rate at which the potential of the insulated electrode rose, as indicated by a quadrant electrometer connected with it.

When it was desired to use only the penetrating rays from radium, a thin copper sheet, 0·007 cm. thick, intervened between the radio-active material and the gas. In measuring the relative conductivities of two gases, the rate of leak through one was observed at a known pressure. The apparatus was then exhausted, and the other gas admitted, and the rate of leak through it determined. This last rate of leak was corrected, so as to obtain the value which it would have had at the same pressure as that at which the first was examined. The rates of leak through the two gases were then comparable.

The mean results were as follows:—

Gas or vapour.	Density (relative).	Relative conductivity				
		Radium.		Polonium.		Uranium.
		Pene-trating.	Easily absorbed.	I.	II.	
Hydrogen	0·0693	0·157	0·218	0·226	0·219	0·213
Air (assumed)	1·00	1·00	1·00	1·00	1·00	1·00
Oxygen	1·11	1·21	..	1·16		
Carbonic acid........	1·53	1·57	..	1·54		
Cyanogen	1·86	1·86	..	1·94		
Sulphur dioxide......	2.19	2·32	1·92	2·04	2·03	2·08
Chloroform	4·32	4·89	..	4·44		
Methyl iodide	5·05	5·18	3·74	3·51	3·47	3·55
Carbon tetrachloride..	5·31	5·83	..	5·34		

The general conclusions are that,

(1.) Both the deflectable and undeflectable rays give relative conductivities nearly, but certainly not quite, equal to the relative densities.

(2.) All the different kinds of undeflectable rays give the same relative conductivities, but the deflectable rays give somewhat different relative conductivities.

Both these kinds of rays are in this respect sharply distinguished from Röntgen rays, which give relative conductivities several times greater than the relative densities in the case of gases containing sulphur or the halogens.

"Some Physical Properties of Nitric Acid Solutions." By V. H. Veley, F.R.S., and J. J. Manley, Daubeny Curator, Magdalen College, Oxford. Received February 11,—Read March 7, 1901.

(Abstract.)

The results obtained by the authors on the electric conductivity of solutions of nitric acid have led them to continue their investigations on other physical properties of the same substance with a view of confirming the conclusions drawn therefrom.

In the present paper the properties examined are the densities, with especial reference to the contractions, and the refractive indices.

The various sources of error and their possible magnitude are discussed in full: for the densities, those of analysis, unavoidable in this case, temperature, errors of filling pyknometers both with acid and water; for the refractive indices, those of micrometer screws, divided circle, parallelism of quartz plates are more especially alluded to, as also the several effects likely to be produced by the various substances with which the acid solutions of necessity came into contact. The results obtained by both methods are given in a series of tables, and compared with those calculated from various equations for straight lines. These show that the physical properties are discontinuous at points corresponding very approximately to the concentrations required for simple molecular combinations *only* of nitric acid and water. In the case of the densities and contractions, the best defined points of discontinuity correspond to the composition of the hydrates with 14, 7, 4, 3, 1·5, and 1 molecular proportions of water; in the case of the refractive indices, the most marked points correspond to the 14, 7, and 1·5 hydrates.

The results for the contractions further confirm those for the electric conductivities as to a remarkable discontinuity at concentrations 95 per

[redacted]

cent. to 100 per cent., which can possibly be explained by some cause other than the combination of acid with water.

The contractions show that these points of discontinuity, though to some degree real, yet to another degree are ideal in that there is within the limits of 1 to 2 per cent. in the vicinity of such points a transition stage.

The values for μ are further expressed in terms both of Gladstone and Dale's, and of Lorentz' formula, and it is shown that the values in neither case are constant, but decrease with increase of concentration, and also that Pulfrich's formula which expresses the relation between the refractive index and the contraction in terms of a constant is only approximately applicable for results differing by small percentage concentrations, but not so in the case of considerable differences.

The results are illustrated by a selection of curves, with especial reference to the points of discontinuity.

‘The Anatomy of Symmetrical Double Monstrosities in the Trout.”

By James F. Gemmill, M.A., M.D., Lecturer in Embryology and University Assistant in Anatomy, University of Glasgow. Communicated by Professor Cleland, F.R.S.

Received February 6,—Read March 7, 1901.

(Abstract.)

This paper contains the results of an investigation into the anatomy of a series of trout embryos exhibiting different degrees of symmetrical duplicity, and gives an account of the structural details which attend the fusion, disappearance, or special adaptation of parts in the region of transition from the double to the single condition. Some general questions suggested by these results are also discussed.

The monstrosities examined were four months old counting from the time of fertilisation, and they form a fairly complete series ranging from specimens in which the duplicity does not affect more than the anterior part of the head to specimens in which there is union by the posterior part of the body or by the yolk-sac only. The classification adopted has special reference to the material at my disposal and is on the same general lines as that given by Professor Windle in the ‘Proceedings of the Zoological Society,’ 1895.

The examination of the monstrosities was necessarily preceded by an investigation into the anatomy of normal trout embryos at corresponding stages in development. The results of this investigation are briefly given, special attention being paid to the cranial, visceral and vertebral skeleton, which at this period is wholly cartilaginous.

[redacted]

The following is a short summary of the anatomy of the various kinds of double monstrosity described:—

Type 1. *Union in head region*—

- *a. The twin brains united at the mesencephalon.*
- *b. The twin brains united at the medulla oblongata.*

Type 2. *Union in pectoral region*—

- *a. The pectoral fins absent on adjacent sides.*
- *b. The pectoral fins present but united on adjacent sides.*

Type 3. *Union behind the pectoral region*—

- *a. The twin bodies united at a considerable distance in front of the vent.*
- *b. The twin bodies united close to the vent.*

Type 4. *Union by the yolk-sac only.*

Type 1*a* shows the following characteristics:—

The cerebral lobes and the thalamencephala are doubled.

There are two infundibula, two hypophyses and two pairs of hypoaria. The optic lobes have a single cavity, but their basal parts show marked evidence of duplicity. Cerebellum pons and medulla are single, but there is a remarkable reappearance of duplicity in the cervical part of the spinal cord.

There are two pairs of 1st, 2nd, 3rd (and 4th) nerves, but only single pairs of the 5th, 6th, 7th, 8th, and vagus nerves are present. The cervical part of the spinal cord gives off in each segment a small extra pair of ventral roots.

There are two pairs of olfactory organs; all of which are normal. There are also two pairs of eyes, the outer ones (right of right head and left of left head) being normal. The inner or adjacent eyes (left of right head and right of left head) lie close to one another, and are more or less united. They have a common sclerotic and cornea, but the retinæ and choroids are separate. In some cases the lens is a single composite structure; in others it is doubled. Of eye muscles the external recti are always, and the superior obliques are sometimes, awanting. The other eye muscles are all present, and each eye has its own optic nerve, choroidal fissure, choroidal gland and choroidal artery.

In front there are two sets of skeletal structures which converge rapidly as one goes backwards. The adjacent trabecular, supraorbital, and palatopterygoid bars coalesce posteriorly, while the adjacent parachordals are united along their whole length. There are two pituitary spaces. Only a vestige remains of the adjacent Meckelian cartilages. The notochords are double in front and remain separate for about twenty somites. They retain duplicity longer than any other structure. Adjacent neural and costal arch cartilages unite, become

[redacted]

reduced in size, and finally disappear as one goes backwards. The two outer series of cartilages are continued posteriorly into the single region of the body.

Head Kidney.—The glomerulus is sometimes double and sometimes single; when single it has two glomerular tufts, and is divided into three chambers. Each of the outer chambers gives origin to a normal Wolffian duct. The middle chamber is closed. When there are two glomeruli, a normal Wolffian duct arises from the outer half of each glomerulus, but the Wolffian ducts which should arise from the inner or adjacent sides of the glomeruli are either entirely absent or are represented only by short blind sacculated tubules.

Alimentary Canal.—Two mouth openings lead into a single buccal cavity. Pharynx, stomach, liver, and intestine are single, but there are two air-bladder diverticula.

Type 1*b*. *Union in Head Region, the brains being united at the medulla oblongata.*

The medulla and the fourth ventricle cavity bifurcate anteriorly and lead to two separate sets of mid- and fore-brain cavities and masses. Pons and cerebellum are double. There are two sets of cranial nerves. The inner or adjacent elements of the 5th, 7th, and 8th pairs are reduced in size, while the corresponding vagi are extremely rudimentary. The anterior part of the medulla is double; the posterior part is single and composite. The cervical part of the spinal cord shows striking evidence of original duplicity, and has a set of small extra roots coming off from its ventral aspect as in Type 1*a*.

There are two pairs of olfactory organs and two pairs of eyes, all of which are normal. The outer auditory organs (right of right head and left of left head) are normal. In addition there is a small malformed auditory organ placed in the angle between the two converging heads; it consists of united adjacent labyrinths and capsules, and has distributed to it on either side the small adjacent 8th nerves previously mentioned.

Cranial Skeleton.—In front, the cranial skeletal elements are in two separate sets; these converge posteriorly, their basal parts uniting at the level of the medulla oblongata. There are thus two separate nasal cartilages, two separate sets of trabeculæ cranii and two pituitary spaces. The adjacent parachordal cartilages unite and form with the outer ones a single plate which underlies the composite medulla oblongata and covers the cranial parts of the two notochords. The inner or adjacent palatopterygoids, supraorbitals, hyo-mandibulars and periotic capsules are united and reduced in size. In the visceral skeleton there are elements representing fused adjacent Meckelian and hyoid bars, while the copular cartilage which succeeds the glossohyal is bifid anteriorly. The notochords remain separate for at least thirty somites, and have the same arrangement of neural and costal arch cartilages as was described in connection with Type 1*a*.

Heart, &c.—The heart chambers and the truncus arteriosus are single, and there are the usual number of gills and gill vessels. There are, however, two sets of carotid and hyoid arteries, the inner or adjacent pairs being derived directly from the truncus arteriosus. The truncus arteriosus arches dorsally in the septum between the two mouths to reach the base of the skull, and then divides into two limbs which are continued backwards to join the aortic collecting roots on either side. The dorsal aorta remains double so long as the notochord is double.

Head Kidney.—There is a large composite glomerulus containing two vascular tufts and divided into three compartments. Normal Wolffian ducts arise from the outer compartments, while the middle one gives origin to a coiled sacculated tubule which ends blindly in the tissue of the head kidney and represents united adjacent Wolffian ducts.

The *alimentary canal* has two mouth openings, two buccal cavities, and two air-bladder diverticula. Pharynx, œsophagus, stomach, liver, intestine, and vent are single.

Muscles.—In both (*a*) and (*b*), so long as the notochords are separate, there exists between and ventral to them a median muscular mass, divided into segments corresponding with the mesoblastic somites, innervated by the small extra ventral spinal roots previously mentioned, and representing united adjacent lateral muscles.

Type 2. *Union in Pectoral Region.*

(*a.*) *Adjacent Pectoral Fins absent.*
(*b.*) *Adjacent Pectoral Fins present, but united.*

In both cases the brains, the cranial and visceral skeletons, the organs of sense, and the upper parts of the spinal cords are completely doubled. There are two hearts and two trunci arteriosi. In (*a*) the auricles communicate, and the sinus venosus is a large common chamber receiving two sets of jugular veins, but receiving only a single pair of cardinals. In (*b*) the auricles are separate, the sinus venosi have only a narrow neck of communication, and there are two complete sets of jugular and cardinal veins. The inner or adjacent set of cardinals is, however, much reduced in size.

Pectoral Fins.—In (*a*) pectoral fins are entirely absent from the adjacent sides of the twin bodies; in (*b*) they are present in a more or less united condition, the union being greatest towards the posterior border.

The head kidney resembles that described for Type 1 (*b*); the median tubule is, however, larger, and is continued further backwards.

Alimentary Canal.—Mouth, pharynx, air bladder and stomach are double. Union takes place in the pyloric region. Liver, intestine and vent are single.

Type 3. *Union by Posterior Part of Body.*

The intestines are united for a greater or less distance forwards from the vent, which is almost always single. The sagittal planes of the twin bodies converge ventrally in a degree which, roughly speaking, varies directly as the degree of duplicity. The spinal cords may or may not unite anterior to the place of union of the notochords. In some cases the spinal cords remain separate along their whole length. As a rule, in cases where ventral convergence of the sagittal planes is well marked, dorsal structures, such as the spinal cords, dorsal fins, and dorsal edge membranes, remain double longer than structures which are more ventrally placed.

The twin head kidneys are quite separate, and each gives origin to two Wolffian ducts. The relations of the posterior parts of these ducts and of the bladders show remarkable variety. In rare cases the two adjacent Wolffian ducts (*i.e.*, left duct of right twin and right duct of left twin) end blindly and separately, while the two outer ducts open into a single normal bladder. In all other cases there are two bladders, each of which receives a right and a left Wolffian duct belonging to different twins. The two bladders may be quite separate, or they may communicate with one another. When they are separate each of them may open by a urinary pore, or one of them may have no outlet, and may be greatly enlarged through retention. When the bladders communicate with each other, only one of them possesses a urinary pore.

The intestines are separate in front, but in all my specimens they unite posteriorly. The united part usually ends by a single vent, but in one remarkable instance two vents were present which terminated by anal orifices situated on opposite sides of the composite body of the monstrosity.

Type 4. *Union by Yolk-sac only.*

Each embryo has a complete and separate complement of organs. The alimentary canals are shut off altogether from one another and from the yolk. The vitelline circulations are crossed.

General.

The general part of the paper discusses briefly—

(1.) The idiosyncrasies and general arrangement of mesial and paired organs at the transitional region in symmetrical double monstrosities.

(2.) Certain instances of correlation and irregularity in development. Mode of origin of double monstrosities in the trout.

The discussion under these heads is based on the evidence brought forward in the descriptive part of the paper.

(1.) It is shown that at the region of transition in laterally symmetrical double monstrosities the notochords are the last structures to unite, while equally primitive structures, both dorsal and ventral to the notochords, viz., the neural axis and the alimentary canal, lose their duplicity earlier. It is further shown that those parts of the neural axis and alimentary canal which are most closely apposed to the notochords retain evidence of original duplicity longer than parts which are more remote. The floor and roof of the neural axis and of the alimentary canal are seen to be in marked contrast in this respect.

Duplicity of the dorsal aorta, of the pronephric glomerulus, of the vertebral cartilages, of the body muscles and of various other structures is correlated with duplicity of the notochord.

In paired organs the transition from the double to the single condition takes place at the expense of the inner or adjacent elements, which are usually united and reduced in size before they disappear altogether. A list is given of the more important examples of union and reduction in size of adjacent elements in the transitional region, which are mentioned in the descriptive part of the paper.

From the evidence brought forward it is inferred that fusion has played a not unimportant part in moulding the form of the neural axis and the alimentary tract in the transition region. The union of adjacent paired structures is probably to be explained by the fusion of mesoblastic blastema developing laterally from each of the embryonic axes near the place of convergence and union.

(2.) The law that union takes place between homologous structures always holds good. Both twins usually contribute equally and symmetrically to the sum of structures in the transitional region. A short list of exceptions to this rule is tabulated, but their paucity and want of importance only serve to make more striking the general symmetry of structure in all the specimens examined.

With the rarest exceptions, all double monstrosities in the trout are examples either of anterior duplicity or of union by the yolk-sac only. This contrasts very markedly with the types of double monstrosity found in the higher vertebrates, particularly in the birds and mammals. An explanation is suggested which depends on the mode of origin of the primitive streak in osseous fishes and on the manner in which the blastoderm overgrows the yolk mass.

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"Preliminary Communication on the Œstrous Cycle and the Formation of the Corpus Luteum in the Sheep."

By F. H. A. Marshall, B.A. Communicated by Professor J. C. Ewart, F.R.S.

Received February 15,—Read March 7, 1901.

The sheep employed in this research were for the most part half-breeds between Cheviots or Leicesters and Scotch Black-faced. Some were very kindly kept for me by Professor Ewart at Penycuik, while others were obtained from a neighbouring farmer, and killed at various intervals after copulation. A quantity of material was also obtained from the slaughter-house. In all these breeds the lambs are born in February or March, and the ewes come into season in the following October or November.* Yearling lambs are ready to take the ram about the same time.

Between March and October (period of anœstrum)† the uterus remains in the normal condition (the resting stage). A large number of ovaries from sheep killed in July and August were examined and sections cut, but in no case were there seen either protruding follicles or corpora lutea, or follicles beginning to undergo atresia. Moreover, the walls of the Fallopian tubes showed no sign of congestion of the blood-vessels. Ovaries from sheep killed in the middle of October showed that the follicles were nearly approaching ripeness, this being indicated by the extent of their protrusion, and a little later burst follicles were first observed. From that time to the end of December recently ruptured follicles in sheeps' ovaries were quite common. It has been found impossible to draw any hard and fast line between the procœstrum and œstrus for sheep. The latter follows on the procœstrum very quickly, and the two combined are of short duration, probably not more than two days. They will here be considered together, as certain stages which appear to correspond to those which Heape regards as forming part of the procœstrum in other animals occur in sheep at or even after the time of copulation.

At the close of the period of anœstrum certain changes take place in the external reproductive organs, the uterus, and the Fallopian tubes. The vulva becomes distinctly swollen and congested, and I have observed a slight flow of mucus from the external opening, but no blood. Subsequent examination of the uterus has shown that bleeding of the uterine wall is extremely slight, but it is, in some cases at any rate, undoubtedly present. From an examination of the external generative organs it is impossible to determine through what stage of the period of growth or period of degeneration the uterus is passing,

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* Dorset sheep alone of British breeds have two gestations a year.

† Heape, "The Sexual Season in Mammals," 'Q. J. M. S.,' vol. 44, November, 1900. The terms "anœstrum," "diœstrum," &c., are here explained.

nor has it been, as yet at any rate, possible to state the duration of each or all of these stages. The period of growth is marked by the hypertrophy of the uterine stroma by nuclear division, both in and between the cotyledons. The nuclei in the early stages are distributed most thickly in the region closest to the epithelium of the cotyledons. The blood-vessels increase both in size and number, not at first so much in the cotyledons as between them, and deeper in the stroma and in the muscle layers below the stroma. The uterine cavity, never very large, is at this period almost obliterated. The changes above mentioned result in the breaking down of certain of the blood-vessels. The blood corpuscles thus set free become scattered throughout the stroma, where they form irregularly shaped patches and streaks lying a little below the epithelium, but I have never seen spaces large enough to be described as lacunæ. These corpuscles no doubt go largely to form pigment,* as supposed by Bonnet† and Kazzander.‡ Only in a few places does the epithelium of the cotyledons, as seen in section, lose its continuity, and then not more than four or five cells have disappeared. Passing to such places may be seen small streams of blood corpuscles which were being poured into the uterine cavity. Thus the characteristics of all Heape's stages from I to VI are more or less clearly recognisable.

The sheep, sections through the uterine wall of which show the last-mentioned characters (stage VI), was killed within three hours after coition. A Graafian follicle had just ruptured, as was at once apparent from the bloodstain on its surface, but the blood had not yet clotted. Subsequently cut sections revealed the point of rupture, and also the ovum and discus proligerus, which had not yet been dehisced. It was apparently from such a case as this that Hausmann§ drew the conclusion that in sheep ovulation cannot take place without coition. That this is not the case, at any rate for the virgin ewe at its first œstrus, I subsequently proved. Some yearling lambs were kept along with a ram which was rendered temporarily incapable of insemination by the method generally followed by sheep breeders. The time when the ewes came into season was indicated by their attitude towards the ram. Œstrus having been detected by this means, the ewe in

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* Black pigment may not infrequently be observed, especially between and round the bases of the cotyledons, beneath the uterine epithelium. In one case the pigment was so distributed as to render the interior of the uterus perfectly black between the cotyledons. I have never observed this pigment in the uterus of yearling lambs.

† Bonnet. See Ellenberger's 'Vergleichende Physiol. d. Haussäugethiere,' vol. 2, Berlin, 1892.

‡ Kazzander, "Über d. Pigmentation d. Uterinschleimhaut des Schafes," 'Arch. f. Mikr. Anat.,' vol. 36, 1892.

§ Hausmann, 'Ueber die Zeugung und Entstehung des wahren weiblichen Eies,' &c., Hanover, 1840.

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question was separated from the rest, and a day afterwards killed, when it became evident at once from the blood-clot on the surface of one of the ovaries that ovulation had recently taken place. Sections through this ovary showed the point of rupture of the follicle. This fact, that ewes need not be served in order to induce ovulation, is of considerable importance, as it indicates the possibility of obtaining successful results from the artificial insemination of sheep.

When ovulation takes place, one follicle only may rupture at a time, or one follicle in each ovary, or two in the same ovary. I have never observed any greater number of discharged follicles of the same age in the ovaries of a sheep.*

The period of "heat" in sheep is further marked by the distension of the blood-vessels of the Fallopian tubes, which may throughout almost their entire length be coloured a deep purple. The increased size of the vessels is also seen in section, but there is no breaking down of vessels. There is too some evidence of increased blood supply to the ovaries, apart from the region of the ruptured follicle.

The changes which take place in the metœstrous period have not as yet been fully worked out, but at a period three days after coition, red blood corpuscles in a state of hæmorrhage, and arranged in streaks below the epithelium, have been observed. It would also appear that new capillaries have been formed. Metœstrum is succeeded by a period of rest (diœstrum), which after not many days is followed by another procœstrum, and so on, until the sheep becomes pregnant or the breeding season is over. The complete diœstrous cycle in the sheep in the only case which came under my observation was fifteen days, but from the observations of others with whom I have spoken it would appear to vary from about thirteen to eighteen days.

The Formation of the Corpus luteum.—The age of the corpus luteum in this investigation was in each case reckoned, either from copulation, or, where copulation did not or was not known to have taken place, from the time when œstrus was observed. Of course it is possible that ovulation does not always take place during œstrus, but the observed relation between the state of development of the corpus luteum and the time that had elapsed between œstrus and the killing of the animal is by itself strong evidence that in the sheep the two phenomena are approximately coincident. In no case after a sheep in which œstrus had been observed, was killed to obtain a stage in the development of the corpus luteum, was the corpus luteum not found. It could usually be at once readily detected by the blood-clot which remains on the surface of the ovary for several days after the rupture of the follicle.

The corpus luteum of seven hours differs from the unburst follicle in its size and in the fact that the ovum and discus proligerus have

* Triplets are, however, not uncommon in some breeds of sheep.

been discharged. It is rather more than half as large as the ripe follicle, and consequently does not protrude from the surface of the ovary. Very little blood remains within the cavity, but corpuscles are seen scattered through the membrana granulosa, these being derived from vessels whose walls have broken down, not only near the point of rupture of the follicle, but to a less extent around the whole theca interna. The membrana granulosa is approximately twice the thickness of that of the ripe follicle, some of the cells having increased largely in size, while others, especially those nearest to the periphery, retain the characters of the original follicular epithelial cells. The central cavity contains a fluid resembling in all respects the liquor folliculi. At this stage there is no sign of any growth inward of the theca interna, and I have not observed any mitoses among the cells of that layer.

The corpus luteum of twenty-four hours has undergone considerable changes. Its increase in size is well marked, its dimensions now approaching those of the ripe Graafian follicle. Its shape is generally irregular, and its walls are much folded. The central cavity is smaller. This cavity, which, as in the earlier stage, contains a fluid, communicates with the exterior by a slit-like passage opening into a cup-shaped depression on the surface of the ovary, from which the corpus luteum now appreciably protrudes. The depression and slit-like passage represent the point of rupture of the follicle. The epithelial wall of the cavity is at this period at least twice as thick as that of the seven hour stage, this increase being due for the most part to the simple hypertrophy of the individual cells composing it, these appearing in section two or three times the size of those of the membrana granulosa of the Graafian follicle. Division is, however, not very infrequently to be observed among the epithelial cells. But the thickness of this layer is also increased by the ingrowth of connective tissue, strands of which, arising by cell proliferation of the theca interna, are growing inwards and penetrating the epithelium. These connective tissue strands present a radial appearance. The cells of which they are composed are commonly fusiform in shape, and mitotic division is very common among them. But although the connective tissue element of the corpus luteum of the sheep is provided chiefly by the proliferation of the cells of the theca interna, it is in part derived from the more fibrous theca externa, from which layer strands of cells, usually in close connection with those of the inner layer, are at this stage beginning to grow inwards between the epithelial cells. Red blood corpuscles occur in scattered patches and streaks, as in the earlier stage.

In the corpus luteum thirty hours after coition, the inner theca layer has all but disappeared, having been used up in the formation of the inter-epithelial connective tissue. The epithelial cells, which have still further hypertrophied, are now in places surrounded by a network of fusiform cells. The point of rupture of the follicle is still open, and communicates with the fluid-containing cavity.

The epithelial cells of the corpus luteum of about fifty hours are four or five times the size of those of the undischarged follicle, as seen in section. Mitotic division is very rare among them, but evidence of it may still occasionally be observed. Proliferation of the connective tissue cells continues to take place, chiefly in the direction of the central cavity, which has become smaller. Leucocytes are to be seen among the epithelial cells, as well as free red corpuscles. The inner theca layer, as such, has disappeared. The corpus luteum as a whole presents a radial appearance.

The corpus luteum of sixty hours has undergone a further change. The connective tissue cells are dividing in all directions, so that nearly every epithelial cell is surrounded by an anastomosis of fusiform cells. The central cavity also is completely enclosed by a layer of connective tissue. The epithelial cells are still increasing in size by simple hypertrophy, but I have not observed any case of division. Large blood-vessels, derived from those of the inner theca, may be seen in the epithelium near the periphery. The corpus luteum is now larger than the ripe follicle.

The succeeding stages in the development of the corpus luteum show the still further increase in the connective tissue proliferation, and in the hypertrophy of the epithelial cells, and the consequent growth in size of the whole structure. The dimensions of the developing corpus luteum are, however, no sure guide to its age, for I have observed two in the same ovary and of the same age, but with an appreciable difference in size. Blood vessels, at first only to be observed near the theca interna, spread towards the centre. The cavity becomes obliterated by the inward growth of connective tissue, and the point of rupture ceases to be visible. The connective tissue becomes more and more finely distributed throughout the epithelium. When the cells of the latter have attained a size of about six times the dimensions of those of the unaltered membrana granulosa of the ripe follicle, fatty degeneration sets in, and they become converted into lutein cells.

The above account of the development of the corpus luteum in the sheep agrees substantially with that given by Sobotta* for the mouse and the rabbit, and by Stratz† for *Tupaia* and *Tarsius*. It differs from Sobotta in the description of the part played by the theca externa, and in recording the not infrequently observed multiplication of the epi-

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* **Sobotta,** "Ueber die Bildung des Corpus luteum bei der Maus," 'Archiv f. Mikr. Anat.,' vol. 47, 1896; "Ueber die Bildung des Corpus luteum beim Kaninchen, &c.," 'Anatomische Hefte,' vol. 8, 1897.

† **Stratz,** 'Der geschlechtsreife Säugetiereierstock,' Haag, 1898.

(*c*) The number of nerves forming the collector;
(*d*) The number and position of the nerve canals;
(*e*) The number of the fin rays;
(*f*) The number of the whole vertebræ.

(2) Asymmetry occurred in an appreciable number of cases.
(3) Differences occurred in the two sexes on the following points: The position of the girdle is more rostral in the male than in the female. The post-girdle fin innervation area is greater in the male than in the female, owing to the development of the mixipterygium.
(4) The female is, on the whole, more variable than the male.
(5) A well-marked correlation exists between—

(*a*) The position of the girdle and the number of collector nerves;
(*b*) The position of the girdle and the number of post-girdle nerves;
(*c*) The position of the girdle and the number of whole vertebræ.

(6) No correlation was found between the number of the fin rays and the number of fin nerves.
(7) At certain stages in ontogeny the number of collector nerves is greater than in the adult.
(8) At certain stages in ontogeny the number of post-girdle nerves is greater than in the adult. The most caudal two or three of these form a posterior collector—a structure which is never found in the adult.

The facts recorded have been used as criteria between the two rival theories of limb origin with the following results:—

(1) To explain the variations on the side-fold excalation theory, it must be assumed that excalation of segments is going on in the collector and pre-collector areas whilst, at the same time, intercalation is taking place in the post-girdle area; or, in other words, that the portion of the vertebral column in front of the girdle is tending to split up into fewer segments, whilst simultaneously that portion behind the girdle is tending to become divided into more segments. Leaving on one side the improbability of two contiguous portions of the vertebral column undergoing at the same time two opposite processes, an examination of the number of whole vertebræ associated with different positions of the girdle lends practically no support to the view that intercalation is going on in this area.

(2) On the side-fold excalation theory, an explanation of the variations in the position and number of the nerve canals of the girdle, and of the occasional instances of asymmetry, necessitates the assumption

that the pelvic girdle in different specimens is not homologous—an assumption which at present seems unjustifiable.

(3) The different variations observed are not discordant with the view that the limb is capable of migrating along the body, on which view it must be supposed that a secondary rostral migration has followed a primary caudal one. Moreover, such a view receives confirmation from the existence of a posterior collector and of a more extensive anterior collector in certain embryonic stages.

"Further Observations on Nova Persei." By Sir NORMAN LOCKYER, K.C.B., F.R.S. Received and Read March 7, 1901.

[PLATE 1.]

Since the preliminary note on this star was communicated to the Royal Society on February 28th, observations have been possible on the nights of February 28th, March 1st, 3rd, and 5th, and twenty-four photographs of the spectrum have been taken with the instruments before detailed.

It may be stated generally that the light is slowly waning. On February 28th the star was only slightly brighter than α Persei. On March 1st it was estimated as about equal to α Persei, *i.e.*, about 2·0 magnitude. When it was again visible on the evening of March 3rd, it was distinctly less bright than β Persei, and its magnitude probably near 2·5; on the 5th its estimated magnitude was 2·7.

The above refers to the visual brightness. A photograph of the region occupied by the Nova on March 3rd showed it to be photographically brighter than α Persei.

General Description of the Spectrum.

The photographs show that the bright hydrogen lines are successively feebler as the ultra-violet is approached, and the whole of the series of hydrogen lines have during the past week become relatively brighter with respect to the remaining lines and the continuous spectrum. The spectrum extends far into the ultra-violet.

Among the changes which have taken place in the visible part of the spectrum, it may be mentioned that while the lines of hydrogen have become relatively brighter during the past week, the remaining lines, with the possible exception of the prominent one at λ 5169, have become distinctly dimmer. There has also been a diminution of the intensity of the continuous spectrum. The line in the yellow, the identity of which has not yet been definitely determined, has gradually decreased in intensity with the diminution of brightness of the star.

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In the visible part of the spectrum the bright green-blue F line o hydrogen has become more conspicuous as the neighbouring gree lines have become fainter, and the bright C line is intensely brilliant.

From all these causes, which give us blue light on the one hand an red on the other, the star should present to us the precise quality o red which has been observed.

Colour.

At discovery the star was described as bluish-white. No observations on its variation in hue during its brightening were possible owing to unfavourable weather conditions. The observations durin the period of decline have indicated a change to the present colour o a decided claret red. In comparison with this, it is interesting to not that in the case of the Nova which appeared in 1604, Kepler alludes t purple and red tints assumed by the star.

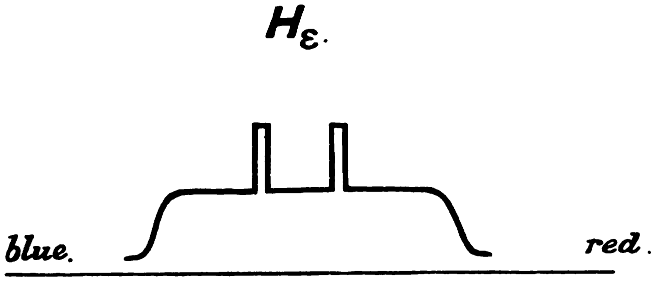
Changes in the Photographic Spectrum.

Between February 25th and March 5th, to take the extreme differenc of dates on which photographs were obtained, it has been noted tha while some of the dark lines were absent at the later date, either new lines had come in or previously feeble lines had become intensified There has not yet been time to determine accurately the positions o these lines (see Plate 1).

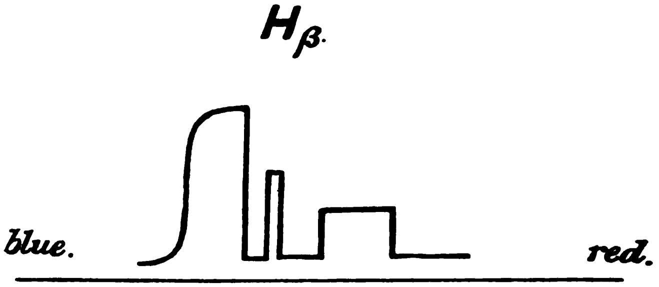
The appearance of the bright lines of hydrogen which I describe as being reversed on February 25th, had very materially changed b March 3rd.

In inspecting the dark band representing the bright hydrogen at H two darker fine lines are seen nearly coincident in position with th edges of Hε in the spectrum of α Persei.

To my eye the light curve is as follows:—



The appearance is different in the case of the F line (Hβ), light curve of which I also give—



No doubt the differences in the appearances are due to the fact that at Hε we are dealing with the lines both of hydrogen and calcium.

Rough measurements on the bright line Hβ show that the interval between the centres of the two extreme maxima shown in the light curve corresponds to about 25 tenth-metres. This would give a differential velocity of 960 miles per second between the different sets of hydrogen atoms in the bright-line swarm itself.

It may be then that the appearances described as reversals of the hydrogen lines on February 25th, were but the beginning of the subsequent changes.

The comparisons with stars which have been taken with the slit spectroscope on each evening of observation, indicate that no great change in the velocity of the dark-line component has occurred.

So much, however, cannot be said of the bright lines, in which a change has been observed. In addition to the hydrogen lines the strong lines in the green already ascribed to iron, appear to be double in the photographs most recently obtained.

Comparison with α Cygni.

The view of the apparent similarity between the spectra of Nova Persei and Nova Aurigæ, to which I drew attention in my previous paper, has been strengthened by the comparisons which have since been made.

The bright lines in the spectrum of Nova Persei are so broad, especially in the blue and violet, that accurate determinations of their wave-lengths are difficult to obtain. The lines less refrangible than F, however, besides being more isolated, are narrower than those in the more refrangible part of the spectrum. A direct comparison of these with the lines in the spectrum of a star which is known to contain the enhanced lines of iron, &c., has been considered a better method of arriving at some definite conclusion as to the connection between the Nova lines and the enhanced lines, than that of determining the wave-lengths of the broad lines and comparing the results with the known wave-lengths of the enhanced lines.

The best star for this purpose is α Cygni, but unfortunately no good photograph has been obtained at Kensington of the green portion of the spectrum of that star. The star most nearly approaching α Cygni in relation to enhanced lines is α Canis Majoris, which in the Kensington classification has been placed nearly on a level with the former star, but on the descending side of the temperature curve. In the spectrum of this star the enhanced lines of iron λλ 4924·11, 5018·63, $\left\{\begin{matrix}5169\cdot07\\5169\cdot22\end{matrix}\right.$ and 5316·79 occur as well-marked lines. This spectrum has been directly compared with that of Nova Persei taken with the same instrument, and the fact that all the lines apparently coincide, affords good evidence that the connection is a real one, and that the first four strong Nova lines beyond F on the less refrangible side are the representatives of the enhanced lines of iron. These are the only enhanced lines which occur in that part of the iron spectrum, with the exception of a weak one at λ 5276·17. There is only a trace of this line in the spectra of either the Nova or α Canis Majoris which have been compared. In the spectra of the Nova obtained with lower dispersion, however, a line is distinctly shown in this position, though it is considerably weaker than the four lines previously mentioned.

The absence of the strong lines which are familiar in the arc spectrum, and in the ordinary spark spectrum in this region, is to be ascribed to higher temperature; experiments which are in progress show that under certain conditions, the two lines λ 5018·6 and λ 5169 are by far the strongest lines in the spectrum of iron between λ 500 and D, while that at λ 4924·1 is distinctly stronger than any of the well-known group of four arc lines in which it falls.

The published wave-lengths of the lines of Nova Aurigæ show that the same lines were present in that star. Further investigations of the spectrum of Nova Aurigæ have strengthened the conclusion that most of the lines, after we pass from those of hydrogen, are enhanced lines of a comparatively small number of metals.

When the inquiry is extended into the region more refrangible than Hβ, the evidence in favour of the similarity of the spectra of the two Novæ with that of α Cygni is not so conclusive, because of the greater breadth of the lines (since the spectra have been obtained by the use of prisms) and because of the fact that in this region the enhanced lines of iron frequently occur in groups.

In the region between Hδ and Hγ, however, there is a well marked enhanced line of iron at λ 4233·3 and also two doubles at λλ 4173·7, 4179·0, and λλ 4296·7, 4303·3, and a comparison of α Cygni with Nova Persei indicates that these fall on broad bright bands of the Nova spectrum.

It is not claimed that all the enhanced lines which appear in the spectrum of α Cygni are represented in that of Nova Aurigæ. There is, however, a sufficient reason why at a particular stage in the spectrum of such Novæ the enhanced lines of certain substances should predominate. Thus, in γ Cygni, titanium is most strongly represented by enhanced lines; in α Cygni, iron, chromium, and nickel; in β Orionis, silicium and magnesium, and so on. We may thus expect to find the lines of different substances most prominent at different stages in the history of the star.

In the work above referred to I have been assisted as follows:—The new photographs have been taken by Dr. Lockyer and Messrs. Fowler, Baxandall, Shackleton, Butler, Shaw, and Hodgson. The detailed examination of the photographs has been made by Messrs. Fowler and Baxandall. The visual observations have been chiefly made by Messrs. Fowler and Butler. The photographs have been enlarged and the illustrations for this paper prepared by Sapper Wilkie. To all, my best thanks are due.

March 14, 1901.

Sir WILLIAM HUGGINS, K.C.B., D.C.L., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "The Action of Magnetised Electrodes upon Electrical Discharge Phenomena in Rarefied Gases." By C. E. S. PHILLIPS. Communicated by Sir W. CROOKES, F.R.S.

II. "The Chemistry of Nerve-degeneration." By Dr. MOTT, F.R.S., and Professor HALLIBURTON, F.R.S.

III. "On the Ionisation of Atmospheric Air." By C. T. R. WILSON, F.R.S.

IV. "On the Preparation of Large Quantities of Tellurium." By E. MATTHEY. Communicated by Sir GEORGE STOKES, Bart., F.R.S.

[redacted]

"The Action of Magnetised Electrodes upon Electrical Discharge Phenomena in Rarefied Gases." By C. E. S. Phillips. Communicated by Sir William Crookes, F.R.S. Received February 28,—Read March 14, 1901.

(Abstract.)

A preliminary account of this investigation has already been laid before the Society.* The present paper deals more particularly with the conditions necessary for the production of a luminous ring in rarefied gases and under the influence of electrostatic and magnetic forces.

The cause of the luminous phenomenon is traced to the action of the magnetic field upon electrified gaseous particles within the rarefied space, and experimental evidence is given to show that the rate of change of the magnetic lines is an important factor.

Numerous experiments relating to the loss of positive electrification from a charged body when placed in a rarefied space, and in the neighbourhood of a magnetic field, are also described in detail.†

An apparatus similar to that referred to in a previous communication was generally found most suitable for observing the formation and behaviour of the luminous ring. It consisted of a small spherical glass bulb 2·5 inches in diameter, and provided with short projecting necks for the purpose of carrying two oppositely placed soft iron rods. These rods were pushed one through each of the short tubes, cemented in position, and arranged to have their pointed ends within the bulb and a sixteenth of an inch apart.

The cores of two electro-magnets were then butted against the external ends of the rods, for the purpose of magnetising them when required.

When the gas within the bulb had been rarefied to a pressure of about 0·005 mm. of mercury, a discharge from an induction coil was sent through it for a few seconds, the rods (now used as electrodes) meanwhile remaining unmagnetised. But when the discharge was stopped and the magnets were excited, a luminous ring appeared within the bulb, in a plane at right angles to the magnetic axis, between the pointed ends of the electrodes, and in rotation about the lines of magnetic induction.

The luminosity of the ring was found to be intermittent, its spectrum showed no peculiarity, and it was not possible to obtain satisfactory photographs of the revolving glow. In oxygen the ring appeared a little brighter, but in hydrogen or carbonic dioxide the luminosity seemed about the same as in air.

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* 'Roy. Soc. Proc.,' vol. 64, p. 172.

† 'Roy. Soc. Proc.,' vol. 65, p. 320.

Two or more rings could be made to appear by placing an electrified platinum circle of wire equatorially within the bulb. When the platinum circle was negatively electrified, the luminous ring was repelled by it. In this manner the ring itself was invariably shown to be negatively electrified. Its direction of rotation was found to be that of the current induced in a loop of wire when the loop is suddenly moved up to a north magnetic pole—clockwise, looking through the loop at the pole. The outside of the glass bulb was always negatively electrified when a luminous ring appeared in the interior. This pointed to the removal of a layer of positively electrified gas from the inner surface of the bulb through the action of the magnetic field. Although such radial streams of positive ions so produced might account for the luminosity of the ring through their collisions with an accumulation of negative ions at the more central part of the bulb, they would not have produced rotation of the luminous ring in the direction already observed. The incoming radial streams of positive ions were studied in detail with an apparatus more suitable for examining the diselectrifying action of the magnetic field. Those experiments established two facts, viz., that the loss of positive electrification from charged bodies is brought about by the magnet, through the concentration of negative ions which occurs at the strongest part of the magnetic field immediately the electrodes are magnetised, and also that the luminosity of the ring itself is due largely to the collisions between the incoming streams of positive ions and this accumulation of negatively electrified gas between the pointed ends of the electrodes. A potential difference is thus set up within the bulb between the negative gas-mass at the centre and the positively electrified layer of ions residing upon the inner surface of the glass, which rapidly reaches a value sufficient to give rise to a discharge through the residual gas. It is then that the positive ions stream inwards, accompanied by a corresponding outward-moving whirl of negative ions.

Experiments upon the effect of causing the magnetic field to either slowly or rapidly reach its maximum value, as well as diminish either slowly or rapidly to zero, have shown that the rate of change of the magnetic lines plays an important part in the actions here described. A very rapidly growing field would diselectrify a positively charged body, whereas, when the magnets were slowly increased in strength there was no diselectrification in such cases. In certain experiments, the act of suddenly destroying the magnetic field produced diselectrification, while if the current were slowly diminished in the coils of the electro-magnets there was no evidence of any such effect.

Both the luminous ring and the diselectrification phenomena are attributable to the same causes. The direction of rotation of the ring, however, forms a difficulty, on the assumption that a rapidly moving ion is equivalent to a current along a flexible conductor. Incoming streams of positive ions would give a direction opposite to that observed, and if the rotation were produced by the changing strength of the magnetic field upon the negative ions, then also would the direction of rotation be opposite to that actually obtained. The viscosity of the gas would tend to annul any sudden twist which the changing magnetic field might give to the cloud of negative ions within the bulb, although the reaction set up between the magnets and the ions under such conditions would be sufficient to cause the negative particles to be thrown forward, and to concentrate in a manner consistent with the experimental results given. It is not clear, however, why the sudden cessation of the magnetic field should also produce such a concentration of negative ions. But we have already seen that under those conditions diselectrification is easily produced; moreover, a luminous ring that has grown dim, can usually be momentarily brightened by suddenly destroying the magnetic field.

A pause was sometimes noticed between the excitation of the magnets and either the formation of the ring or the loss of charge from a positively electrified body.

This result showed that the steady magnetic field itself so modified the paths of moving negative ions within the bulb, that a concentration of them at the strongest part of the field took place for this reason also.

The direction of rotation of the luminous ring can be accounted for in the following manner:—

When the potential difference between the accumulation of negative ions at the centre of the bulb and the layer of electrified gas upon the inner surface of the glass is such that a shower of incoming positive ions occurs and the luminous ring appears, the outer portion of the ring will be more positive than the surrounding negatively electrified cloud of gaseous particles. These will therefore be attracted inwards, and in that way give a rotatory motion to the luminous gas-mass in the direction actually observed.

"The Chemistry of Nerve-degeneration." By F. W. Mott, M.D., F.R.S., and W. D. Halliburton, M.D., F.R.S. Received March 1,—Read March 14, 1901.

(Abstract.)

We have previously shown that in the disease, General Paralysis of the Insane, the marked degeneration that occurs in the brain is accompanied by the passing of the products of degeneration into the cerebro-spinal fluid. Of these, nucleo-proteid and choline are those which can be most readily detected. Choline can also be found in the blood.

[redacted]

We have continued our work, and we find that this is not peculiar to the disease just mentioned, but that in various other degenerative nervous diseases (combined sclerosis, disseminated sclerosis, alcoholic neuritis, beri-beri) choline can also be detected in the blood. The tests we have employed to detect choline are mainly two: (1) a chemical test, namely, the obtaining of the characteristic octahedral crystals of the platinum double salt from the alcoholic extract of the blood; (2) a physiological test, namely, the lowering of blood pressure (partly cardiac in origin, and partly due to dilatation of peripheral vessels) which a saline solution of the residue of the alcoholic extract produces; this fall is abolished, or even replaced by a rise of arterial pressure, if the animal has been atropinised. It is possible that such tests may be of diagnostic value in the distinction between organic and so-called functional diseases of the nervous system. The chemical test can frequently be obtained with 10 c.c. of blood.

A similar condition was produced artificially in cats by a division of both sciatic nerves, and is most marked in those animals in which the degenerative process is at its height, as tested histologically by the Marchi reaction. A chemical analysis of the nerves themselves was also made. A series of eighteen cats was taken, both sciatic nerves divided, and the animals subsequently killed at intervals varying from 1 to 106 days. The nerves remain practically normal as long as they remain irritable, that is, up to three days after the operation. They then show a progressive increase in the percentage of water, and a progressive decrease in the percentage of phosphorus, until degeneration is complete. When regeneration occurs, the nerves return approximately to their previous chemical condition. The chemical explanation of the Marchi reaction appears to be the replacement of phosphorised by non-phosphorised fat. When the Marchi reaction disappears in the later stages of degeneration, the non-phosphorised fat has been absorbed. This absorption occurs earlier in the peripheral nerves than in the central nervous system.

This confirms previous observations by one of us (M.) in the spinal cord in which unilateral degeneration of the pyramidal tract by brain lesions produced an increase of water and a diminution of phosphorus in the degenerated side of the cord, which stained by the Marchi reaction.

The full paper is illustrated by tracings of the effects on arterial pressure of the choline separated out from the blood of the cases of nervous disease mentioned, and from the blood of the cats operated on.

Tables are also given of the analyses of the nerves, and drawings and photo-micrographs from histological specimens of the nerves.

A summary giving the main results of the experiments on animals is shown in the following table:—

[redacted]

ys after ction.	Cats' sciatic nerves.			Condition of blood.	Condition of nerves.
	Water.	Solids.	Percentage of phosphorus in solids.		
rmal ..	65·1	34·9	1·1	Minimal traces of choline present.	Nerves irritable and histologically healthy.
3	64·5	35·5	0·9		
6	69·3	30·7	0·9	Choline more abundant.	Irritability lost; degeneration beginning.
......	68·2	31·8	0·5	Choline abundant.	Degeneration well shown by Marchi reaction.
......	70·7	29·3	0·3		
......	71·3	28·7	0·2		
-27 ..	72·1	27·9	traces	Choline much less.	Marchi reaction still seen, but absorption of degenerated fat has set in.
......	72·5	27·5	0·0		
......	72·6	27·4	0·0	Choline almost disappeared.	Absorption of fat practically complete.
—106..	66·2	33·8	0·9		Return of function; nerves regenerated.

. the Ionisation of Atmospheric Air." By C. T. R. Wilson, M.A., F.R.S., Fellow of Sidney Sussex College, Cambridge.

Received February 1,—Read March 14, 1901.

ıe present communication contains an account of some of the lts of investigations undertaken for the Meteorological Council the object of throwing light on the phenomena of atmospheric ricity.

ı a paper* containing an account of the results arrived at during earlier stages of the investigation, I described the behaviour of tively and negatively charged ions as nuclei on which water vapour condense.

he question whether free ions are likely to occur under such conıns as would make these experimental results applicable to the anation of atmospheric phenomena was left undecided in that r. My first experiments† on condensation phenomena had, it is , proved that in ordinary dust-free moist air, a very few nuclei are

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* 'Phil. Trans.,' A., vol. 193, pp. 289–308.

† 'Roy. Soc. Proc.,' vol. 59, p. 338, 1896.

[redacted]

always present requiring, in order that water should condense upon them, exactly the same degree of supersaturation as the nuclei produced in enormously greater numbers by Röntgen rays; and I concluded that they are identical with them in nature and that they are probably ions.* While, however, [illegible] experiments proved that the nuclei formed by Röntgen or uranium rays can be removed by an electric field and are therefore ions, similar experiments made with the nuclei which occur in the absence of [illegible] radiation led to negative results.† In the light of facts brought forward in the present paper I should now feel disposed to attribute the negative character of the results in the latter case to the small number of nuclei present.‡

Subsequently to the publication of the work on the behaviour of ions as condensation nuclei, Elster and Geitel showed that an electrified conductor exposed in the open air or in a room lost its charge by leakage through the air; and that the facts concerning this conduction of electricity through the air are most readily explained on the supposition that positively and negatively charged ions are present in the atmosphere. The question where and how these ions are produced remained, however, undetermined; it would therefore be incorrect to assume their properties, and in particular their behaviour as condensation nuclei, to be necessarily identical with those of freshly produced ions; the carriers of the charge might consist of much more considerable aggregates of matter than those attached to the ions with which the condensation experiments had been concerned. Moreover, so long as the source and conditions of production of these ions remained undetermined, one could not assume their presence in the regions of the atmosphere where supersaturation might be expected to occur.

Before going further afield in search of possible sources of ionisation of the atmospheric air, it seemed advisable to make further attempts to determine whether a certain degree of ionisation might not be a normal property of air, in spite of the somewhat ambiguous results given by the condensation experiments to which I have referred.

After much time had been spent in attempts to devise some satisfactory method of obtaining a continuous production of drops from the supersaturated condition, I abandoned the condensation method, and resolved to try the purely electrical method of detecting ionisation. Attacked from this side the problem resolves itself into the question. Does an insulated-charged conductor suspended within a closed vessel containing dust-free air lose its charge otherwise than through its supports, when its potential is well below that required to cause luminous discharges?

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[*] 'Camb. Phil. Soc. Proc.,' vol. 9, p. 337.

[†] 'Phil. Trans.,' A, vol. 193, pp. 289–308.

[‡] The similar results obtained with nuclei produced in air exposed to ultra-violet light require, however, some other explanation.

Several investigators from the time of Coulomb onwards have believed that there is a loss of electricity from a charged body suspended in air in a closed vessel in addition to what can be accounted for by leakage through the supports.* In recent years, however, the generally accepted view seems to have been that such leakage through the air is to be attributed to the convection of the charge by dust particles.

The experiments were begun in July, 1900, and immediately led to positive results. A summary of the principal conclusions then arrived at was given in a preliminary note "On the Leakage of Electricity through Dust-free Air," read before the Cambridge Philosophical Society on November 26. Almost simultaneously a paper by Geitel appeared in the 'Physikalische Zeitschrift'† on the same subject, in which identical conclusions were arrived at in spite of great differences in the methods employed.

The following are the results included in the preliminary note, which I read :—

(1.) If a charged conductor be suspended in a vessel containing dust-free air, there is a continual leakage of electricity from the conductor through the air.

(2.) The leakage takes place in the dark at the same rate as in diffuse daylight.

(3.) The rate of leak is the same for positive as for negative charges.

(4.) The quantity lost per second is the same when the initial potential is 120 volts as when it is 210 volts.

(5.) The rate of leak is approximately proportional to the pressure.

(6.) The loss of charge per second is such as would result from the production of about 20 ions of either sign in each c.c. per second, in air at atmospheric pressure.

Of these conclusions, the first four were also arrived at by Geitel.

As Geitel has pointed out, Matteucci,‡ as early as 1850, had arrived at the conclusion that the rate of loss of electricity is independent of the potential. He had also noticed the decrease in the leakage as the pressure is lowered.§

The volume of air used in my experiments was small, less than 500 c.c. in every case, many of the measurements being made with a

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* Perhaps the most convincing evidence of this is furnished by the experiments of Professor Boys, described in a paper on "Quartz as an Insulator" ('Phil. Mag.,' vol. 28, p. 14, 1889).

† 'Physikalische Zeitschrift,' 2 Jahrgang, No. 8, pp. 116—119 (published November 24).

‡ 'Annales de Chim. et de Phys.,' vol. 28, p. 385, 1850.

§ This was also observed by Warburg ('Annalen der Physik u. Chemie,' vol. 145, p. 578, 1872).

vessel containing only 163 c.c. This made it much more easy to ensure the freedom of the air from dust particles. Geitel worked with volumes amounting to about 30 litres; his observations show the interesting phenomenon of a gradual increase of the conductivity of the air in the vessel towards a limiting value, which was only attained when the air had been standing in the vessel for several days. This, as Geitel points out, is to be explained by the gradual settling of the dust particles, the conductivity of the air being greatest when there are no dust particles present to entangle the ions.

The principal difficulty in the way of obtaining a decisive answer to the question whether any leakage of electricity takes place through dust-free air is the fact that one is so liable to be misled by the leakage due to the insulating support. As will be seen from the description which follows, this source of uncertainty was entirely eliminated in the method which I adopted. It had, moreover, the advantage of reducing to the smallest possible value the capacity of the conducting system in which any loss of charge is measured by the fall of potential.

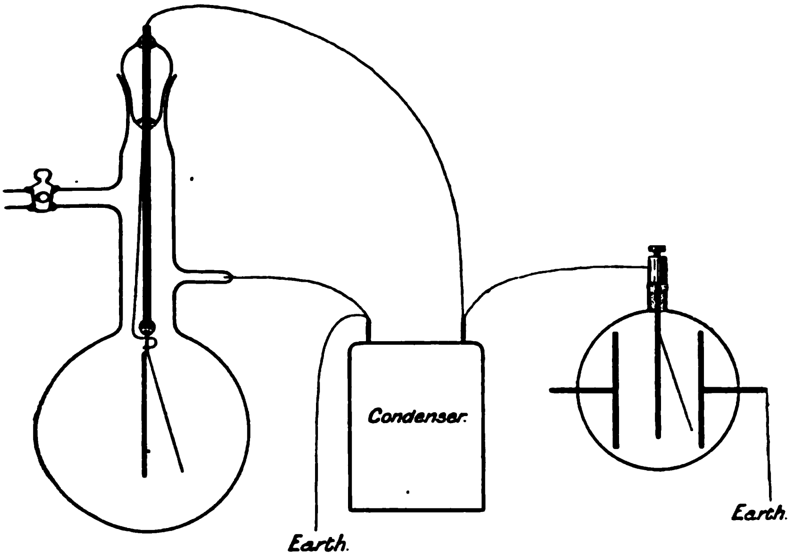
The conducting system, from which any leakage is to be detected and measured, consists solely of a narrow metal strip (with a narrow gold leaf attached to indicate the potential), fixed by means of a small bead of sulphur to a conducting rod which is maintained at a constant potential, equal to the initial potential of the gold leaf and strip. With this arrangement, if any continuous fall of potential is indicated by the gold leaf, it can only be due to leakage through the air; any conduction by way of the sulphur bead can only be in such a direction as to cause the leakage through the air to be under-estimated.

The form of apparatus used in all the later experiments is indicated in fig. 1. The gold leaf and thin brass strip to which it was attached were placed within a thin glass bulb of 163 c.c. capacity; the inner surface of the bulb being coated with a layer of silver so thin that the gold leaf could readily be seen through the silvered glass. The upper end of the strip had a narrow prolongation, by means of which it was attached by a sulphur bead of about 2 mm. in diameter to the lower end of the brass supporting rod. The latter passed axially through the neck of the bulb, its lower end just reaching to the point where the neck joined the bulb. The interior of the neck of the bulb was thickly silvered to secure efficient electrical connection between the thin silver coating of the inside of the bulb and a platinum wire sealed through the side of the tube. The platinum wire was connected to the earthed terminal of a condenser consisting of zinc plates embedded in sulphur, the other terminal of the condenser being connected to the brass supporting rod and maintaining it at a nearly constant potential. An Exner electroscope connected to the same terminal of the condenser was used to test the constancy of the potential, and any loss could from time to time be made up by contact with a rubbed ebonite rod or a miniature electrophorus.

Both the gold leaf of which the motion served to measure the leakage which was the subject of investigation, and that of the Exner electrometer, were read by means of microscopes provided with eyepiece micrometers.

To give the leaking system an initial potential equal to that of the supporting rod, momentary electrical connection between them was made by means of a magnetic contact-maker. This consisted of a fine steel wire fixed to the supporting rod near its upper end and extending just below the sulphur bead, where it was bent into a loop surrounding the prolongation of the brass strip which carried the gold leaf. A magnet brought near the outside of the tube attracted the wire till the loop came in contact with the brass and brought it into electrical communication with the supporting rod. This operation was repeated every time the potential of the leaking system had fallen so far that the gold leaf approached the lower end of the scale. The potential of the supporting rod was not allowed to vary by more than a very few volts, and before each reading of the potential of the leaking system was always brought to within a fraction of a volt of its initial value; the Exner electroscope served to indicate when this was the case. The initial difference of potential used in most of the experiments amounted to about 200 volts.

Fig. 1.



To determine the fall in potential corresponding to a movement of the gold leaf through one scale division, a series of Clark cells was inserted between the condenser and its earth connection, and the number of scale divisions through which the gold leaf moved on reversing the Clark cells was determined; contact between the leaking system and its supporting rod being of course made before and after the reversal. The scale values of the Exner electrometer were determined similarly.

In the apparatus now described, a movement of the gold leaf of the leaking system through one scale division corresponded to a fall of potential ranging from 0·56 volt at the top of the micrometer scale to 0·60 volt at the bottom of the scale.

Any imperfection in the insulating power of the sulphur bead will, as we have seen, tend to give too low a value for the leakage. The error thus introduced was, however, found to be negligible; for the rate of fall of potential of the leaking system was sensibly the same when its potential was equal to that of the supporting rod as towards the close of an experiment when this difference was greatest.

The apparatus used in the earlier experiments differed in some respects from that which has just been described. The vessel was of brass in the form of a short cylinder, 6 cm. long and 5 cm. in radius, the flat ends being vertical, each being provided with a rectangular window closed by a glass plate, so that the position of the gold leaf might be read. A purely mechanical contact-maker was used instead of the magnetic one. With the voltage usually employed, a movement of the gold leaf over one scale division corresponded to a change of potential of 0·36 volt.

With this apparatus, filled with air at atmospheric pressure (whether this had been filtered or had merely been allowed to stand for some hours in the apparatus), a continuous fall of potential of about 4·0 volts per hour occurred, showing no tendency to diminish even after many weeks. Contact had to be made with the supporting rod (kept as described at constant potential by means of the condenser) about once in twelve hours to prevent the image of the gold leaf from going off the scale of the microscope.

Although care had been taken to avoid bringing the apparatus, during or after its construction, into any room where radio-active substances had been used, it was considered desirable to repeat the experiments elsewhere than in the Cavendish Laboratory (where contamination by such substances might be feared), and with pure country air in the apparatus. Experiments were therefore carried out at Peebles during the month of September, but with the same results as before obtained.

The rate of leakage was the same during the night as during the day, and was not diminished by completely darkening the room in which the experiments were carried out. It is plainly, therefore, not due to the action of light.

[redacted]

It might be considered as possible that the conducting power of the air was due to some effect of the walls of the apparatus, related perhaps to the Russell[*] photographic effect and the nucleus-producing[†] effects of metals. These effects, however, are in the case of brass certainly very slight (I have not been able to detect any cloud-nuclei arising from the presence of brass); they are enormously greater in the case of amalgamated zinc. Yet the presence of a piece of amalgamated zinc in the apparatus was without effect on the rate of leak. If then the walls of the vessel influence in any way the ionisation of the air in the vessel, this influence is not proportional to the photographic or nucleus-producing effects of the metals.

To find the loss of electricity corresponding to the observed fall of potential of the leaking system, the condenser was removed, and the capacity of the Exner electroscope, with the connecting wires and the rod supporting the leaking system, was first determined by finding the fall of potential resulting from contact with a brass sphere of which the radius was 2·13 cm. The sphere, suspended by a silk thread, was in contact with a thin earth-connected wire, except when momentarily drawn aside by a second silk thread and brought into contact with the end of another thin wire leading to the electroscope. Except for these two wires the sphere was at a distance great compared with its radius from all other conductors. The rise of potential which occurred in the leaking system after a momentary contact with the system consisting of the supporting rod, electroscope, and connecting wires was then compared with the simultaneous fall of potential of the latter system. The loss of electricity corresponding to a given fall of potential of the leaking system was thus obtained. It was found to be sensibly the same for potentials in the neighbourhood of 100 volts as for the higher voltages (about 200 volts) generally used, the variations in capacity due to the change of position of the gold leaf being too small to be detected. The system had a practically constant capacity equal to 1·1 cm.

It was possible now to compare the rates of leakage for different strengths of the electric field.

Brass apparatus used, air at atmospheric pressure.

Initial difference of potential.	Fall of potential per hour.
210 volts.	4·1 volts.
120 „	4·0 „

The leakage of electricity through the air is thus the same for a potential difference between the leaking system and the walls of the vessel of 210 volts as for one of 120 volts. On the view that the conduction

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[*] Russell, 'Roy. Soc. Proc.,' vol. 61, p. 424, 1897; vol. 63, p. 102, 1898.

[†] Wilson, 'Phil. Trans.,' A, vol. 192, p. 431.

is due to the continual production of ions throughout the air, this is easily explained as indicating that the saturation current has been attained; the field being sufficiently strong to cause practically all the ions which are produced to reach the electrodes; the number destroyed by recombination being negligible in comparison with those removed by contact with the electrodes. Thus under the conditions of the experiments the loss of electricity from the leaking system in a given time is, if the charge be positive, equal to the total charge carried by all the negative ions produced in the vessel in that time.

The sum of the charges of all the negative ions (or of all the positive ions) set free in the vessel is thus $1{\cdot}1 \times 4{\cdot}1/300$ E.U. per hour, or $4{\cdot}3 \times 10^{-6}$ E.U. per second. If we divide by 471, the volume of the vessel in c.c., we obtain for the charge on all the ions of each sign set free in each c.c. per second, $9{\cdot}1 \times 10^{-9}$ E.U. Finally, taking $6{\cdot}5 \times 10^{-10}$ E.U., the value found by J. J. Thomson, as the charge on one ion, we find that about 14 ions of each sign are produced in each c.c. per second.

There are, however, two defects in the older form of apparatus, with which the above results were obtained, tending to make this number too small; firstly, the field in the corners where the flat ends meet the cylindrical wall must be very much weaker than elsewhere, and some of the ions set free in these regions may have time to recombine, although the strength of the field throughout most of the vessel is more than sufficient for "saturation"; secondly, since in this apparatus both the rod supporting the leaking system and the contact-maker projected for about a centimetre into the interior of the vessel, a certain proportion of the ions set free would be caught by them and not by the leaking system.

These defects are avoided in the other apparatus which has been described (fig. 1).

In this apparatus the capacity of the leaking system was 0·73 cm. The constant potential of the supporting rod, and thus the initial potential of the leaking system, was in all cases about 220 volts.

At atmospheric pressure the fall of potential per hour was found to be 2·9 volts. The loss of charge was therefore $0{\cdot}73 \times 2{\cdot}9/300 = 7{\cdot}1 \times 10^{-3}$ E.U. per hour $= 2{\cdot}0 \times 10^{-6}$ E.U. per second. This is the total charge carried by all the positive ions, or by all the negative ions, set free per second. The volume of the bulb being 163 c.c., the charge on the positive or negative ions set free per second in each c.c. $= 2{\cdot}0 \times 10^{-6}/163 = 1{\cdot}2 \times 10^{-8}$ E.U., and the number of ions of either sign set free per second in each c.c. $= 1{\cdot}2 \times 10^{-8}/6{\cdot}5 \times 10^{-10} = 19$. This is somewhat greater than the number obtained before, but, as was pointed out above, there were sources of error in the older apparatus tending to give too low a result for the rate of production of ions per c.c.

Experiments were now made on the variation of the rate of leak with pressure. The measurements were made at a temperature of about 15° C. Each experiment gave the leakage in a period varying from six and a half to twenty-four hours. The silvered glass apparatus was used.

The following results were obtained:—

Pressure in millimetres.	Leakage in volts per hour.	$\frac{\text{Leakage}}{\text{pressure.}}$
43	0·22	0·0052
89	0·53	0·0058
220	1·14	0·0052
341	1·59	0·0047
533	2·30	0·0043
619	2.40	0·0039
635	2·65	0·0042
731	2·78	0·0038
743	2·99	0·0040

These numbers show that the leakage is approximately proportional to the pressure. While the pressure is varied from 43 mm. to 743 mm., the ratio of leakage to pressure only varies between 0·0038 and 0·0058. Since the individual measurements of the leakage at a given pressure differed among themselves by as much as 10 per cent., it would hardly be safe until more accurate experiments have been performed to base any conclusions on the apparent departure from exact proportionality between leakage and pressure. From these results one would infer that it should be impossible to detect any leakage through air at really low pressures. This is in agreement with the observations of Crookes,* who found that a pair of gold leaves could maintain their charge for months in a high vacuum.

Experiments were now carried out to test whether the continuous production of ions in dust-free air could be explained as being due to radiation from sources outside our atmosphere, possibly radiation like Röntgen rays or like cathode rays, but of enormously greater penetrating power. The experiments consisted in first observing the rate of leakage through the air in a closed vessel as before, the apparatus being then taken into an underground tunnel and the observations repeated there. If the ionisation were due to such a cause, we should expect to observe a smaller leakage underground on account of absorption of the rays by the rocks above the tunnel.

For these experiments a portable apparatus had to be made (shown in fig. 2). It differed from that already described (fig. 1) in the following respects:—The vessel, of thinly silvered glass as before, was inverted and attached directly to the sulphur condenser, its neck

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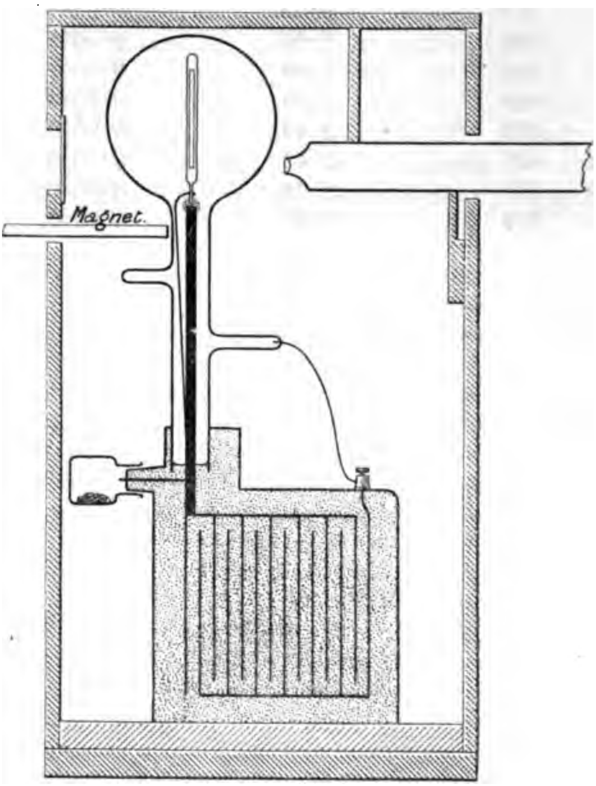
* 'Roy. Soc. Proc.,' vol. 28, p. 347, 1879.

being embedded in the sulphur. The electroscope formerly us
test the constancy of the potential of the supporting rod was
pensed with; all need for external wires was thus removed.
the end of the wire by which the charge was put into the cond
protruded from the sulphur, and this was covered as shown in
figure, except at the moment of charging, by a small bottle contai
calcium chloride; this fitted tightly on a conical projection of

FIG. 2.



sulphur, through the centre of which the wire passed. The
cient constancy of potential of the supporting rod under these
ditions was shown by the fact that when it had been put, by m
of the magnet, in momentary electrical connection with the lea
system, a second contact, made twenty-four hours later, caused
gold leaf, which indicated the potential, to return to within two m
meter scale divisions of its position immediately after the first
tact. The change in the potential of the leaking system prod

[redacted]

by such a change in the potential of the support was much too small to be detected.

The experiments with this apparatus were carried out at Peebles. The mean rate of leak when the apparatus was in an ordinary room amounted to 6·6 divisions of the micrometer scale per hour. An experiment made in the Caledonian Railway tunnel near Peebles (at night after the traffic had ceased) gave a leakage of 7·0 divisions per hour, the fall of potential amounting to 14 scale divisions in the two hours for which the experiment lasted. The difference is well within the range of experimental errors. There is thus no evidence of any falling off of the rate of production of ions in the vessel, although there were many feet of solid rock overhead.

It is unlikely, therefore, that the ionisation is due to radiation which has traversed our atmosphere; it seems to be, as Geitel concludes, a property of the air itself.

The experiments described in this paper were carried out with ordinary atmospheric air, which had in most cases been filtered through a tightly fitting plug of wool. The air was not dried, and no experiments have yet been made to determine whether the ionisation depends on the amount of moisture in the air.

It can hardly be doubted that the very few nuclei which can always be detected in moist air by the expansion method, provided the expansion be great enough to catch ions, are themselves ions merely made visible by the expansion, not, as some former experiments seemed to suggest, produced by it. The negative results then obtained, in attempts to remove the nuclei by a strong electric field, may perhaps be explained if we consider that all ions set free in the interval during which the supersaturation exceeds the value necessary to make water condense upon them, are necessarily caught, so that complete absence of drops is not to be expected even with the strongest fields.

The principal results arrived at in this investigation are (1) that ions are continually being produced in atmospheric air (as is proved also by Geitel's experiments), and (2) that the number of each kind (positively and negatively charged) produced per second in each cubic centimetre amounts to about twenty.

"On the Preparation of Large Quantities of Tellurium."

By EDWARD MATTHEY, A.R.S.M. Communicated by Sir GEORGE STOKES, Bart., F.R.S.

Received February 19,—Read March 14, 1901.

For several years I have worked upon bismuth ores of varying richness for the extraction of the bismuth they contain, and I have already communicated the results to the Royal Society.[*] Many, if not most of these ores, contained traces of tellurium.

Tellurium has a marked tendency to associate itself with bismuth, as silver may be said to do with lead, or phosphorus with iron, and accordingly the crude bismuth extracted from these ores invariably contained small quantities of tellurium, which was reduced together with the bismuth, and was found to exist in it in a greater proportion than in the ores.

The presence of even minute traces of tellurium in bismuth being sufficient to render this metal unsaleable, it is necessary to remove every portion of the tellurium whilst refining the crude bismuth. The alkalies containing the tellurium resulting from the refining of the crude bismuth were thrown aside, and were left for future investigation.

I have now been able to treat these alkaline residues, and have extracted from them a substantial amount of metallic tellurium, weighing 26 kilos. This amount of tellurium was produced from 321 tons of mineral containing an average amount of 22·50 per cent. of bismuth.

The amount of metallic tellurium obtained corresponds to an average of 0·007 per cent. of the original mineral.

The 26 kilos. of metallic tellurium was obtained by soaking the telluride alkalies, resulting from refining the telluric bismuth, in hot water—acidifying these solutions with hydrochloric acid, and precipitating the tellurium with sodium sulphite. A crude mixture of bismuth and tellurium was thus obtained, the tellurium forming about 47·5 per cent. of the crude metal.

This was dissolved in nitric acid, and again treated in the same way, and yielded the amount of tellurium represented by the 26 kilos. This shows on analysis :—

Tellurium	97·00
Bismuth	2·15
Copper	0·65
Iron	0·10
Loss	0·10
	100·00

The appearance of the metal when broken shows a crystalline fracture, of needle-like structure, and of bright metallic lustre. It does not readily tarnish in the air at the ordinary temperature. If slowly cooled, a crystalline form very much resembling that of bismuth is obtained.

Its specific gravity is 6·27, as against 6·23 the density of uncompressed tellurium found by Spring.

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[*] 'Roy. Soc. Proc.,' vol. 42, 1887, p. 89; vol. 49, 1890, p. 78; and vol. 52, 1893, p. 467.

The temperature of solidification was determined by means of the Le Chatelier pyrometer, and proved to be 450° C., or 5° lower than that given by Carnelly and Williams.[*]

Some tellurium prepared from this 26 kilos. to chemical purity also gave 450° C. as the solidifying point.

Commercial tellurium obtained from Germany proved to have the same melting point and specific gravity as my own tellurium.

I found the electrical resistance to be about 800 times that of copper. The resistance, however, appears to be very greatly dependent on the crystalline conditions.

A rod cast and cooled quickly has a lower resistance than one that has been cooled slowly. A current of a few amperes will quickly raise the temperature of a rod 0·2 inch in diameter. In casting small rods of tellurium, of say $\frac{3}{8}$ inch diameter, there is much contraction, and partial separation takes place even after some hours.

The thermo-electric power of tellurium appears to be great.

It has been a source of great satisfaction to me, as a metallurgist, to produce so large an amount of tellurium from a mineral in which it existed only in minute traces. The amount of 57½ lb. (26 kilos.) of tellurium was derived from 187,019 lbs. of crude bismuth, which resulted from the treatment of 831,168 lbs. of mineral.

"The Transmission of the *Trypanosoma Evansi* by Horse Flies, and other Experiments pointing to the Probable Identity of Surra of India and Nagana or Tsetse-fly Disease of Africa."

By LEONARD ROGERS, M.D., M.R.C.P., Indian Medical Service.

Communicated by Major D. BRUCE, R.A.M.C., F.R.S. Received January 28,—Read February 14, 1901.

(Communicated to the Tsetse-fly Committee of the Royal Society.)

The close resemblance between surra of India and tsetse-fly disease of Africa has long been known, while Koch, after having seen the living *Trypanosoma Evansi* at Muktesar in India, and soon after studied the parallel disease in German East Africa, pronounces them to be the same, and in his 'Reiseberichte' calls the disease seen in the latter place "Surrakrankheit." The appearance of the report made to the Tsetse-fly Committee of the Royal Society by Kanthack, Durham, and Blandford on their experimental investigation of the latter disease, suggested to me to repeat some of their experiments in the case of

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[*] 'Chem. Soc. Journ.,' vol. 37, p. 125.

[redacted]

urra, with a view to contributing towards the solution of the question of the identity or otherwise of the two diseases, and the following is a brief account of the results obtained while I was in charge of the Imperial Bacteriological Laboratory at Muktesar, during the absence of Dr. Lingard on sick leave.

I. *The Transmission of Surra by the Bites of Horse Flies.*

It was proved some years ago by Bruce that the *Trypanosoma Brucei* is carried from one animal to another by the bites of the tsetse fly. As surra can be certainly produced in susceptible animals by the application of infected blood to the smallest scratch in the skin of another susceptible animal, it appeared to be likely that horse flies might carry the infection from one animal to another. A series of experiments were carried out to test this possibility with the following results. Horse flies were caught and kept for varying periods of time after having been allowed to bite and suck the blood of an animal which was suffering from surra, and whose blood at the time contained the *Trypanosoma Evansi* in considerable or large numbers. They were subsequently allowed to bite a healthy animal, dogs and rabbits being used in the experiments, and the former were kept in a different house at some distance from the infected animals, and the latter in separate cages during the incubation period. In every case in which the flies had been kept from one to four or more days after biting the infected animals, no disease ensued in the healthy ones. Many such flies were dissected and microscopically examined, but in no case was anything which might be taken for a development of the trypanosoma in the tissues of the insect detected. A rat was also fed on a number of flies, which had bitten infected animals at varying periods previously, but no infection was thus produced.

When, however, flies which had just sucked infected blood were immediately allowed to bite another healthy animal, positive results were obtained after an incubation period corresponding with that of the disease produced when a minimal dose of infected blood is inoculated into an animal of the same species. The result was uncertain if only one or two flies were allowed to bite, and especially if they were allowed to suck as much blood as they wished without being disturbed. If, on the other hand, several flies, which had just sucked an infected animal, were induced to bite a healthy one, and especially if they were disturbed and allowed to bite again several times, infection was always readily produced in both rabbits and dogs, the fur of the latter having been carefully cut, without abrading the skin, at the site over which the flies were applied. The following is the chart of a typical experiment of this kind. The dog was bitten by twelve flies which had just previously sucked blood from a dog, which was swarming with the

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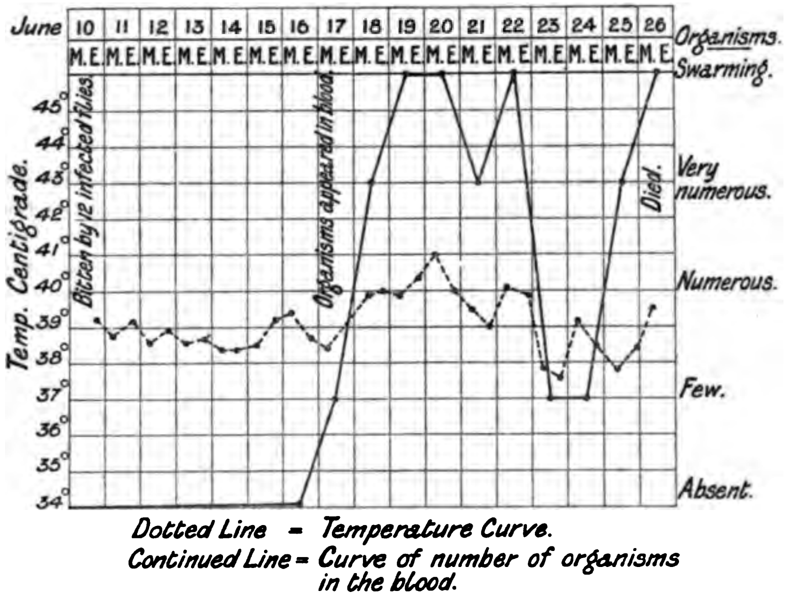
Trypanosoma Evansi, and which had itself been previously infected by the bites of flies experimentally. On the seventh day the organisms were found in the blood in small numbers, and steadily increased during the next two days to swarming—that is, over fifty in the field of a Zeiss D lens, and after oscillations the animal died on the tenth day after the appearance of the organisms in the blood. Post-mortem the usual lesions were found, the spleen being very much enlarged. The right axillary glands were much enlarged, and contained the organisms, while those of the left axilla were but half the size of those of the right side, which is of importance in connection with the fact that the flies had been applied to the upper part of the right side of the body within the area whose lymphatics pass to the right axillary glands. The glands of the right groin were also larger than those of the left, and also contained the organisms in large numbers.

Chart of dog infected by the bites of horse flies which had just previously bitten a surra dog.



Unfortunately these experiments could not be extended to horses on account of the necessary flies only being found at the height of the Muktesar Laboratory (7800 feet above sea level) during the three or four hottest months, and they were not available in the rainy season when a horse had been obtained for the experiment. The skin of this animal, however, is so thin that it would be likely to be at least as easily infected as a dog, while the facts above recorded will readily explain the slow and irregular spread of surra through a stable of horses, by the occasional occurrence of the event of a fly which has bitten a diseased animal being disturbed and immediately going off to bite another healthy one. Further, the proof that infection may take place through flies, brings surra into closer resemblance to tsetse-fly disease, and increases the probability of the two being identical, or, at least, caused by very closely allied species of the same family of parasite.

II. *Latent Cases of Surra in Cattle as a Possible Source of Infection.*

Bruce has shown that the parasite of tsetse-fly disease may be present in the blood of big game animals without causing acute symptoms or definite sign of disease, and that their blood when inoculated into susceptible animals will produce the typical acute affection; and further that a very protracted form of the disease may occur in sheep and goats, and possibly form a source of infection for animals. Lingard, in his first volume on "Surra," records the case of a bull which he inoculated with surra, and in whose blood the trypanosoma was found for three days only, shortly afterwards, yet guinea-pigs inoculated with the blood of this bull on the 85th and 163rd days after the first appearance of the parasite developed fatal surra with numerous trypanosoma in their blood. Further inoculations from the bull on the 234th and 267th day proved negative. He has also recorded two naturally acquired cases of the surra in cattle, which proved fatal. These facts suggest the possibility of the latent disease in cattle acting as a source from which biting flies might carry the disease to horses, especially as surra is so frequently met with on the roads to hill stations in India, where numbers of bullock carts are going up and down. It seemed advisable, therefore, to repeat this observation on surra in cattle, so I inoculated a small hill bull intravenously with a small quantity of blood from a rabbit, which contained numerous trypanosoma. The result confirmed Dr. Lingard's observation, for on the seventh day after inoculation the organism appeared in small numbers in the blood of the bull, remained present for four days, and subsequently was not detected during the next 161 days of the disease, while the animal, after showing slight signs of illness for about a month, remained subsequently in apparently good health, except for an occasional slight rise of temperature for two or three days. A rat, which was inoculated on the 30th day of the disease, and two rabbits inoculated on the 59th and 141st days respectively, developed fatal surra, with large numbers of the trypanosoma in their blood; that on the latest-mentioned date having been done during a temporary rise of temperature of the bull without the presence of any trypanosoma.*

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* All the rats used in experiments mentioned in this paper had been first proved to be free from the *Trypanosoma sanguinis*, except where otherwise stated.

However, the incubation period was an unusually long one, namely, fifteen days, against from four to six days in the case of rabbits inoculated with the blood of a surra animal which contained the trypanosoma. My observations on intermediate developmental forms of the trypanosoma are not sufficiently advanced for any definite statement on the forms present in the bull's blood at the time these inoculations were made.

A very similar result was obtained in the case of a sheep, in which the trypanosoma appeared seven days after inoculation with the blood of a surra dog, remained present for six days in small numbers, and was then absent for thirty days, during which the animal showed definite symptoms of somewhat mild surra, but improved somewhat latterly. At this period it was handed over to Dr. Lingard, on his resuming charge of the Muktesar Laboratory, and I am unable to give the final result as he has not acceded to my request for information on the point. A goat inoculated at the same time showed the surra organism in its blood on the fourth day, and continued to show it at intervals up to the twenty-sixth day, after which it was absent for the remaining thirteen days that it was under my observation; but this animal was much more ill than the sheep, and became greatly wasted, and presented œdematous swellings on the legs, enlargement of the lymphatic glands, yellow marks on the conjunctiva, and nasal discharge. Lingard also records one case in a sheep which was fatal after 127 days, and three experiments on goats in which the disease was fatal on from the 58th to the 186th day.

In all three animals, then, surra tends to run a prolonged and chronic course, and especially in the case of cattle and sheep; in the latter of which surra affords an additional point of resemblance with tsetse of Africa. It has been thought by some that the difference in the course of the two diseases in the case of cattle is a strong argument against surra and tsetse-fly disease being identical, as the latter is a much more fatal disease in these animals than surra is in India. The difference, however, is but one of degree, for cattle in South Africa not unfrequently do recover from the disease of that country, while surra may be fatal to cattle in India, and may, indeed, prove to be much more frequently so than is at present imagined, when diseases of cattle are more closely studied in India than they have as yet been. Further, Koch has recently shown that the disease in German East Africa is absolutely fatal to the ordinary breeds of donkeys in that country, yet the Masai donkeys are absolutely immune. This shows a difference of susceptibility between different breeds of the same animal to the same (African) disease, much greater than that existing between two breeds of cattle in South Africa and India respectively towards the two diseases nagana and surra. Hence this argument against the identity of the two affections loses much, if not all, its weight. The possibility of latent forms of surra in cattle, and possibly also in sheep and goats, in India taking the place of similar infections in wild game in the case of tsetse-fly disease in South Africa is, then, worthy of consideration, and the two may be closely analogous.

III. *Feeding Experiments.*

Kanthack, Durham, and Blandford record that they were unsuccessful in most of their experiments in producing infection of Nagana, by feeding animals on material containing the organism of the disease, the possibility of infection appearing to depend on accidental lesions of the nose and mouth, &c. Lingard, on the contrary, records in his first volume on "Surra" one negative result in a horse after the ingestion of 200 c.c. of infected blood, and one positive one 75 days after the last, and 130 after the first, dose of blood by the mouth, small quantities of material being given at frequent intervals. As he was working in an infected district, and the incubation period was an extraordinarily long one, this experiment can hardly be accepted as conclusive, especially in view of the proof given above, that the disease can be carried by flies. That spontaneous infection did occur in some way in the course of his experiments is clear from the case which he records, in which a horse, which was being given large doses of arsenic as a prophylactic measure, spontaneously developed the disease before he was inoculated, very possibly through infection by flies from some other animal under experiment. This possible source of fallacy is excluded in the few experiments I have carried out on this point, by the fact that they were performed at a time of the year when there were no biting flies to be found. With the exception of one rabbit, which was fed on $\frac{1}{2}$ c.c. of surra blood swarming with the organism, in 10 c.c. of milk, with a negative result, rats were used in these experiments, either some organ of an animal dead of surra, or the blood of the same in milk being given. At first the results, although usually negative, were not always so, as in the case of Kanthack's experiments. A possible source of infection was found in the fact that some of the animals had previously been examined for the *Trypanosoma sanguinis* the same morning as the feeding experiment was carried out, and one of the animals was observed to lick the wound in its tail in the intervals of feeding on the infected material. This source of infection was then carefully excluded, and several experiments were done in which a little surra blood in milk was given to two rats, one of which was untouched, while in the case of the other the nose and mouth were first abraded. In each case the untouched rat escaped infection, while the one with abrasions contracted fatal surra after the usual incubation period for the inoculated disease. These experiments, then, support the view that infection in the case of feeding is through some lesion in the skin or mucou membranes, and once more the results obtained in the case of surra are precisely similar to those got in the researches on tsetse-fly disease conducted under the Committee of the Royal Society.

IV. *Is the* Trypanosoma sanguinis *related to Surra?*

It is pretty generally agreed that the *Trypanosoma sanguinis* of rats is distinct, both morphologically and pathologically, from nagana and surra, although in the case of the latter disease Dr. Lingard claims to have produced surra in horses and other animals by inoculating this organism. The incubation period, however, in his four successful out of twelve experiments in horses, varied between 7 and 65 days, although on the next passage it returned at once to the ordinary period for surra of about 7 days. This remarkable fact, taken in conjunction with his having worked in an infected area, and with the proof of the possibility of flies carrying the disease, makes it possible that the infection was produced by some other agency than the rat's parasites. I recently inoculated a pony intravenously with 2 c.c. of the blood of a rat infected with the *Trypanosoma sanguinis*, with a negative result during the 55 days it was under my observation, the blood being examined daily, the experiment having being carried out at a time of the year when no biting flies were to be found, and in a non-endemic area. It may thus be worthy of record in this connection, as although but an isolated one, it is in agreement with the results of Vandyke later.

Another pony inoculated with a few drops of the blood of a surra dog five days after the one just mentioned, developed surra on the ninth day, as shown by the presence of the *Trypanosoma Evansi* in its blood. A negative result was also obtained in the case of a dog which was twice inoculated with the *Trypanosoma sanguinis* and examined daily for 82 days.

Rats, which had been found to harbour the *Trypanosoma sanguinis*, were also inoculated with surra, and after the usual incubation period in these animals of about four days the *Trypanosoma Evansi* appeared in the blood, and were easily distinguished from the former parasite by their much shorter and blunter ends. They increased daily until in most of the cases over 50 were present in a field of a Zeiss D lens, while the original rat organisms remained at about the same numbers as before the inoculation with the surra blood. The two organisms, therefore, appear to me to be quite distinct both morphologically and pathologically.

In every point, then, that I have so far investigated, the results obtained in the case of surra closely agree with those of the Royal Society's Committee in tsetse-fly disease, and so far as they go they support the view that the two diseases are probably identical. I had hoped to have been able to make arrangements for studying both diseases side by side, but have not yet been able to do so on account of the disturbed state of South Africa.

March 21, 1901.

Sir WILLIAM HUGGINS, K.C.B., D.C.L., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The Croonian Lecture, "Studies in Visual Sensation," was delivered by Professor C. LLOYD MORGAN, F.R.S.

March 28, 1901.

Mr. TEALL, F.G.S., Vice-President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On the Arc Spectrum of Vanadium." By Sir N. LOCKYER, F.R.S., and F. E. BAXANDALL.

II. "On the Enhanced Lines in the Spectrum of the Chromosphere." By Sir N. LOCKYER, F.R.S., and F. E. BAXANDALL.

III. "Further Observations on Nova Persei, No. 2." By Sir N. LOCKYER, F.R.S.

IV. "The Growth of Magnetism in Iron under Alternating Magnetic Force." By Professor ERNEST WILSON. Communicated by Professor J. M. THOMSON, F.R.S.

V. "On the Electrical Conductivity of Air and Salt Vapours." By Dr. H. A. WILSON. Communicated by Professor J. J. THOMSON, F.R.S.

The Society adjourned over the Easter Recess to Thursday, May

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"On the Results of Chilling Copper-Tin Alloys." By C. T. Heycock, F.R.S., and F. H. Neville, F.R.S. Received February 12,—Read February 28, 1901.

(Plates 2-3.)

In the Third Report of the Alloys Research Committee, published in 1895, Sir W. Roberts-Austen gives an appendix, by Dr. Stansfield, containing an extremely interesting series of cooling curves of the copper-tin alloys. These curves made it evident that for many percentage compositions there were three or even four halts in the cooling due to separate evolutions of heat, and that some of these changes must have occurred when the metal was solid. A freezing-point curve was also deduced from the cooling curves. The report contained interesting remarks on the meaning of the curves, but a satisfactory explanation was not at that time possible. In June, 1895, Professor H. Le Chatelier also published a freezing-point curve, giving the upper points only. These two curves agree in locating a singular point near the composition Cu_4Sn, but do not give any singular point nearer to the copper end of the curve.

In 1897 we also gave, in the 'Philosophical Transactions,' a freezing-point curve of these alloys. This curve was inferior to Dr. Stansfield's, inasmuch as it gave no information concerning the changes that go on in the solid metal, but it was a more accurate statement of the upper freezing points than had been given before. In particular, it pointed out a new singular point at 15·5 atomic per cents. of tin, the point marked C in the figure (fig. 1), and a straight branch of the curve joining C to the other singular point marked D in the figure. Both C and D are the origins of rows of second isothermal freezing points, better called transformation points. Like Dr. Stansfield, we found it impossible to offer a satisfactory explanation to the curve, but we hazarded the surmise that the steepness of the branch ABC might be due to chemical combination, and that in the region CDE solid solutions existed. Both of these surmises have since been confirmed, but at that time we felt no certainty on the subject.

In their report on alloys presented to the Congrès International de Physique in 1900, Sir W. Roberts-Austen and Dr. Stansfield give a curve embodying all the above-mentioned details and some others, in particular a most important lower curve of changes that take place in the solid alloys.*

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* Our attention has been called to the fact that the copper-tin curve given by Roberts-Austen and Stansfield in the International Report on Physics in 1900 had already been published by them in the Fourth Report to the Alloys Research Committee in 1897. This correction does not alter the chronological sequence as stated in the text, since our paper was read before the Royal Society in June 1896.

It may be remarked that the freezing-point curve forms a chart to the general character of the alloys. For example, whose composition lies in the region AB of the figure are red br and gun metals, tough, but not very hard, while as we appro the alloys become paler in colour and much harder. Alloys a lit the left of C are nearly white and extremely tough and strong; are ideal bell metals. The moment we pass C the alloys beg become brittle, and the brittleness becomes very great near D. alloys between C and D are steel coloured; they have a glas

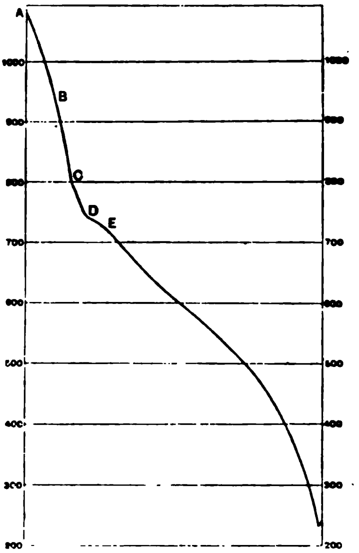

FIG. 1.—Freezing-point curve of the copper-tin alloys. Atomic percentag are reckoned from 0 per cent. on left to 100 per cent. on right of di (Extracted from 'Phil. Trans.,' A, vol 189, p. 63.)

hardness and take a fine polish; they are speculum metals, Lord R being the alloy at D. With more tin than that present at the po the alloys deteriorate from a mechanical point of view, and exc anti-friction metals are not much used.

In 1900 we commenced a study of these alloys by means o microscope. As regards the regions ABC and that to the right we at first did little more than confirm results which we foun been already published both by Mr. Stead and by M. Charpy; the region CDE we appear to have observed more detail than i tained in the published work of these observers. We were espe struck by a discrepancy, in the region CD, between the crysta the outside of the alloys and the internal pattern. Our habit make the alloys in an atmosphere of coal-gas or hydrogen, and to allow them to cool in this atmosphere. If made in this way, we found that all alloys, from A almost to D, showed on the top of the ingot a regular crystallisation in relief, of the rectangular comb-like character so often seen on the surface of cast metal. This was as perfect in the white metals between C and D as in the red alloys between A and B. These crystals disappear when the point D is reached, although with much more tin other types of raised crystals are seen. These combs are of course primary crystals, standing out on account of the contraction of the solidifying mass and the consequent retirement of the mother liquid. When the ingots of alloy are cut, the surfaces polished, and the internal pattern brought out by ignition or etching, one sees, as Charpy and Stead have shown, that similar combs, rich in copper, occur in the interior of the ABC alloys, the combs being embedded in a matrix which is itself complex (see photo. 1, Pl. 2). These combs are numerous and large in the gun-metals of the region AB, but decrease in numbers, size, and perfection as we approach C. For some distance to the left of C they are much broken and distorted, and to the right of C they do not appear at all in the body of the alloys; but they exist on the outside in the same perfection as before. Moreover, if the top of one of the alloys anywhere between a point a little to the left of C and the point D be slightly ground down so as to obtain sections half through the raised crystals, and the pattern examined, it is found that the crystals are not homogeneous, as one would expect a crystal to be, but that each crystal is full of a well-marked pattern identical with that of the body of the alloy. To illustrate this peculiarity, we give a photograph of the top of the alloy containing 14 atomic per cents. of tin (photo. 2). Hence it appeared that the alloys underwent remarkable changes both during and after solidification. In the alloy of photograph (2) the larger detail in the substance of the bars of raised crystal, or something not unlike it, was formed before the raised pattern, but the smaller detail, hardly seen at this magnification, is more recent than the raised pattern.

Photograph (1) shows the large primary combs existing in the interior of an alloy containing 12 atomic per cents. of tin, and photograph (3) shows the utterly different pattern existing on the other side of C. It is that of an alloy containing 16·7 atomic per cents. of tin. It must be remembered that on the outside the alloy still shows the combs. These alloys were slowly cooled, that is, not subjected to any sudden chill during cooling. A pattern like that of photograph (3) is given by Charpy for an alloy containing equal weights of copper and zinc. We have also found it in some silver-zinc alloys, and we think it always means that changes have taken place in the solid alloy.

The patterns at all points on the curve were so puzzling that we

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almost despaired of being able to interpret them, until after reading Professor Roozeboom's paper on the "Solidification of Mixed Crystals of Two Bodies,' published in the 'Zeitschrift für Physikalische Chemie' of December, 1899. The beautiful theory contained in this paper made the attempt to decipher the hieroglyphic of the copper-tin alloys more promising; but the experimental method recommended by Roozeboom, that of isolating the first crystals that form when a liquid begins to solidify, is beset with almost insuperable difficulties in the case of metals melting at high temperatures. Cooling curves will, it is true, give the approximate moment of complete solidification of an alloy, and enable us to plot in a rough way the "solidus" curve, as Roozeboom calls it; but the solidus curve thus obtained is not nearly so accurate as the "liquidus" or freezing-point curve. We therefore had recourse to the microscopic examination of chilled alloys, a method which has thrown so much light on the nature of steel.

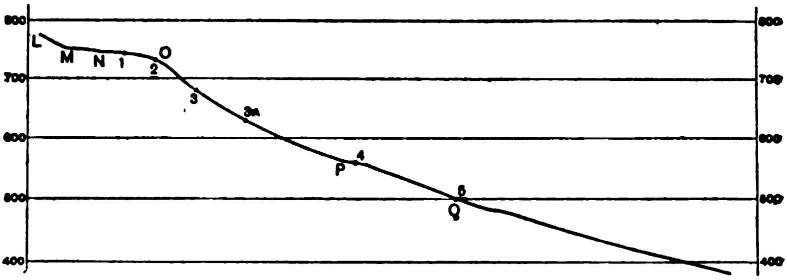

FIG. 2.—Cooling curve of the alloy $Cu_{81}Sn_{19}$. Percentages by weight: Cu 69·56, Sn 30·44. Time is measured horizontally. Equal vertical distances correspond to equal differences in platinum temperatures. The numbers at sides of diagram give temperatures on the Centigrade scale. The numbers *on the curve* are the points of chilling.

The first step was to imitate Austen and Stansfield and obtain a cooling curve of an alloy by means of a recording instrument. We used a Callendar recorder in connection with a platinum pyrometer. Fig. 2 is a small scale reproduction of the cooling curve thus obtained in the case of an alloy containing 19 atomic per cents. of tin. In this curve the temperature of the cooling alloy is measured vertically, and the time is measured horizontally. It will be seen that evolutions of heat occur during the period MNO and also at P and Q. Below the temperature O the alloy was a rigid mass, a solid. The temperatures marked 1, 2, 3, 3A, 4, 5 on the curve were then selected as points at which it seemed well to chill portions of the alloy. The pyrometer was therefore transferred to a bath of molten tin, heated well above the highest freezing-point of the alloy, and small amounts

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of from 5 to 10 grammes of the alloy, contained in little test-tubes of Jena glass, were immersed in the bath; these were in an atmosphere of coal-gas, and so did not oxidise. The bath of tin was then allowed to cool slowly and uniformly, and when the temperature fell to one of the selected points, a tube was taken out and plunged into water. The alloy was thus chilled, the slow cooling being brought to an abrupt end at any desired temperature.

The chilled alloys were afterwards ground down and polished in the usual way. After the trial of many reagents for bringing out pattern, we adopted the method of slightly heating the surface until the film of oxide formed was of a pale yellow colour. Behrens some years ago recommended this method, and Mr. Stead has pointed out that it develops differences of chemical composition very well, while etching reagents complicate the picture by revealing the orientation of crystals and other details which are not always needed. With one or two doubtful exceptions, we find that in alloys richer in copper than Cu_3Sn, the parts which oxidise most rapidly, and are therefore darkest in the yellow stage, are the softer parts containing most copper. When alloys on the branch ABC are oxidised the pattern is very distinct to the eye, but it is sometimes difficult to obtain much contrast in the photographs; in such cases (for example, in the alloy of photograph 1) we etched the surface with strong ammonia, which also darkens the parts richest in copper. Alloys on the branch ABC are very sensitive to reagents such as ammonia or hydrochloric acid, and from C to D, where these have but little action, a mixture of hydrochloric acid and potassium chlorate etches rapidly. One can use these reagents to control the effect of heat oxidation in cases where the low temperature of chilling makes it possible that the heating needed to produce the yellow colour may have reversed the result of chilling; but we find that there is not much danger of such a reversal.

The upper point alloy, chilled at the commencement of solidification, was generally found to be granulated by the operation of dropping into water, but portions could always be found suitable for polishing; the other alloys had always solidified before the chilling, and therefore gave compact ingots.

After polishing, the alloys were heated until a pale yellow oxidation colour was produced on the surface.

Alloy (1), chilled when much of the metal was still liquid, shows a pattern of large primary skeletons, more or less comb-like in appearance, which oxidise much more rapidly than the mother substance, and which therefore contain more copper than it (photo. 4).

Alloy (2), chilled when the solidification was almost complete, shows skeletons much softer in outline and not differing much in oxidation colour from the ground; but these skeletons occupy a much larger area than in (1), nearly filling the field, and being only separated from each other by an imperfect network of less oxidised mother substance.

These two alloys are deeply etched in the process of polishing with rouge, the softer primaries rich in copper being eaten away. The pattern is so large that it is best examined with a power of 10 or 20 diameters.

In striking contrast to the above, alloys (3) and (3) A, chilled when the alloy has been solid some time, show no pattern even with a power of 300 or 400 diameters (photo. 5).

Alloy (4), chilled at P, the next point of heat evolution on the cooling curve, shows a pattern which is a close approximation to that of a slowly cooled alloy, and alloy (5), chilled at a still lower temperature, is an almost perfect reproduction of the slow-cooled pattern (photo. 6). It will be noticed, however, that a little below the chilling point of (5) there is another stage of heat evolution, and in harmony with this we can find one point of difference between the pattern of (5) and that of the slowly cooled alloys of the region CD. Both in these and in (5) the surface is divided into large polygons bounded by bands of a smooth material, and the interior of each polygon is more or less full of a broken fern or flower-like crystallisation of the same smooth body as that of the bands. The ground in which the fern leaf lies is more easily oxidised than the material of the fern leaf and bands, so that the ground probably has more copper in it. In the slowly cooled alloys near C there is very little of the fern leaf, but as we approach D it increases in amount until at D it almost fills the whole area, not absolutely, however, for a network of the darker ground can still be traced here and there. A comparison of photos 3 and 6 illustrates this growth of the fern leaf with the increase in the percentage of tin. In the slow-cooled alloys the ground is granular—in fact, an immersion lens defines it as a well-marked eutectic. In (5), on the contrary, the ground appears to be uniform; probably chilling at a temperature below Q would convert it into the eutectic.

All the alloys from a little to the left of C to beyond D exhibit similar contrasts between the chilled and slow-cooled patterns, there being for each alloy a region of temperature such that if it be chilled in this region it shows no pattern. Alloys between D and E are still more remarkable when chilled.

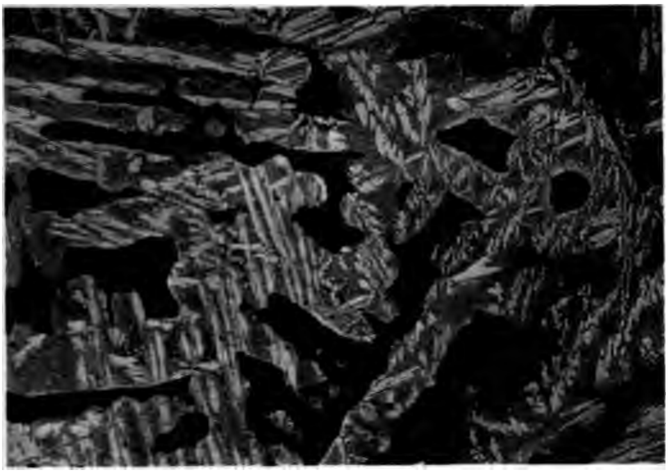
If we apply Roozeboom's theory to these results, we see that in the cooling curve the branch LM corresponds, as is obvious, to the cooling of a liquid, and the short branch MN to the formation of mixed crystals separating out of a liquid that is continually growing richer in tin, so that the crystals are suffering transformation. The branch NO, almost flat at first, and then only slightly sloping, corresponds to an isothermal transformation of the mixed crystals followed by

DESCRIPTION OF PLATE 2.

Slowly cooled alloys.

	Formula.	Percentage by weight.	Magnification.	Treatment.
1.	$Cu_{88}Sn_{12}$	Cu = 79·7. Sn = 20·3.	50 diameters.	Ammonia etch.
2.	$Cu_{86}Sn_{14}$	Cu = 76·7. Sn = 23·3.	50 ,,	Heat-oxidised.
3.	$Cu_{83\cdot3}Sn_{16\cdot7}$	Cu = 72·8. Sn = 27·2.	300 ,,	,, ,,

EYCOCK & NEVILLE. *Roy. Soc. Proc., Vol. 68, Pl. 2.*



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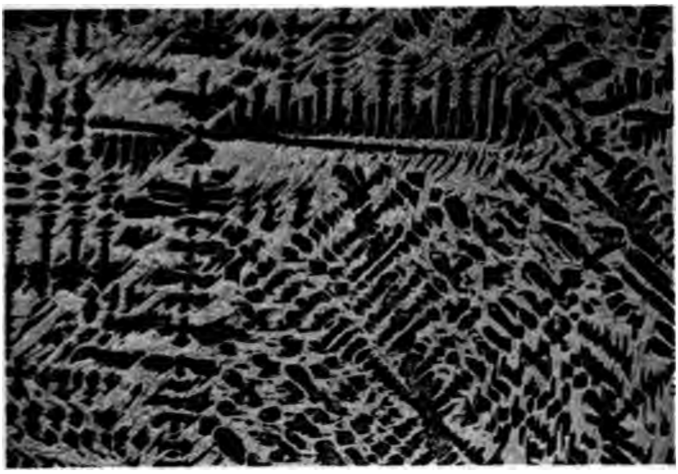

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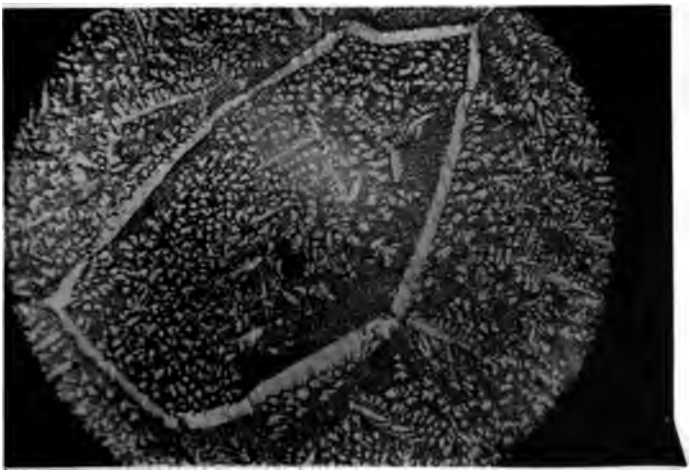

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DESCRIPTION OF PLATE 3.

The same alloy chilled at different temperatures.

	Formula	Percentage by weight.		Magnification.	Treatment.
4.	$Cu_{81}Sn_{19}$	$Cu = 69 \cdot 6$ $Sn = 30 \cdot 4$	Chill 1.	50 diameters.	Heat-oxidised.
5.	„	„	Chill 3.	50 „	„ „
6.	„	„	Chill 5.	50 „	„ „

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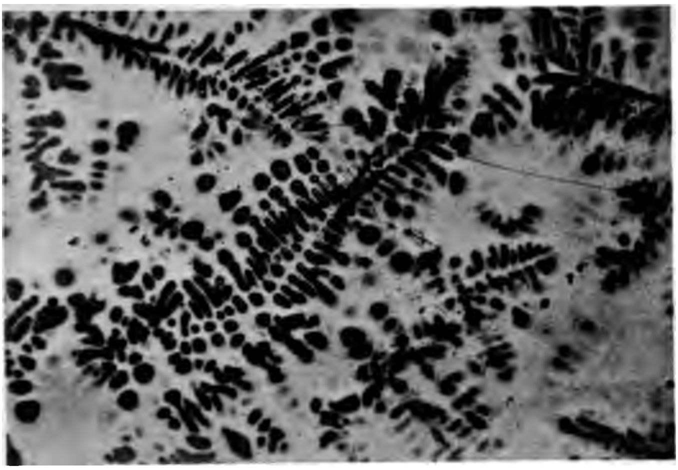

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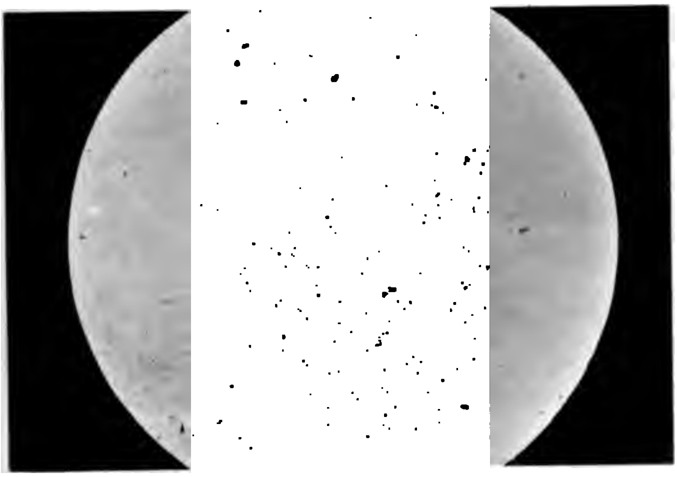

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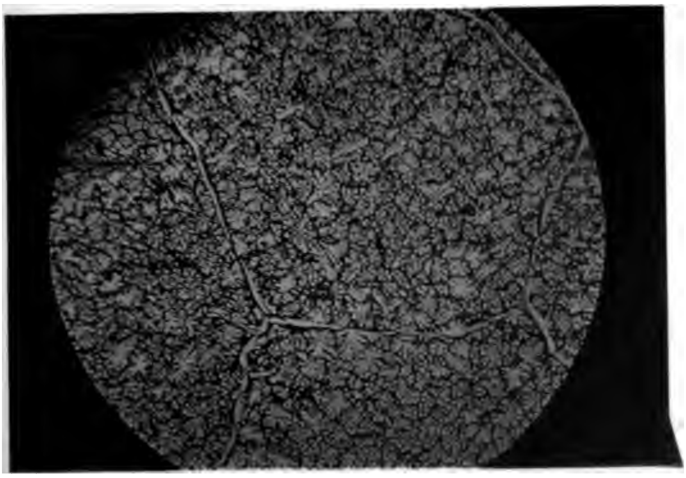

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the solidification of the whole mass to mixed crystals, which, assuming no lag in the transformations, should be uniform. The long slope OP would then correspond to the cooling of a solid mass of uniform crystals, and therefore the alloys chilled in this region of temperature show no pattern. But at P the solid solution becomes saturated, and on cooling below this point the band and fern leaf crystallises out. At a still lower temperature, probably Q, the mother substance of the fern leaf breaks up into a eutectic, formed in the solid. We think that P is a point on Austen and Stansfield's lower curve, and that Q is the eutectic angle of that curve. It will probably be found that the mother substance in all alloys from about B to D breaks up into a complex when the alloys cool to the temperature Q, so that if cooled slowly it is a eutectic, but if chilled above Q a homogeneous body.

It is not difficult to form a conception of how the type of pattern found below the temperature P originates. Slightly above the temperature O the alloy consisted of crystal grains surrounded by mother liquid somewhat richer in tin. At the moment of complete solidification the grains should have adjusted themselves so as to be identical throughout, but it is improbable that so perfect an equilibrium was attained, and the solid mass at temperatures below O must have contained nuclei richer in copper than the material surrounding them. In fact, prolonged polishing brings out a vague pattern in relief, showing differences of hardness, and therefore of composition. Now the alloy that we are considering lies to the right of Austen and Stansfield's eutectic angle in their lower curve; hence when the solid solution became saturated the new crystallisation commenced in the interspaces rich in tin, and more or less took their form. It is clear that the resulting structure would in section give the bands and polygons of the slow-cooled alloys. Similarly the inclusions of mother substance in the grains existing at O would be the origin of the isolated fern leaf.

Although it was hardly necessary, we thought it would be interesting to arrive at the condition of no pattern, starting from the solid alloy instead of from the liquid. We therefore took a fragment from an ingot of the same slowly cooled alloy, heated it to a faint red heat in the Bunsen flame, and dropped it into water. It showed no pattern after being polished and ignited to a pale orange. It was then heated to a temperature a little below redness, and allowed to cool for five minutes above the flame, repolished, and brought to the orange state. It then showed a very perfect slow-cooled pattern, the fern leaf being particularly good. The polygons appeared to be of the same size as in the original alloy, which had taken an hour or more to cool, but the bands were much thinner and the fern leaf smaller; the eutectic also was very scanty, while in the original ingot there were large spaces of

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it. Thus the same alloy, without being melted, can by heating and chilling have all pattern removed, and by reheating, followed by a not very rapid cool, the pattern can be restored. The constancy in the size of the polygons points to their having been formed at an earlier period in the history of the alloy.

We see from the above that the patterns of slowly cooled copper-tin alloys are, at all events until they have been confirmed by the examination of chilled portions, entirely misleading as to the separations that occurred during solidification. Even the evidence for the existence of the compound Cu_3Sn will have to be revised; although in a somewhat altered form it will probably be found to be satisfactory.

We hope shortly to present to the Royal Society a more complete account of these alloys.

"On the Enhanced Lines in the Spectrum of the Chromosphere." By Sir NORMAN LOCKYER, K.C.B., F.R.S., and F. E. BAXANDALL, A.R.C.S. Received March 19,—Read March 28, 1901.

In the recently published account* of the spectroscopic results obtained by members of the expedition from the Yerkes Observatory, during the solar eclipse of May 28th, 1900, although the record of the wave-lengths of the lines photographed on the different eclipse plates is of great value, exception must be taken to the method of assigning origins to the lines. This question is so important just now that it is desirable to deal with it without delay. The only origins which Professor Frost appears to accept are those given by Rowland to any moderately strong solar line which agrees in position, either exactly or very nearly, with an eclipse line. In discussing the eclipse lines he has made specific allusions to the "enhanced" lines of some of the metals, and to their relationship—or non-relationship—to the eclipse lines.

On p. 347 he says, "These plates give no evidence of any relationship between the bright lines and the 'enhanced' lines, or lines distinctly more intense in the spark than in the arc spectrum, although Sir Norman Lockyer has attached much significance to a supposed connection between them. Some of the enhanced lines are present and some are not, or at least were not conspicuous enough for measurement." In the paragraph immediately following, he says, "In case of titanium, for which Lockyer gives 48 enhanced lines within our limits, we may summarise the comparison as follows: 17 lines do

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* Frost, 'Ast.-Phys. Journ.,' vol. 12, p. 307, 1900.

not appear as bright on the eclipse plates; one pair is doubtful, the remainder occur as quite strong lines of the ordinary dark line spectrum, and hence would be expected to appear in the reversing layer, as they do."

If a difference of 0·3 tenth metre be allowed between the wave-length of an eclipse line and that of the possibly corresponding metallic line (and in some cases Professor Frost accepts a difference of 0·35 or more between his adopted wave-length and Rowland's solar wave-length), the seventeen lines above mentioned dwindle down to ten. That leaves, then, thirty-eight out of forty-eight of the enhanced lines, or about 80 per cent., which agree in position within 0·3 tenth-metre with the eclipse lines. Surely this shows as close a relationship between the enhanced lines of titanium and the eclipse lines, as that between the latter and the stronger of the Fraunhofer lines, for it is stated on p. 345, "of 171 of Rowland's lines, 61 per cent. were measured as bright on the plates."

Nowhere has it been contended that the whole set of enhanced lines belonging to any one metal are represented in the spectrum of any one celestial body; what has been stated is that the enhanced lines of some of the metals are, in general, of paramount importance in the spectra of some stars (*e.g.*, α Cygni), specially prominent in others (*e.g.*, γ Cygni, the spectrum of which, with the exception of the absence of helium lines, very closely resembles that of the chromosphere), and are a marked feature of the spectrum of the chromosphere itself.

Professor Frost either has not noticed, or does not point out, that most of the enhanced lines of titanium, as compared with the ordinary lines of that element, are specially prominent, and are amongst the lines of greatest intensity in his list, as shown in the following table. The first two columns of the table contain respectively the wave-lengths and intensities of Rowland's solar lines (in the region covered by the eclipse lines), which have an intensity of 2 or more, and which have been ascribed to Ti only. Double assignations, of which Ti forms one, have been omitted, as it is difficult, if not impossible, to determine what proportion of the intensity of the solar line is due to each element. The third column indicates whether the titanium line at the given wave-length is an enhanced one or not. The fourth gives the wave-lengths, the fifth and sixth the intensities, and the eighth the origins which Professor Frost has adopted for the corresponding eclipse lines, and the seventh the intensities of the lines reduced from the Kensington eclipse photographs. To make them roughly comparable with Professor Frost's, these intensities have been multiplied by ten throughout, as 1 is adopted for the weakest lines in the Kensington photographs, whereas he adopts 10 for lines just visible.

[redacted]

Solar Lines of Intensity 2 or greater, ascribed by Rowland to Ti only.

Solar – Ti lines λ (Rowland).	Int. in sun.	If enhanced line.	Eclipse.					Remarks.
			Frost.			Kensington.	Frost's origin.	
			Adopted wave-length.	Intensity. Max. 500. Prism spectra.		Int. Max. 100.		
				"Flash" II.	Cusp II.			
4028 ·50	4	yes	4028 ·28	35	20	25		Eclipse line undoubtedly due to Ti.
4078 ·63	3	no	4073 ·6	15	—	—	Fe, Ti	
4171 ·21	4	no	4171 ·30	20	15	—	Ti	
4274 ·75	2	no	4274 ·93	75	30	50	Cr	Eclipse line undoubtedly due to Cr.
4285 ·16	2	no						
4286 ·17	2	no	4286 ·0	6				
4288 ·04	2	no	4287 ·91	25	25	—	Ti	
4289 ·24	2	no						
4290 ·38	2	yes	4290 ·34	40	20	65	Ti	Line in Kensington photograph probably compounded of Cr 4289 ·89 and Ti 4290 ·38
4291 ·11	3	no }	4291 ·11	12	12	—	Ti	
4291 ·28	2	no }						
4294 ·20	2	yes	4294 ·41	70	—	50	Fe	Probably due to Fe 4294·30 + Ti 4294·20, but there is more evidence for Ti than Fe.
4298 ·83	2	no						
4299 ·80	2	no						
4300 ·21	3	yes	4300 ·36	60	20	50	Mn	Evidence in favour of Mn origin very weak, that for Ti very strong.

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				Grating spectra.				
				"Flash" I.	"Flash" II.			
4300 ·73	2	no						
4301 ·16	2	no						
4302 ·09	2	yes	4301 ·96	40	15	—	Ti	
4306 ·08	4	no						
4313 ·03	3	yes	4312 ·99	40	25	20	Ti	
4315 ·14	3	yes	4315 ·28	40	30	45	Ti, Fe	Eclipse line probably Ti 4315 ·14 + Fe 4315 ·26.
4338 ·08	4	yes	4337 ·99	25	20	50	Ti, Sr?	Evidence for Sr negligible.
4341 ·53	2	yes	—	—	—	—	—	Probably masked by Hγ.
4344 ·45	2	yes	4344 ·42	50	25	30	Ti	
4367 ·84	2	yes	4367 ·64	25	15	25	Fe	Probably due to Ti 4367 ·84 + Fe 4367 ·68, but evidence for Ti much better than that for Fe.
4394 ·22	2	no						
4395 ·20	3	yes	4395 ·27	50	50	70	Ti	
4417 ·88	3	yes	4417 ·80	18	30	45	Ti	
4427 ·27	2	no	4427 ·4	12	12	30	Ti, Fe	Possibly due to Fe 4427 ·44 + Ti 4427 ·27, but evidence for Fe greater than that for Ti.
4443 ·98	5	yes	4444 ·0	40	35	70	Ti	
4449 ·31	2	no						
4450 ·65	2	yes	4450 ·6	18	20	50	Ti?	
4453 ·49	2	no						
4464 ·62	2	yes	4464 ·6	6	12	25	Ti?	
4468 ·66	5	yes	4468 ·8	50	30	60	Ti	
4501 ·45	5	yes	4501 ·44	35	35	70	Ti	
4512 ·91	3	no						
4518 ·20	3	no	4518 ·0	—	5			
4522 ·97	2	no	4522 ·7	15	25	40	Ti	Eclipse line undoubtedly due, in the main, to enhanced Fe 4522 ·69.

Solar Lines of Intensity 2 or greater, ascribed by Rowland to Ti only—*continued.*

Solar – Ti lines λ (Rowland).	Int. in sun.	If enhanced line.	Eclipse.					Remarks.
			Frost.			Kensington.	Frost's origin.	
			Adopted wave-length.	Intensity. Max. 500. Prism spectra. "Flash" II.	Intensity. Max. 500. Prism spectra. Cusp II.	Int. Max. 100.		
4527 ·49	3	no						
4533 ·42	4	no						
4534 ·95	4	no						
4535 ·74	3	no	—	—	—	20		λ of eclipse line 4535 ·9.
4536 ·09	2	no	—	—	—			
4536 ·22	2	no						
4544 ·86	3	no	—	—	—	30		
4548 ·94	2	no						
4552 ·63	2	no						
4555 ·66	3	no						
4563 ·94	4	yes	4563 ·94	30	40	75		
4572 ·16	6	yes	4572 ·16	45	45	70		
4617 ·45	3	no						
4623 ·28	2	no						

In the above list of solar-titanium lines there are thirty-three which are not "enhanced" in the spark spectrum. It will be seen that twenty-three of these—or 70 per cent.—have no corresponding line (within 0·3 tenth-metre) in Professor Frost's record of eclipse lines. Of the nine eclipse lines in the table which do agree approximately in position with unenhanced titanium lines, two are with certainty due to other metals, and in another case there is more evidence for an iron origin than one of titanium. These are indicated in the column for remarks. The remainder are nearly all lines of insignificant intensity.

Of the twenty "enhanced" lines of titanium which occur in the list, nineteen have corresponding lines in Professor Frost's eclipse spectra, the remaining one being also possibly represented, but it falls so near the strong Hγ line that it might be easily masked. Not only are they represented in the eclipse spectra, but in nearly every case the corresponding eclipse line is a prominent one, as will be gathered at once from a glance at the tabular list given.

Professor Frost summarily dismisses the significance of the enhanced lines of titanium in the eclipse spectra, because "most of them occur as quite strong lines in the ordinary dark line spectrum, and hence would be expected to appear in the reversing layer, as they do." But if he would expect one line of a certain solar intensity, he should expect all lines due to the same element which are of an equal solar intensity, to appear in the eclipse spectra. Yet another glance at the foregoing table will show that many of the titanium lines strongly represented in the eclipse spectra are of the lowest intensity in the Fraunhofer spectrum, and that if lines of a certain solar intensity be considered, those that are enhanced lines appear in the eclipse spectra, whereas the unenhanced ones do not.

In this comparison no account has been taken of the relative intensities of the lines in the titanium spectrum itself. Hasselberg has published* a lengthy list of titanium arc lines, and in the region covered by the eclipse spectra records about 250. To compare all these with the eclipse lines would take too much time and space, nor is it necessary. To show the difference in behaviour in the eclipse spectra of the enhanced and the strongest arc lines, two separate lists of titanium lines have been made. The first, which follows immediately, contains all the enhanced lines which occur in Hasselberg's arc list, and the intensities of Professor Frost's and the Kensington eclipse lines which correspond within 0·3 tenth-metre are also given.

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* 'Kongl. Svenska Vetenskaps Akad. Handl.,' vol. 28, No. 1, 1895.

Enhanced Lines of Titanium recorded by Hasselberg in Arc Spectrum, and their behaviour in Eclipse Spectra.

Enhanced lines in Hasselberg's Ti arc spectrum.		Eclipse.					Remarks.
		Frost.			Kensington.	Frost's origin.	
		Adopted wave-length.	Intensity max. 500. Prism spectra.		Int. max. 100.		
λ.	Int. Max. 8.		"Flash" II.	Cusp II.			
4025·26	2					—	Undoubtedly due to Ti.
4028·48	3	4028·28	35	20	25		
4053·96	3	4053·9	12	—	30	Fe, Ti	Probably due to enhanced Ti 4053·98 + enhanced V 4053·80.
4055·18	5	4054·98	40	?	—	Fe	Evidence for Ti stronger than that for Fe.
4161·67	2	4161·81	80	5	35		
4163·80	5	4163·86	50	12	40	Ti, Cr	Evidence for Cr weak.
4172·04	4	4172·15	80	15	35	Ti, Fe	
4173·66	3	4173·75	50	?	45	—	Probably due to enhanced Fe 4173·52 + enhanced Ti 4173·70.
4174·20	2						
4290·37	5	4290·34	40	20	65	Ti	Line in Kensington photograph probably compounded of Cr 4289·89 and Ti 4290·38.
4294·28	6	4294·41	70	—	50	Fe	Probably due to Fe 4294·30 + Ti 4294·20. More evidence for Ti than Fe.
4300·19	6	4300·36	60	20	50	Mn	Evidence for Ti origin far outweighs that for Mn.
4302·08	5	4301·96	40	15	—	Ti	
4313·01	6	4312·99	40	25	20	Ti	
4315·15	4	4315·28	40	30	45	Ti Fe	Probably due to Ti 4315·14 + Fe 4315·26.

4316·96	4	4316·79	12	6			
4321·12	3	4321·06	60	50	50	Sc	Probably due to enhanced Ti 4321·20 + Sc 4320·91.
4330·85	3	4330·71	30	?	25		
4338·05	6	4337·99	25	20	50	Ti, Sr?	Evidence for Sr negligible.
4341·51	3	—	—	—	—	—	Probably masked by Hγ.
4344·47	3	4344·42	50	25	30	Ti	
4350·99	2						
4367·81	3	4367·64	25	15	25	Fe	Probably due to Ti 4367·84 + Fe 4367·68. Better evidence for Ti than Fe.
4374·97	2	4374·8	60	30	70	—	Probably due to enhanced Ti 4374·90 + Sc 4374·63.
4387·00	2						
			"Flash" I	"Flash" II			
4395·17	7	4395·20	50	50	70	Ti	
4395·99	3						
4399·92	5	4399·9	7	—	55	Ti, Cr	
		4400·3	25	30		Sc	
4417·88	5	4417·80	18	30	45	Ti	
4464·60	3	4464·6	6	12	25	Ti?	
4468·65	6	4468·8	50	30	60	Ti	
4488·47	3						
4501·43	6	4501·44	35	35	70	Ti	
4534·15	5	4534·2	40	60	75	Ti, Co	Probably due solely to Ti.
4549·79	6	4549·9	40	55	75	Ti, Co	Probably due to enhanced Fe 4549·64 + enhanced Ti 4549·81.
4563·94	5	4563·94	30	40	75	Ti	
4572·15	6	4572·16	45	45	70	Ti	
4590·11	4	4590·1	12	10	30		

strong as the majority of those which are the representatives of the enhanced lines.

In the case of iron, all the well-enhanced lines are represented in the eclipse spectra, but they are not of quite the same prominence as the titanium enhanced lines. They are, so far as their intrinsic intensities in the iron arc spectrum are concerned, quite insignificant lines as compared with the majority of other iron lines, but their importance lies in the fact that they are a class of lines of special behaviour, being relatively stronger in the spark spectrum than in the arc. In the eclipse spectra they are undoubtedly represented by stronger lines than are the *great majority* of unenhanced iron lines, however strong the latter may be in the iron arc spectrum itself.

Owing to the great number of iron lines in the solar spectrum, a comparison similar to that given for titanium over the whole region covered by the eclipse lines would necessitate the compilation of a very lengthy list. But whatever evidence there is either one way or another should be revealed by a comparison over a limited region, so it is proposed to take that between λ 4500 and λ 4600, since the proportion of enhanced to unenhanced iron lines is there greatest, and therefore a better opportunity is afforded of a fair comparison of the behaviour of the two classes of lines. The table given on p. 187 is arranged in exactly the same way as in the case of titanium, with the exception that there is an additional column showing the intensities in the arc spectrum, as recorded by Kayser and Runge.

It will be seen that the unenhanced lines are here also unrepresented in the eclipse spectra, with the possible exception of three, which are recorded as very weak lines in one of Professor Frost's spectra, but are missing from the other. All the enhanced lines, however, although they have the weakest arc intensities, appear in each of the eclipse spectra, and have abnormal intensities compared with those corresponding to the unenhanced lines. It must be pointed out that only four of the nine enhanced iron lines in the part of the spectrum considered appear in the above list, because they are the only ones which are given in Rowland's origins for solar lines. At least four out of the remaining five—those at λλ 4515·51, 4522·69, 4556·10, 4576·51, probably correspond to the solar lines 4515·51, 4522·69 (or possibly 4522·80), 4556·06, and 4576·51, to which Rowland has assigned no origin. The outstanding line at λ 4541·40 is doubtfully present in the solar spectrum. The first three of these five have corresponding lines in the eclipse record; the other two have not. In the Kensington reductions of eclipse spectra there are, however, lines agreeing (within 0·3 tenth-metre) with every one of the enhanced lines mentioned.

"On the Arc Spectrum of Vanadium." By Sir NORMAN LOCKYER, K.C.B., F.R.S., and F. E. BAXANDALL, A.R.C.S. Received March 19,—Read March 28, 1901.

The spectrum of vanadium is so important, especially on account of the prominent part which lines of that element play in the spectra of sun-spots, and the existing records of vanadium lines differ so considerably, that it has been thought desirable to publish a list of the lines reduced some time ago from the Kensington photographs of the arc spectrum.

These photographs were obtained by Mr. C. P. Butler with a 6-inch Rowland concave grating of 21½ feet focal length and 14,438 lines to the inch. The region of the spectrum investigated extends from λ 3887 to λ 4932, and occupies on the plates a length of 16¼ inches.

The sources of the spectra were (1) vanadium chloride, and (2) a pure sample of vanadium oxide supplied by Sir Henry Roscoe, to whom we wish to express our thanks. In each case they were volatilised in the arc between poles of the purest silver which could be obtained, and which were kindly placed at our disposal by Sir W. C. Roberts-Austen. These are used because the number of lines due to the poles themselves is so small compared with that produced when carbon poles are employed, that it is much easier to detect the lines really due to the substance under consideration.

Lists of lines in the arc spectrum of vanadium have been published by Rowland and Harrison,* and by Hasselberg.† The former investigators used some compound of vanadium (not stated in their paper) volatilised on carbon poles; the latter employed poles made of the metal itself.

The three records naturally contain a large number of lines in common, but there are many differences between any two of them for which it is difficult to account. To show these differences it has been considered best to give side by side in tabular form the lines in the three lists, and analyse the lines special to any one list, with the object of either properly establishing their claim to be accepted as true lines of vanadium, or possibly tracing them to their real origin. It may be safely assumed that lines common to any two of the lists really belong to vanadium.

To eliminate lines due to impurities, the vanadium spectrum has been directly compared with the arc spectra of all the other elements available at Kensington, photographed exactly on the same scale. If the "strongest" lines of an element are not represented in the vanadium spectrum, apparent coincidences with any of the "weaker" lines are

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* 'Astro.-Phys. Jour.,' vol. 7, p. 273, 1898.

† 'Svenska Vetenskaps Akad. Handl.,' vol. 32, No. 2, 1899.

[redacted]

not accepted as furnishing any proof of the existence of that element as an impurity in the vanadium. This comparison shows that, in addition to those belonging to silver, the only lines which with any degree of probability can be attributed to other metals, are traces of the very strongest lines only of iron, manganese, chromium, cobalt, calcium, strontium, aluminium, and lead. Such lines (a list of which is given later in the paper) have been left out of the following table.

Although Rowland gives his wave-lengths to one-thousandth of a tenth-metre, for convenience of comparison with the other records his values are quoted, throughout the present paper, to the nearest hundredth of a tenth-metre. A brief reference must be made to Rowland's scale of intensities. In his paper he states that the scale he has adopted is from 1 to 15. There are, however, several intensities given which are beyond these limits; but they are probably due to typographical errors. Such cases are indicated in the column for remarks. It would seem rather difficult to reconcile his adoption of such a scale with the opinion expressed in the introduction to his "Preliminary Table of Solar Spectrum Wave-lengths" to the effect that "the ordinary scale from 1 to 10 or from 1 to 6 is far too limited for the spectral lines, especially for the metallic spectra; 1 to 1000 is hardly great enough for the enormous difference in intensity. The small range, 1 to 10, ordinarily used gives an entirely wrong idea to the worker in this subject, and many books with spectroscopic theories might have been saved by using a scale from 1 to 1000."

Vanadium Arc Lines.

Comparison of Kensington Records with Hasselberg's and Rowland's.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. =10.	λ.	Int. Max. =4–5.	λ.	Int. Max. =15.	
3887 ·69	<1					
88 ·20	2	3888 ·23	1			
88 ·47	3	88 ·50	2			
89 ·36	1–2					
89 ·91	<1					
90 ·30	7	90 ·33	3	3890 ·30	4	
91 ·25	5	91 ·27	2			
91 ·88	1					
92 ·53	2–3			92 ·47	4	
92 ·95	6–7	93 ·03	3			
93 ·88	<1					
94 ·16	4–5	94 ·19	2			
95 ·86	2–3					
96 ·29	4	96 ·29	2	96 ·26	2	

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. = 10.	λ.	Int. Max. = 4-5.	λ.	Int. Max. = 15.	
3896·83	2					
97·20	4	3897·22	2			
98·17	6	98·15	3	3898·08	1	
98·44	3					
99·23	3–4	99·30	1			
3900·29	4–5	3900·33	2–3			
01·28	4–5	01·30	2–3			
01·81	2					
02·45	10	02·40	3–4	3902·37	7	
		02·71	1			
03·32	3-4	03·42	1-2			
03·86	<1					
04·51	3–4	04·63	1			
06·92	4	06·89	2			
07·33	2					
08·46	3					
09·58	<1					
09·96	9	10·01	3	09·99	5	
10·57	<1					
10·92	4	10·95	2			
11·90	1					
12·35	5	12·36	2-3			
13·04	3	13·03	2			
13·71	1					
14·08	<1					
14·49	4			14·44	1	
15·30	1-2					
15·57	2					
16·57	3–4	16·55	1–2			
				19·60	1	
20·10	1	20·15	1			
20·67	4	20·65	1–2			
22·11	4	22·15	2	22·02	1	
22·57	5	22·58	2–3	22·55	3	
24·85	5	24·84	2–3	24·77	3	
25·36	5	25·36	2	25·35	3	
26·64	<1					
26·86	1-2					
28·07	5					
28·64	1-2					
29·93	1					
30·19	6	30·19	2–3			
31·46	5	{ 31·40	1			
		31·50	2			
				33·77	3	Ca (K).
34·18	5–6	34·16	3-4			
35·28	4-5	35·28	2-3			
36·43	3-4	36·42	2			
37·65	3	37·68	2			
38·37	3	38·35	2			
39·04	1-2					
39·49	3	39·48	2			

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. =10.	λ.	Int. Max. =4–5.	λ	Int. Max. =15.	
3940 ·75	2	3940 ·75	1			
41 ·40	3	41 ·40	1–2			
42 ·18	4	42 ·16	2			
43 ·81	5	43 ·77	2–3			
				3944 ·13	3	Al.
45 ·36	1					
46 ·04	<1					
48 ·79	3					
50 ·38	4	50 ·37	2			
52 ·12	5	52 ·09	2	52 ·07	1	
				61 ·65	5	Al.
63 ·78	3	63 ·77	2			
64 ·64	1–2					
68 ·29	3	68 ·24	2			
				68 ·59	1	Ca (H).
72 ·12	2	72 ·10	1			
73 ·53	1	73 ·49	1			
73 ·79	3–4	73 ·79	2			
75 ·48	1–2					
77 ·88	2					
79 ·31	3	79 ·30	2			
79 ·61	3	79 ·59	2	79 ·54		
80 ·66	3	80 ·66	2			
81 ·78	4–5					
84 ·51	3					
84 ·78	3–4	84 ·75	2			
88 ·21	<1					
88 ·98	4	88 ·97	2			
89 ·95	1					
90 ·72	7	90 ·71	3	90 ·69	5	
91 ·22	1					
92 ·95	7	92 ·95	3	92 ·92	3	
95 ·08	2					
97 ·31	3–4	97 ·30	1–2			
98 ·91	7	98 ·87	3	98 ·85	3	
4000 ·24	2	4000 ·24	1			
03 ·12	3	03 ·10	1–2			
03 ·70	2–3	03 ·70	1–2			
05 ·90	4–5	05 ·86	2	4005 ·84	1	
08 ·33	<1					
09 ·99	1–2	09 ·94	1			
11 ·50	2–3	11 ·45	1			
13 ·69	<1					
15 ·26	1	15 ·20	1			
16 ·86	<1					
19 ·18	<1					
19 ·58	<1					
20 ·73	1					
22 ·07	2–3			22 ·04	1	
23 ·28	2–3					
23 ·48	3–4	23 ·50	2	23 ·51	1	
24 ·63	<1					

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. = 10.	λ.	Int. Max. = 4–5.	λ.	Int. Max. = 15.	
4025·47	1	4025·46	1			
30·05	1–2	30·04	1–2			
31·36	2	31·37	1–2			
31·99	4	31·98	2	4031·96	1	
32·64	1–2	32·62	1–2			
33·00	1	33·01	1			
				33·19	3	Mn.
				34·62	2	Mn.
35·77	4	35·77	2			
36·93	2	36·93	1			
39·76	<1					
40·43	1–2	40·46	1			
41·66	2–3	41·72	2			
42·80	3–4	42·78	2	42·76	1	
46·99	1	47·05	1			
48·77	2–3	48·77	2			
51·10	5	51·11	2–3			
51·52	5	51·48	2–3			
52·60	1	52·60	1			
53·41	2–3					
53·81	<1					
57·21	5	57·21	3	57·21	2	
				57·96	1	Pb
61·00	1	60·97	1			
61·76	1					
62·92	1					
64·11	4–5	64·09	2–3	64·06	2	
65·54	1–2					
67·96	2–3	67·90	1–2			
68·16	2–3					
70·94	2–3					
71·67	4–5	71·67	2–3	71·66	2	
72·28	2–3	72·30	2			
				77·85	1	Sr.
78·10	1					
83·07	3–4					
83·44	<1					
84·92	<1					
88·00	<1					
90 05	1					
90·74	8	90·70	3	90·70	5	
92·08	3	92·09	1–2			
92·55	4	92·54	2	92·53	2	
92·81	8	92·83	3			
93·61	3–4	93·65	2			
94·38	3	94·42	2			
95·60	7	95·64	3	95·61	5	
97·05	2–3	97·09	1–2			
98·50	3–4	98·54	2	98·51	1	
98·99	1					
99·94	9	99·93	3–4	99·92	7	
4101·99	1–2					

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. = 10.	λ.	Int. Max. = 4–5.	λ.	Int. Max. = 15.	
4101·65	<1					
02·25	6–7	4102·32	3	4102·28		
03·54	1–2					
04·52	4	04·55	2	04·52	2	
04·93	3–4	04·92	2			
05·33	7	05·32	3			
06·08	1					
07·60	3.	07·64	1–2	07·60	1	
08·32	4	08·36	2			
09·20	2					
09·89	8	09·94	3–4	09·91	7	
10·86	1					
11·22	<1					
12·00	10	11·92	4	11·92	5	
12·50	4	12·47	1–2			
13·62	5	13·65	2–3	13·64	3	
14·69	3	14·69	1–2			
15·33	9	15·32	3–4	15·31	7	
16 64	8	16·64	3	16·63	9	
		16·85	1·2			
18·34	4–5	18·34	2·3	18·32	1	
18·76	4–5	18·73	2			
19·23	1					
19·56	4–5	19·58	2	19·57	3	
20·65	4–5	20·69	2	20·65	2	
21·08	2	21·13	1			
21·75	2–3					
22·45	1					
22·94	<1					
23·30	3					
23·59	7	23·65	3			
24·15	3–4	24·23	2	24·20	1	
27·15	1					
27·56	<1					
28·20	9	28·25	3–4	28·15	7	
28·94	4	29·00	2			
30·28	<1					
30·44	1					
31·07	<1					
31·26	1	31·32	1	31·30	1	
32·08	9	32·13	3–4	32·13	6	
32·93	1					
33·86	3	33·92	2			
34·61	9	34·61	3–4	34·62	7	
35·40	1					
36·27	3	36·25	2			
36·55	2–3	36·52				
37·06	1					
37·36	<1					
38·17	2					
39·34	3–4	39·39	2			
41·50	3					

Vanadium Arc Lines—continued.

Kensington.		**Hasselberg.**		**Rowland.**		**Remarks.**
λ.	Int. Max. =10.	λ.	Int. Max. =4–5.	λ.	Int. Max. =15.	
4141 ·91	1–2	4141 ·96	1–2			
42 ·80	1–2	42 ·75	1–2			
43 ·02	1	43 ·02	1			
43 ·47	<1					
45 ·62	2					
46 ·15	<1					
47 ·90	2					
49 ·01	2-3	49 ·02	1–2			
50 ·22	<1					
50 ·80	2–3	50 ·84	2			
51 ·46	<1	51 ·52	1			
52 ·80	2–3	52 ·81	2			
53 ·47	2–3	53 ·49	1–2			
54 ·16	<1					
55 ·34	<1	55 ·39	1			
55 ·95	1	56 ·00	1–2			
56 ·65	<1					
58 ·11	1	58 ·14	1			
58 ·58	<1					
59 ·82	5	59 ·84	2–3	4159 ·82	2	
60 ·48	1	60 ·57	1			
62 ·48	<1	62 ·51	1			
66 ·86	1–2					
67 ·15	1					
69 ·08	<1					
69 ·37	2–3	69 ·40	1–2			
71 ·42	3–4	71 ·45	2			
74 ·13	4	74 ·18	2	74 ·16	1	
75 ·24	1	75 ·30	1			
76 ·85	<1	76 ·83	1			
77 ·00	<1	77 ·02	1			
77 ·19	3	77 ·25	1			
77 ·67	1					
78 ·53	1					
79 ·54	6	79 ·53	2–3			
80 ·12	1					
80 ·95	1	80 ·99	1			
82 ·21	2–3	82 ·23	1–2			
82 ·74	5–6	82 ·74	2-3	82 ·73	1	
				83 ·07	4	
83 ·45	1	83 ·43	1			
83 ·60	2–3	83 ·59	1			
84 ·55	<1					
86 ·91	1	86 ·95	1			
87 ·74	1	87 ·82	1			
89 ·95	5–6	89 ·99	2-3	90 ·01	2	
91 ·69	5–6	91 ·70	2–3			
94 ·13	1–2	94 ·17	1			
95 ·73	2–3					
97 ·43	1	97 ·45	1			
97 ·74	3-4	97 ·77	2			
98 ·74	3–4	98 ·78	2			

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. =10.	λ.	Int. Max. =4–5.	λ.	Int. Max. =15.	
4199·75	<1					
99·97	1					
4200·30	3	4200·35	2			
01·05	1–2					
02·50	2–3	02·52	1	4202·51	2	
04·34	<1					
04·67	<1	04·67	1			
05·28	2–3	05·23	1	05·20	2	
06·73	1					
10·00	4–5	09·98	2–3	10·00	5	
		10·55	1	..	..	Probably masked in Kensington photograph by a strong broad line of Ag at λ 4212·1
		11·02	1	..	..	
16·50	1	16·52	1			
18·89	3–4	18·86	2			
19·66	1–2	19·65	1–2			
21·22	1	21·17	1			
22·54	1–2	22·49	1			
23·15	1					
24·36	3–4	24·30	2			
25·41	1–2	25·40	1	25·37	1	
		26·78	2	..	..	Probably masked by Ca line at λ 4226·91.
				26·87	4	Ca.
27·92	3–4	27·90	2			
29·92	3–4	29·87	2			
32·68	5–6	32·62	3	32·60	7	
33·09	5–6	33·09	3	33·11	7	
34·18	5–6	34·12	3	34·15	7	
34·71	4	34·70	2–3	34·67	7	
35·92	4–5	35·90	2–3	35·91	4	
36·78	<1					
39·15	2	39·12	1–2			
39·80	<1					
40·29	2–3	40·25	2			
40·54	3	40·53	2			
41·52	3	41·48	2			
46·91	1					
47·43	1	47·46	1			
51·42	<1	51·45	1			
53·00	1–2	53·02	1·2			
55·59	<1	55·60	1·2			
57·50	4	57·53	2	57·52	4	
59·47	4	59·46	2	59·45	4	
60·00	1					
60·28	1					
60·46	1					
61·32	2–3	61·37	2			
62·30	4	62·32	2	62·31	4	
65·25	3	65·28	2			
66·07	2					

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. =10.	λ.	Int. Max. =4–5.	λ.	Int. Max. =15.	
4267·48	2	4267·50	1–2			
68·78	6	68·78	3	4268·79	0*	* ? (10)
69·89	3–4	69·92	2			
70·51	3–4	70·49	2			
71·75	6	71·71	3	71·71	17*	* ? (7)
72·93	<1					
73·50	<1					
76·50	<1					
77·10	5–6	77·12	3	77·10	7	
78·53	<1					
79·12	2	79·12	1–2			
83·08	3–4	83·06	2			
84·19	6	84·19	3	84·21	5	
86·57	3–4	86·57	2			
87·93	3–4	87·97	2			
89·00	1					
91·45	3	91·46	2			
91·96	5–6	91·97	3	91·98	1	
96·30	5	96·28	2–3	96·27	7	
97·29	1					
97·85	4–5	97·86	2–3	97·84	7	
98·17	4–5	98·17	2–3			
98·79	<1					
99·27	1–2			99·24	1	
4302·32	1–2					
03·70	2–3	4303·70	2	4303·70	2	
05·64						
06·40	5	06·35	2–3			
06·76	<1					
07·32	5	07·33	2–3			
08·61	<1					
09·75	2	09·69	1–2			
09·95	5	09·95	3	09·95	7	
11·66	1					
11·83	1					
12·58	1	12·56	1			
14·11	2–3	14·06	1–2			
15·02	2					
15·95	<1	16·02	1			
18·04	<1					
				18·80	2	Ca.
20·15	<1					
20·49	1–2	20·46	1			
22·53	1–2	22·51	1			
29·90	<1					
30·18	6	30·18	3	30·18	0*	* ? (10).
31·28	1					
32·60	2	32·56	1–2			
32·96	6	32·98	3	32·98	10	
34·25	3	34·23	1–2			
35·06	<1					
35·69	<1					

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. =10.	λ.	Int. Max. =4–5.	λ.	Int. Max. =15.	
4336·33	2–3	4336·29	1–2			
39·31	<1					
41·19	7	41·15	3	4341·16	10	
42·39	2–3	42·36	1–2			
43·02	3–4	43·00	2			
45·39	<1					
47·02	<1					
47·64	1					
50·86	1					
50·97	2–3					
52·68	2					
53·02	7	53·02	4	53·04	18*	* ? (8).
53·54	2					
55·14	3–4	55·09	2	55·14	4	
56·14	4–5	56·10	2–3	56·10	4	
56·98	2					
57·64	2	57·60	1–2			
57·86	1	57·82	1			
60·77	2–3	60·75	1–2			
61·24	1–2	61·18	1			
61·58	2–3	61·57	1–2			
63·54	<1	63·48	1			
63·75	3–4	63·69	2	63·69	4	
64·40	3–4	64·37	2	64·38	4	
65·94	2–3	65·92	1–2			
66·76	<1					
67·26	1	67·24	1			
68·23	5	68·25	2			
68·78	3–4	68·76	1–2	68·76	4	
69·24	2	69·25	1			
71·98	<1					
73·40	4	73·40	2	73·38	6	
74·01	3–4	73·99	2	73·98	3	
74·38	<1					
75·28	1–2					
75·51	3–4	75·47	2			
76·25	1–2	76·25	1			
77·05	<1					
77·33	<1					
78·13	2–3	78·06	2			
79·44	10	79·38	4–5	79·39	1*	* ? (10). Strongest line in the whole spectrum.
80·75	4	80·69	2	80·72	4	
81·21	2			81·19	1	
81·43	1					
81·93	1					
83·39	<1					
84·13	1	84·07	1			
84·42	2	84·37	1			
84·92	9	84·87	4–5	84·87	1*	* ? (10). Very strong line.
85·53	2					
87·42	2–3	87·40	1–2			
88·32	1					

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. =10.	λ.	Int. Max. =4–5	λ.	Int. Max. =15.	
4390·13	9	4390·13	4–5	4390·14	7	
90·80	2	90·79	1			
91·88	2	91·84	1–2			
92·28	4	92·24	2	92·23	4	
93·28	3	93·26	2	93·26	3	
94·03	3	94·01	2	94·00	4	
95·05	2–3	94·98	1–2			
95·42	8	95·40	4–5	95·38	10	
95·77	1–2					
96·61	<1					
96·93	<1					
				97·39	1	
97·56	<1					
98·09	<1					
99 63	2					
4400·74	8	4400·74	4	4400·74	10	
01·34	1					
01·91	1					
02·79	1					
03·87	3–4	03·86	1–2	03·83	4	
05·20	3–4	05·20	2–3			
06 33	3–4			06·28	8	
06·80	7	06·80	4–5	06·80	8	
07·83	7	07·85	4–5	07·80	8	
08·35	5	08·36	4	08·37	5	
08·67	6	08·67	4–5	08·66	5	
12·33	4–5	12·30	2	12·30	4	
13·60	<1					
13·90	2					
14·74	2	..	..	..	..	Not due to Fe.
15·25	3					
16·71	6	16·63	3	16·63	5	
17·83	<1					
18·88	<1					
20·14	4–5	20·08	2-3			
21·77	6	21·73	3	21·74	10	
22·42	2	22·40	1·2			
22·71	1–2					
23·40	4	{ 23·32	1–2	23·37	8	
		23·41	1–2			
24·11	2	24 10	1–2	24·08	2	
24·77	3	24·74	1–2	24·74	4	
				25·59	1	Ca.
25·95	3	25·86	2			
26·22	5	26·17	3			
27·49	4					
28·72	5-6	28·68	3	28·68	5	
30·02	5	29·95	3			
30·71	2-3	30·68	2			
31·36	<1					
31·91	<1					
32·28	<1					

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. =10.	λ.	Int. Max. =4–5.	λ.	Int. Max. =15.	
4433·09	2					
34·80	4	4434·80	2			
35·60	1					
36·33	6	36·31	3–4	4436·31	7	
38·02	7	38·02	3–4	38·00	7	
39·19	2					
41·90	7	41·88	3–4	41·85	2	
43·56	4	43·52	2	43·51	4	
44·39	6–7	44·40	3–4	44·38	3	
46·04	1					
49·78	3–4	49·77	2–3	49·74	4	
51·13	3–4	51·09	2	51·07	4	
52·19	·7	52·19	4	52·18	8	
52·91	2–3	52·91	2			
53·30	1–2					
54·34	1					
				54·94	1	Ca.
				56·07	1	Ca.
56·68	2–3	56·68	2	56·67	3	
57·67	5	57·65	3–4	57·63	3	
58·00	4	57·97	2–3			
58·57	2					
				58·91	1	
59·96	6–7	59·93	4	59·92	8	
60·52	7	60·46	4–5	60·46	10	
				60·85	4	
61·18	3–4					
62·52	6	62·56	3–4	62·53	10	
64·46	2 3					
64·95	2–3					
65·69	2–3			65·67	3	
67·09	2–3	67·04	2			
67·87	<1					
68·23	4–5	68·19	2–3	68·17	3	
68·95	3–4	68·94	2	68·93	3	
69·87	6	69·88	3–4	69·87	7	
				70·87	1	
71·51	<1					
71·96	<1					
73·45	<1					
74·22	5	74·21	3	74·21	7	
74·91	5–6	74·89	3–4	74·90	7	
		76·06	2			Probably masked by strong Ag line at λ 4476·29.
77·48	<1					
80·21	4	80·20	2 3	80·21	3	
84·24	1					
86·39	<1	86·44	1			
89·08	7	89·03	3–4	89·10	7	
90·99	4–5	90·95	2–3	90·98	4	
91·36	2	91·35	1–2	91·34	2	
91·65	1	91·66	1	91·65	1	

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. = 10.	λ.	Int. Max. = 4–5.	λ.	Int. Max. = 15.	
4495 ·17	1	4495 ·16	1-2			
96 ·24	5	96 ·26	3	4496 ·23	5	
97 ·00	4	97 ·03	2			
97 ·55	3	97 ·57	2	97 ·57	5	
4501 ·00	1–2	4501 ·01	2	4501 ·00	2	
01 ·45	1			01 ·41	1	
02 ·12	5–6	02 ·12	3	02 ·12	4	
06 ·30	2–3	06 ·30	2			
06 ·40	1	06 ·41	1–2			
06 ·73	1–2	06 ·77	2	06 ·74	1	
08 ·10	<1	08 ·11	1			
09 ·46	2-3	09 ·49	2	09 ·46	2	
11 ·63	2–3	11 ·64	2	11 ·60	2	
13 ·83	2–3	13 ·79	2	13 ·79	2	
14 ·36	4	14 ·36	2-3	14 ·36	4	
15 ·73	2	15 ·74	1–2	15 ·73	1	
17 ·75	3	17 ·77	2	17 ·74	3	
20 ·35	2–3	20 ·31	2	20 ·33	2	
20 ·71	2	20 ·67	1–2	20 ·69	2	
24 ·39	5–6	24 ·38	3	24 ·38	5	
25 ·33	3–4	25 ·31	2	25 ·34	2	
28 ·19	3–4	28 ·16	2–3	28 ·17	3	
28 ·64	2	28 ·66	2			
29 ·50	2–3	29 ·47	2	29 ·48	2	
29 ·78	5	29 ·76	2–3			
30 ·98	3	30 ·97	2	30 ·97	3	
34 ·08	3			34 ·11	3	
37 ·83	3–4	37 ·84	2	37 ·83	4	
40 ·18	3–4	40 ·18	2	40 ·18	4	
41 ·60	1	41 ·57	1			
45 ·56	7	45 ·57	3-4	45 ·57	10	
49 ·79	6	49 ·81	3	49 ·82	8	
52 ·03	3	52 ·05	2	52 ·02	2	
				*52 ·73	5	* ? 53 ·27.
53 ·25	5–6	53 ·25	2–3			
55 ·59	<1					
60 ·89	7	60 ·90	3	60 ·89	7	
64 ·79	1	64 ·76	1	64 ·76	1	
70 ·62	3–4	70 ·60	2			
71 ·97	6	71 ·96	3	71 ·96	5	
77 ·33	8	77 ·36	4	77 ·35	7	
78 ·89	5–6	78 ·92	3	78 ·91	5	
79 ·38	3–4	79 ·38	2-3	79 ·37	2	
80 ·57	8	80 ·57	4	80 ·56	8	
81 ·40	1			81 ·41	1	
83 ·96	3	83 ·96	2	83 ·97	2	
86 ·20	1	86 ·15	1–2			
86 ·51	9	86 ·54	4–5	86 ·55	8	
88 ·97	1	88 ·94	1			
91 ·41	5–6	91 ·39	2–3	91 ·41	5	
94 ·27	10	94 ·27	4–5	94 ·22	10	
4600 ·41	1	4600 ·34	1-2			

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland		Remarks.
λ.	Int. Max. =10.	λ.	Int. Max. =4–5.	λ	Int. Max. =15.	
4608·15	1					
06·33	5	4606·33	2–3	4606·32	4	
07·42	1	07·40	1–2	07·39	1	
				08·63	1	
09·84	2–3	09·84	2	09·82	4	
11·11	1–2	11·10	1–2	11·10	1	
11·95	2	11·92	2			
				13·98	1	
14·10	<1	14·08	1	14·09	1	
16·20	<1	16·18	1	16·19	11*	*? (1).
17·00	<1	17·03	1			
18·00	<1	18·00	1			
19·00	1					
19·92	7–8	{19·85 19·97	2 2–3	19·90	0*	*? (10).
21·42	1	21·43	1	21·43	1	
24·61	5	24·62	2	24·58	4	
26·66	4–5	26·67	2	26·67	4	
30·25	<1	30·24	1	30·24	1	
35·38	6	35·35	2–3	35·35	7	
36·36	1	36·34	1–2	36·34	1	
40·27	4	40·25	2	40·23	5	
40·92	4	40·92	2	40·92	5	
44·24	<1			44·24	1	
44·66	2	44·64	2	44·62	2	
46·20	<1	46·17	1	46·16	1	
46·52	6	46·59	2–3	46·57	8	
48·08	1	48·08	1	48·05	1	
49·07	2	49·08	1–2	49·07	2	
53·13	1	53·15	1	53·11	1	
54·80	1	54·84	1–2			
35·50	<1	55·47	1	55·41	1	
57·17	1	57·17	1	57·14	1	
61·00	<1	61·01	1			
62·00	<1	62·02	1			
62·60	1			62·61	1	
				63·31	3	
66·34	2-3	66·33	2			
69·50	<1	69·50	1	69·49	1	
70·66	6-7	70·66	4	70·67	8	
72·48	1	72·48	1			
73·83	1	73·83	1	73·84	1	
79·68	1	79·65	1			
80·03	1-2	79·95	1–2	79·96	1	
81·12	1–2	81·07	1–2	81·07	1	
		82·09	1			
82·93	1					
84 57	2	84·64	2	84·63	3	
87·11	3–4	87·10	2–3	87·10	5	
88·24	<1	88·24	1			
90·45	1–2	90·45	1	90·44	1	
		99·52	2	99·50	2	

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. =10.	λ.	Int. Max. =4–5.	λ.	Int. Max. =15.	
4702·70	1			4702·69	1	
05·23	2–3	4705·26	2	05·28	3	
06·38	4	06·34	2–3	06·36	5	
06·76	5	06·75	2–3	06·76	5	
07·64	2–3	07·62	2	07·63	3	
				08·40	1	
				09·13	1	
09·93	2–3					
10·75	5	10·74	2-3	10·75	5	
13·65	1	13·61	1–2	13·64	1	
14·29	4–5	14·28	2-3			
15·50	<1			15·49	1	
15·62	2	15·61	1–2	15·65	1	
16·11	3	16·08	2	16·08	4	
16·39	1–2	16·36	1–2	16·38	1	
17·89	4–5	17·85	2–3	17·87	5	
21·40	<1	21·42	1–2	21·44	1	
21·71	3–4	21·70	2–3	21·70	4	
23·06	4	23·06	2–3	23·06	4	
23·65	<1	23·65	1	23·63	1	
24·07	<1			24·07	1	
28·85	<1	28·85	1	28·84	1	
29·77	3–4	29·73	2	29·72	5	
30·58	2-3	30·57	2	30·57	2	
31·40	1	31·42	1–2	31·44	1	
31·80	1	31·74	1–2	31·74	1	
32·17	1	32·12	1–2	32·11	1	
37·90	1-2	37·91	1	37·92	1	
38·60	<1	38·51	1–2	38·50	1	
39·80	1	39·79	1	39·85	1	
42·86	3	42·79	2	42·82	5	
46·87	3	46·81	2	46·83	5	
47·30	<1	47·30	1–2	47·31	1	
48·70	3-4	48·70	2	48·72	5	
51·18	3–4	51·16	2	51·21	5	
51·45	1	51·45	1	51·46	1	
51·79	3	51·75	2	51·76	5	
52·05	1			52·04	1	
54·13	3–4	54·13	2–3			
57·62	5–6	57·55 57·68	2 2–3	57·69	4	
58·95	<1	58·92	1–2	58 94	1	
59·20	<1			59·21	1	
64·22	1			64·22	1	
65·91	<1	65·84	1–2	65·86	1	
66·82	5	66·80	2–3	66·84	7	
				69·21	1	
72·76	1	72·74	1	72·78	1	
73·29	1	73·25	1–2	73·26	1	
76·63	6	76·54 76·70	2 3	76·64	5	
				81·51	1	

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. = 10.	λ.	Int. Max. = 4–5.	λ.	Int. Max. = 15.	
4784·72	2–3	4784·65	2	4784·66	5	
86·71	5–6	86·70	3	86·71	7	
				89·10	1	
93·15	1–2	93·10	2	93·13	2	
				94·73	1	
95·35	1	95·27	2	95·29	2	
97·08	5–6	97·07	3	97·12	8	
98·19	<1	98·12	1–2	98·15	1	
99·20	1	99·20	1	99·21	1	
99·98	2–3	99·94	2	99·97	4	
				4802·37	1	
4803·24	<1			03·24	1	
07·73	5–6	4807·70	3–4	07·74	10	
08·84	1			08·84	1	
19·23	1	19·22	1–2	19·22	2	
				23·03	1	
27·63	6	27·62	3–4	27·64	10	
29·00	1	29·00	1–2	29·01	1	
				29·43	1	
30·90	1	30·86	1–2	30·88	1	
31·85	6	31·80	3–4	31·84	8	
32·61	6	32·59	3	32·62	8	
33·24	1–2	33·17	2	33·21	3	
34·00	1			34·01	1	
				34·26	1	
				35·04	1	
43·20	<1	43·16	1–2	43·19	2	
46·80	<1			46·80	1	
49·05	1	48·98	1–2	49·00	1	
				49·26	1	
				49·46	1	
51·69	7	51·65	4	51·69	10	
				52·15	1	
				54·11	1	
				55·55	1	
57·20	<1			57·24	1	
58·80	<1			58·81	2	
59·38	<1	59·34	2			
62·83	2	62·83	2	62·80	4	
64·92	7	64·93	4	64·94	10	
				70·33	1	
71·50	2	71·46	2	71·45	3	
				73·17	1	
75·71	7	75·66	4	75·67	10	
80·82	3	80·77	2–3	80·75	6	
81·75	7–8	81·75	4	81·75	10	
82·36	<1			82·36	2	
85·89	1	85·86	2	85·83	2	
87·03	1	87·02	2	86·99	2	
90·30	1–2	90·32	1–2	90·26	1	
91·40	1	91·43	1–2	91·41	2	
91·74	1	91·81	2	91·77	3	

Vanadium Arc Lines—continued.

Kensington.		Hasselberg.		Rowland.		Remarks.
λ.	Int. Max. =10.	λ.	Int. Max. =4–5.	λ.	Int. Max. =15.	
4894·42	1	4894·43	2	4894·40	3	
4900·82	2–3	4900·84	2–3	4900·82	3	
04·60	3–4	04·59	3	04·57	5	
05·05	1	05·10	1–2	05·05	3	
06·05	<1	06·06	1			
				07·05	1	
08·90	1	08·92	1	08·88	1	
				13·28	1	
16·46	1	16·48	1–2	16·44	1	
				19·17	1	
22·60	1	22·60	1–2	22·54	1	
25·87	3–4	25 83	2–3	25·84	7	
32·23	2	32·24	2	32·21	3	

Reference to the foregoing table will show that the Kensington list and Hasselberg's contain many lines in common which are missing from Rowland's. This is probably due to the fact that the latter used carbon poles, which furnish so many lines themselves that it is extremely difficult to pick up all the lines really due to the substance volatilised on them. As an instance of this, in the region between λ 4130 and λ 4216, throughout which the structure lines in the carbon fluting which commences at the latter wave-length are most crowded, Rowland records only eleven lines, whereas in the corresponding region Hasselberg gives forty-nine, and the Kensington photograph shows seventy-five.

Taking Hasselberg's list as a basis we find that the few lines given below occur only in his list.

Lines given by Hasselberg only.

Hasselberg.		Remarks.
λ.	Int. Max. 4–5.	
3902·71	1	
4116·85	1–2	
4210·55	1	} Probably masked in the Kensington photograph by a broad line of Ag at λ 4212·1.
4211·02	1	
4226·78	2	Probably masked by line of Ca at λ 4226·91.
4476·06	2	„ „ „ Ag at λ 4476·29.
4682·09	1	

Four of these may be present in the Kensington photograph, being probably hidden by lines of Ag and Ca. With regard to the others, reference to unpublished lists of lines in the arc spectra of many other elements suggests no origin which can be assigned to them.

In addition to these lines, Hasselberg has apparently observed as double the following lines recorded as single in the other two lists.

Lines recorded as Double by Hasselberg.

Hasselberg.		Kensington.		Rowland.		Remarks.
λ.	Int. Max. 4–5	λ.	Int. Max. 10.	λ.	Int. Max. 15.	
3931·40	1	3931·46	5			
3931·50	2					
4423·32	1–2	4423·40	4	4423·37	8	
4423·41	1–2					
4619·85	2	4619·92	7–8	4619·90	0*	* ? (10).
4619·97	2–3					
4757·55	2	4757·62	5–6	4757·69	4	
4757·68	2–3					
4776·54	2	4776·63	6	4776·64	5	
4776·70	3					

In considering Rowland's list in relation to the two others, it is found that the following lines are recorded by him only. Some of

Lines given by Rowland only.

Rowland.		Remarks.	Rowland.		Remarks.	Rowland.		Remarks.
λ.	Int. Max. 15.		λ.	Int. Max. 15.		λ.	Int. Max. 15.	
3919·60	1		4456·07	1	Ca.	4823·03	1	
3933·77	3	Ca(K).	4458·91	1		4829·43	1	
3944·13	3	Al.	4460·85	4		4834·26	1	
3961·65	5	Al.	4470·87	1		4835·04	1	
3968·59	1	Ca(H).	4552·73*	5		4849·26	1	
4033·19	3	Mn.	4608·63	1		4849·46	1	
4034·62	2	Mn.	4613·98	1		4852·15	1	
4057·96	1	Pb.	4663·31	8		4854·11	1	
4077·85	1	Sr.	4708·40	1		4855·55	1	
4183·07	4		4709·13	1		4870·33	1	
4226·87	4	Ca.	4769·21	1		4873·17	1	
4318·80	2	Ca.	4781·51	1		4907·05	1	
4397·39	1		4789·10	1		4913·28	1	
4425·59	1	Ca.	4794·73	1		4919·17	1	
4454·94	1	Ca.	4802·37	1				

* *Possibly misprint* for 4553·27. If so, should not appear in this list.

them are obviously due to other metals existing as impurities either in the poles or in the compound of vanadium which was used, and although several of these lines occur in the Kensington photograph, they have been discarded. Attempts to trace the remaining lines to other origins have been unsuccessful.

With reference to the lines which are absent from Rowland's list, but which appear in the other two, it seems certain that many genuine and strong lines of vanadium have either not been identified by him, or have for some reason been discarded from his list. In this connection, it may be stated that many of the lines recorded by Rowland in his "Table of Solar Wave-lengths" as being due to vanadium, do not appear in his list of vanadium arc lines, though nearly all of them occur as strong lines in both Hasselberg's and the Kensington records. A list of these is given on the next page. Those marked with a † are taken from a list of corrections which he has given[*] to his "Tables of Solar Wave-lengths." The remainder are taken from his original tables.

Included in this list are seven lines possibly identical with lines in Rowland's arc spectrum, though the difference in his two recorded wave-lengths of the possibly corresponding arc and solar lines varies from ten to nineteen hundredths of a tenth-metre, a difference which is greatly in excess of what he claims to be his limiting error in the estimation of wave-lengths.

In the Kensington list there are 194 lines which do not appear in either Hasselberg's or Rowland's. It will serve no useful purpose to enumerate these in a special table, as they can be easily referred to in the general comparison table given in an earlier part of the paper. An analysis of their intensities shows that seventy-seven are very weak lines, of intensity designated < 1, fifty-three of intensity 1, thirty-nine of intensity 2, twenty of intensity 3, three of intensity 4, and two of intensity 5, the maximum intensity adopted being 10.

No other probable origin has been found for any of them, although the vanadium spectrum has been compared directly with the arc spectra of the following elements:—Ag, Au, Ba, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Di, Fe, Hg, In, Ir, K, La, Li, Mg, Mn, Mo, Na, Ni, Os, Pb, Pd, Rb, Rh, Ru, Sc, Sn, Sr, Ta, Te, Th, Ti, Tl, U, W, Yt, Zn, Zr.

As these lines appear in the spectrum when either the oxide or chloride of vanadium is used, there seems to be no reason to doubt that they are really due to vanadium.

Several of them are evidently present in Hasselberg's photograph, as in his comparison of certain vanadium lines with lines of equal or nearly equal wave-length belonging to other metals he records the following, but has left them out of his comprehensive list of vanadium lines, presumably as being due to other metals which exist as impurities in his vanadium.

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[*] 'Ast.-Phys. Jour.,' vol. 6, p. 384, 1897.

[redacted]

Lines previously recorded as V by Rowland in his "Table of Solar Wave-lengths," which are not included in his Vanadium Arc Lines.

Solar—V lines (Rowland) λ.	Vanadium arc lines.				Remarks.
	Hasselberg.		Kensington.		
	λ.	Int. Max. 4–5.	λ.	Int. Max. 10.	
3893·03	3893·03	3	3892·95	6–7	
94·17†	94·19	2	94·16	4–5	
3903·40†	3903·42	1–2	3903·32	3–4	
04·31†					
10·98	10·95	2	10·92	4	
12·34	12·36	2–3	12·35	5	
34·11†	34·16	3–4	34·18	5–6	
41·32†	41·40	1–2	41·40	3	
42·16†	42·16	2	42·18	4	
43·72†	43·77	2–3	43·81	5	
48·82†			48·79	3	
73·80†	73·79	2	73·79	3–4	
75·51†			75·48	1–2	
4036·92†	4036·93	1	4036·93	2	
51·20	51·11	2–3	51·10	5	
69·76†					
72·30†	72·30	2	72·28	2–3	
83·09†			83·07	3–4	
92·82	92·83	3	92·81	8	
4104·62	4104·55	2	4104·52	4	Possibly Rowland's V arc line at λ 4104·52
04·91	04·92	2	04·93	3–4	
05·32	05·32	8	05·33	7	
23·66	23·65	3	23·59	7	
28·25	28·25	3–4	28·20	9	Ditto at λ 4128·15.
79·54	79·53	2–3	79·54	6	
4232·76	4232·62	3	4232·68	5–6	Ditto at λ 4232·60.
33·09	33·09	3	33·09	5–6	Ditto at λ 4233·01.
92·14	91·97	3	91·96	5–6	Ditto at λ 4291·98.
4375·10					
4420·10	4420·08	2–3	4420·14	4–5	
29·96	29·95	3	30·02	5	
44·57	44·40	3–4	44·39	6–7	Ditto at λ 4444·38.
57·94	57·97	2–3	58·00	4	
88·93	89·06	3–4	89·08	7	Ditto at λ 4489·10.

Hasselberg.		Kensington.		Hasselberg's imputed origin.	Remarks.
λ.	Int.	λ.	Int.		
3975·51	1	3975·48	1–2	Ba, Co	There is no evidence that the lines in the Kensington photograph are due to any of these metals.
4013·67	1	4013·69	<1	Ti	
4020·69	1	4020·73	1	Fe	
4123·35	2	4123·30	3	Ti, Mn	
4315·00	1–2	4315·02	2	Ti	
4618·96	1	4619·10	1	Fe	

The following lines occur in the photograph, but have been left out of the Kensington record as they are considered to be undoubtedly due to other metals.

Lines of other Metals which occur in the Kensington Vanadium Spectrum.

λ.	Int. in V.	Origin.	λ.	Int. in V.	Origin.
3933·83	5	Ca	4215·66	<1	Sr
44·16	1–2	Al	26·91	6	Ca
61·68	2	Al	50·93	<1	Fe
68·63	5	Ca	54·49	2	Cr
81·87	4–5	Ag	74·91	2	Cr
95·46	2–3	Co	89·87	1	Cr
4030·92	3–4	Mn	4302·68	<1	Ca
33·22	3	Mn	07·96	1	Fe
34·64	2–3	Mn	11·21	1–2	Ag
45·90	2	Fe	25·92	1–2	Fe
55·44	10	Ag	83·70	2	Fe
57·97	3	Pb	4404·70	<1	Fe
63·63	1–2	Fe	76·29	6	Ag
4121·48	2–3	Co	4668·70	7	Ag
4212·10	10	Ag			

All these lines are the very strongest in the spectra to which they respectively belong, and although in the vanadium spectrum there are other lines apparently identical in position with some of the weaker lines of Fe, Mn, Co, and Cr, a comparison of their relative intensities in the two spectra shows that they cannot reasonably be ascribed to the presence of such metals as impurities in the vanadium, but must be accepted as genuine lines of both metals, so far as the dispersion employed enables us to form an opinion. These are given in order of wave-length in the following table:—

[redacted]

Coincidences of Vanadium Lines with Lines of other Metals.

λ (Kensington).	Origin of coincident line.	Int. in V.	Int. of coincident line.	λ (Kensington).	Origin of coincident line.	Int. in V.	Int. of coincident line.
3894·16	Cr	4–5	4	4427·49	Fe	4	7
3913·71	Fe	1	2–3	67·09	Co	2–3	4
77·88	Fe	2	4–5	97·00	Cr	4	5–6
4052·60	Mn	1	4	4514·36	Fe	4	<1
68·16	Fe | Mn	2–3	3 | 5	17·75	Fe	3	1
70·94	Fe	2–3	2–3	25·33	Fe	3–4	4
83·07	Mn	3–4	7	34·08	Co	3	4
90·05	Mn	1	4	49·79	Co	6	5
90·74	Mn	8	1–2	4603·15	Fe	1	5
4224·36	Fe	3–4	3	26·66	Mn	4–5	5
34·18	Co	5–6	1–2	54·80	Fe	1	4
4408·35	Mn	5	4	4709·93	Mn	2–3	7
15·25	Fe	3	10	4871·50	Fe	2	6

"A Preliminary Account of the Development of the Free-swimming Nauplius of *Leptodora hyalina* (Lillj.)." By Ernest Warren, D.Sc., Assistant Professor of Zoology, University College, London. Communicated by Professor Weldon, F.R.S. Received February 4,—Read February 28, 1901.

Leptodora appears to be a primitive daphnid in retaining a long, markedly segmented abdomen, and for this reason it seemed likely that an investigation on the development of the winter-generation might throw some light on the vexed questions in Crustacean development. It was more particularly desired to ascertain whether any vestige of a cœlom occurred, and that if so, whether any remnant of it persists in the adult. With this object in view, it was necessary to inquire into the origin of the genital cells and of the antennary and maxillary glands.

In April, 1898, Professor Hickson obtained a few nauplii from Lake Bassenthwaite, Cumberland, and later in the year a large number of adults. This material was most generously placed at my disposal by Professor Weldon, and I wish to express to him my sincere thanks.

The material was insufficient for my purpose; and in the following spring I visited Lake Bassenthwaite to try to obtain fresh material, but I met with very little success. Last spring, however, sufficient material was obtained to continue the investigation.* The preserving reagent employed was Flemming's solution (strong formula).

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* I am indebted to the Royal Society for a Government Grant in connection with obtaining this material.

Fig. 1 represents the youngest nauplius tow-netted. It should be noticed that Ant. 1 is not a swimming appendage. The posterior end of the body is rounded, as the characteristic caudal forks are not yet developed. The mandible already possesses the rudiment of a biting blade. The first and second maxillæ are represented by the merest rudiments. Thoracic legs 1–6 are present as conspicuous buds. The lower lip is not yet developed.

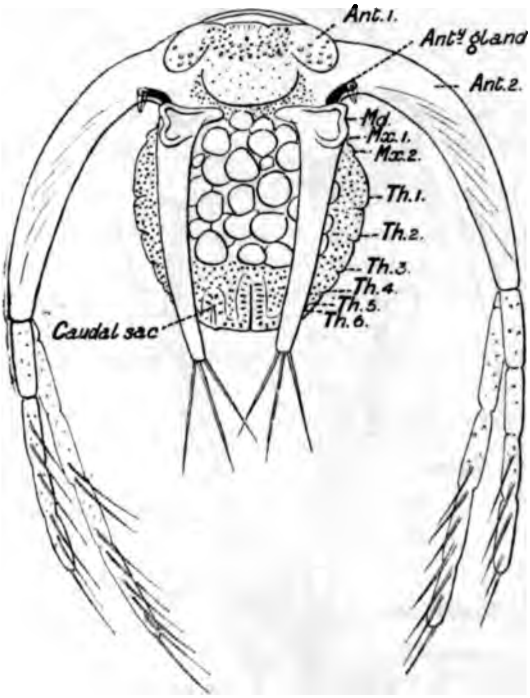

Fig. 1.—Ventral view of the youngest nauplius. Ant. 2 is relatively much longer than at any other period of life. × 110 diameters.

On each side of the proctodæum there is a little ectodermal pit secreting a cuticular (?) substance. In an older nauplius, a prominent spine projects out of these sacs, which are then situated at the ends of the caudal forks (fig. 2). These ectodermal pits bear a strong resemblance to the setal sacs of a Chætopod.

At this time the mesenteron has an incomplete lumen, but both the stomodæum and proctodæum have reached it.

Above the gut there is a large collection of yolk-masses surrounded by a membrane of flattened yolk-digesting cells which send processes inwards between the yolk-masses. There is no yolk-sac duct.

In an older nauplius the biting blades of the mandibles are more

[redacted]

developed, and at every future moult the swimming ramus gradually becomes shorter. Relatively the mandibles travel somewhat forwards, so as to be situated nearer to the mouth. The rudiment of the second maxilla is just visible, that of the first maxilla is only seen in a horizontal section of the embryo.

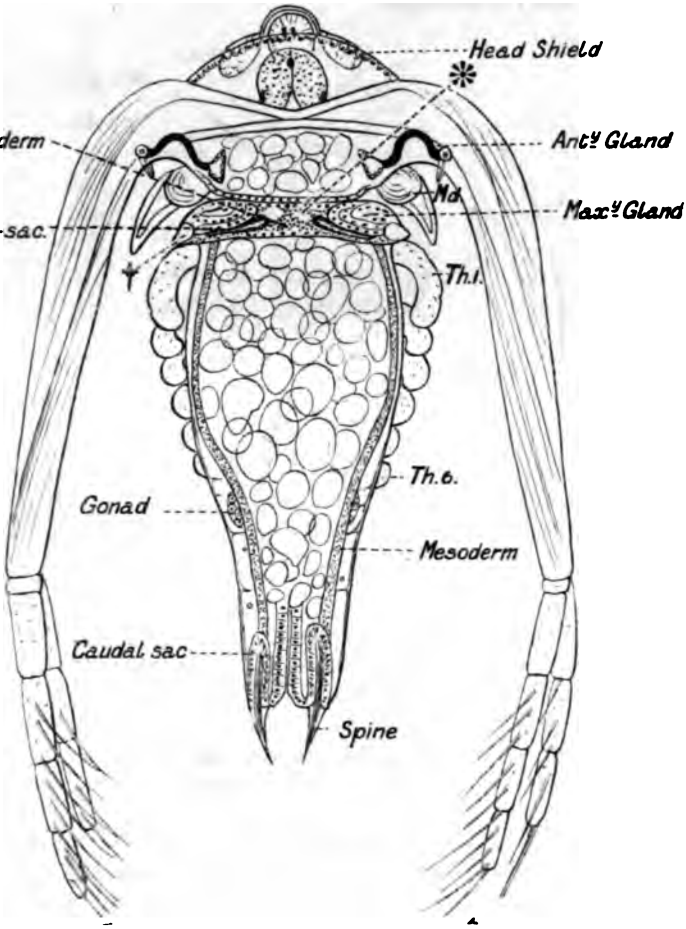

FIG. 2.—Dorsal view of metanauplius. The embryonic carapace, formed by the fusion of the two dorso-lateral swellings, is gradually extending backwards over the thorax. × 110 diameters.

In these nauplii, I met with a remarkable instance of unequal development in the different organs. Several nauplii which were presumably older than those with a rounded posterior end (since they were somewhat larger and possessed caudal forks) were, nevertheless, much less advanced in the development of the internal organs. The subject of variation *in time*, and the partial independence of the different organs in development, would seem to be well worthy of more attention than has been paid to it.

The lower lip appears late; it seems to originate from paired rudiments; but the slight papillæ representing the maxillæ do not enter into its formation, for they flatten out and disappear.

The characteristic shape of the adult thorax, whereby the ventral surface bearing the legs comes to be situated nearly at a right angle to the head, is not assumed, as we might have expected, until the adult structure is attained.

Even in the quite young nauplius the ectoderm over the head is curiously modified; the cells are large and possibly glandular or excretory in nature. They possess large nuclei towards their bases and are much taller than the ordinary ectoderm cells. In the adult animal, these cells form a large patch over the head, the "Kopfschild" of Weismann (fig. 2). I have not detected anything else of the nature of a "dorsal organ," and I suggest that the above-described structure represents it.

As the youngest nauplius captured was a free-swimming creature with many muscles, it might have been anticipated that anything of the nature of segmental cœlom pouches, if present, would be much obliterated. Most of the mesoderm consists of a fairly uniform sheet of cells lying on each side of the gut. Posteriorly the mesoderm is more abundant and compact. The muscles of the thoracic legs are formed from the base of the mesoderm bands (fig. 3, B). The cells

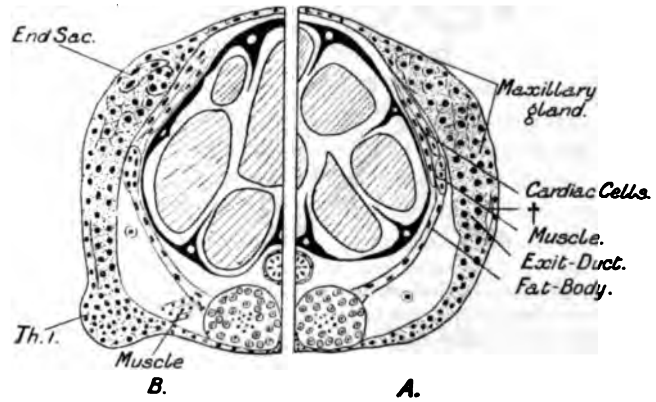

FIG. 3.—A. Cross-section of a young nauplius just behind the rudiment of 2nd maxilla. The exit-duct of the maxillary gland can be seen passing up into the dorso-lateral swelling.

B. Cross-section of a slightly older nauplius; it is a little posterior to A. Differentiation of end-sac and part of glandular tube can be seen in the dorso-lateral swelling.

which will form muscle, are considerably larger than the rest of the mesoderm cells and stain more deeply; they become arranged in parallel cords. By the arrangement of the primitive muscle, the segmentation of the abdomen is marked out quite early in the life of the nauplius.

The cells which will form the heart, can be distinguished at an early period. In the thoracic region, the dorsal portion of the mesoderm bands consists of two closely applied layers of flattened cells (fig. 3). These layers gradually grow up over the yolk-sac, and those of one side meet their fellows of the other side in the mid-dorsal line. Separation of the two layers now occurs, and the sac thus formed is the heart (figs. 4 and 5). The pericardial space originates by two processes—(1) the gradual separation of the ectoderm from the heart-sac, and (2) the disintegration of the deeper layers of this thick ectoderm (figs. 2, 4, 5, *). There appears to be a definite floor to the pericardial space, consisting of flattened cells continuous with those of the heart (fig. 5, B), but the roof would seem to be simply the general dorsal ectoderm of the thorax.

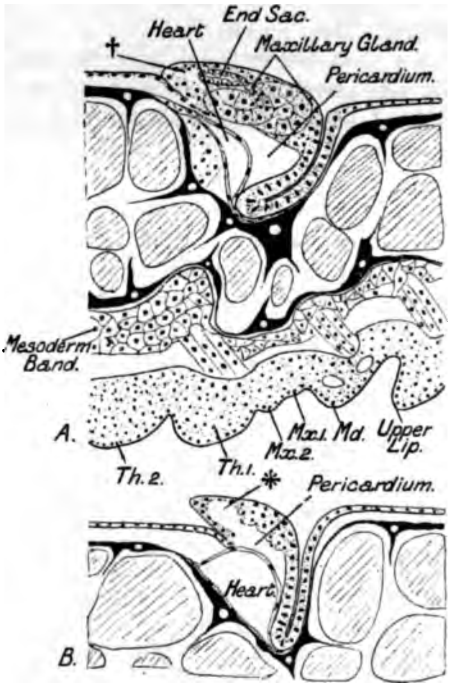

FIG. 4.—A. Longitudinal vertical section through the dorso-lateral swelling; it is taken at some distance from the mid-dorsal line (see fig. 2).
B. Similar section taken close to the mid-dorsal line.

The blood-corpuscles are large and frequently spherical. I think it is probable that they are budded off from the compact mesoderm at the posterior end of the body, but it is very difficult to be certain about their origin.

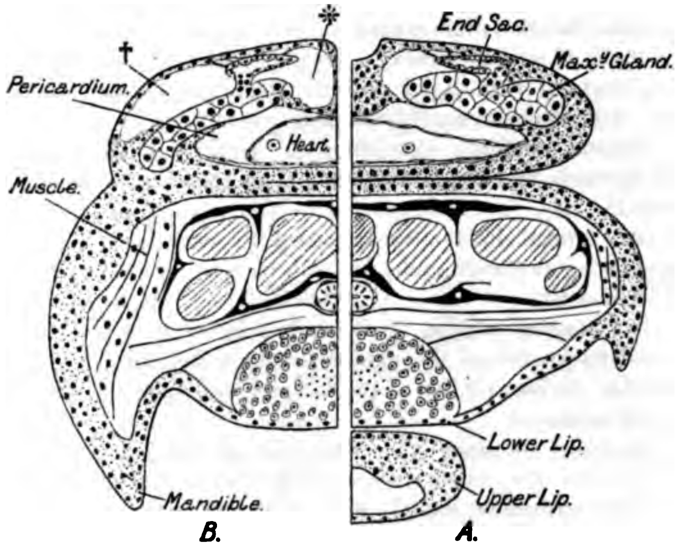

FIG. 5.—A. Obliquely transverse section through the dorso-lateral swelling of a metanauplius. The maxillary gland has become sharply differentiated from the imbedding ectoderm.

B. Similar section through an older metanauplius; the space marked † has developed. The space * will soon become continuous with the space around the heart.

In the earliest nauplius obtained the gonad is quite definitely formed. Without doubt the generative cells originate exceedingly early, probably they could have been distinguished in the blastosphere stage as Grobben has described in the case of Moina. The ovary becomes surrounded by a layer of mesoderm, and the generative duct seems to be solely mesodermal. The main mass of the mesodermal bands becomes converted into the characteristic double-layered fat-body lying on each side of the gut.

The origin of the antennary and maxillary glands has very considerable morphological interest, and I have devoted much care in endeavouring to elucidate it. The development of the maxillary gland will be described first.

On the lateral sides of the body of my youngest nauplius, just posterior to the vertical plane passing through the second maxilla, the ectoderm is several layers thick. This thickening is more pronounced dorsally, and on surface view of the nauplius we can see a distinct dorso-lateral swelling on each side. In the lateral thickening of ectoderm, a band of cells passes nearly vertically downwards to the papilla representing the second maxilla. The band will become the exit-duct of the future gland; the band extends upwards into the dorso-lateral swellings mentioned above (fig. 3, A). It is out of these swellings that the rest of the gland becomes differentiated.

Fig. 3. B is a cross-section a little posterior to A, and is taken from a nauplius very slightly older. Here the end-sac can be seen vaguely marked out from the surrounding ectoderm.

The lateral swellings containing the developing glands gradually extend upwards, and after a time they meet together in the mid-dorsal line (fig. 2).

There is formed simultaneously a deep transverse groove in front of the upgrowing swellings, and a less conspicuous groove occurs behind (fig. 4, A and B).

The overhanging portion of the embyonic carapace (fig. 4, B) will be carried backwards as the animal develops, and will, in the female, expand into the free portion of the carapace overhanging the first two abdominal segments.

As the fused swellings (the embryonic carapace) gradually extend backwards over the dorsal surface of the thorax, the maxillary gland is drawn out with them into the position and shape seen in the adult.

At the same time there is a general expansion of the parts; the maxillary gland begins to separate itself from the surrounding ectoderm (figs. 2, 3, 4, and 5, †), and the space around the heart gradually increases. There is also a certain amount of disintegration of the ectoderm where the dorso-lateral swellings met in the middle-line. The spaces marked * in figs. 2, 4 and 5 are thus formed, and ultimately they become continuous with the space around the heart.

We have already seen that this pericardial space has a definite floor of flat mesoderm cells, but the roof would seem to be simply the ectoderm of the body-wall. The exit-duct with the external opening travels upwards into a dorso-lateral position, so that in the adult it is nearly horizontal.

In the material at my disposal it is not possible to decide for certain whether the antennary gland also arises from the ectoderm, but it is highly probable that it does so.

Fig. 6. A, B, C represent three stages in the growth of this structure. The nuclei in the intracellular duct, and connected ectoderm have been carefully put in the diagrams from actual sections, and their arrangement certainly gives the impression that the duct should be regarded as an ingrowth of ectoderm.

Fig. A represents the condition observed in the youngest nauplius. The end-sac consists of fairly large cells which are not very different in character from the cells forming the intracellular duct. At a slightly later date (fig. B), the cells of the end-sac have become smaller, and there is a more distinct basement membrane; they greatly resemble the cells of the end-sac of the maxillary gland. In an older nauplius (fig. C) the intracellular duct begins to disintegrate, but the end-sac remains adhering to the dorsal ectoderm for a very considerable time; ultimately, however, it disappears.

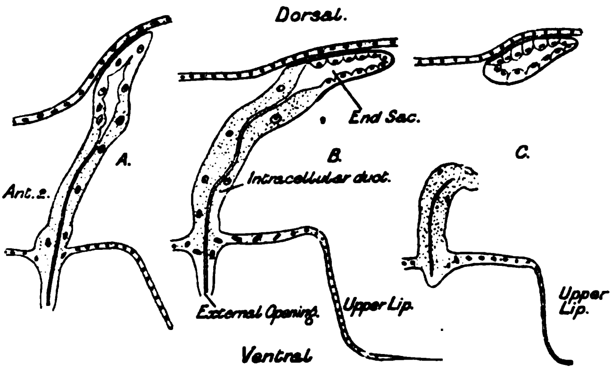

FIG. 6.—A. The antennary gland seen in transverse section through the youngest nauplius at the level of the 2nd antenna.

B. The same gland seen in a slightly older nauplius. The cells of the end-sac are smaller, and there is a more definite basement membrane.

C. The same in an advanced metanauplius. The intracellular duct no longer communicates with the end-sac.

According to these observations, the maxillary and possibly the antennary glands are purely ectodermal in origin, and the end-sac is to be looked upon as merely a terminal thin-walled dilatation of the glandular tube. At one time I believed that mesoderm crept up behind the maxillary gland (see fig. 4, A), and formed the end-sac, but renewed observation convinced me that it is formed out of the ectoderm in *direct continuity* with the glandular tube (see fig. 3, B).

It appears from recent observations that the nephridia of Chætopods should be regarded as ectodermal tubes which generally open into a cœlom, and sometimes may come into connection with a generative funnel. In a trochosphere (*e.g.*, in that of Polygordius), the "head-kidney" is probably budded off from the ectoderm, and since there is no cœlom into which it can open, the tube terminates in a slightly dilated "flame-cell."

Although cœlom sacs are doubtless formed in the development of some crustacea, yet I altogether failed to discover any traces of them in the youngest nauplius of Leptodora that I have examined; and even in those cases where they have been described, it does not follow that the antennary and maxillary glands enter into relationship with these transitory cœlom spaces.

[redacted]

If an ectodermal origin of the antennary and maxillary glands be confirmed in crustacea generally, then we should be led to regard these structures as nephridia, which have lost their primitive connection with a cœlom, and the end-sac would be looked upon as equivalent to the "flame-cell" of a typical intracellular nephridium.

The above preliminary account, which has omitted all reference to the nervous system and sense-organs, is merely a summary of the results already obtained. I hope in a future publication to give a full account, containing careful drawings with the camera lucida.

"The Growth of Magnetism in Iron under Alternating Magnetic Force."

By ERNEST WILSON. Communicated by Professor J. M. THOMSON, F.R.S.

Received February 25,—Read March 28, 1901.

The object of this paper is to investigate the growth of magnetism in an iron cylinder when the magnetising force is alternating. The shielding effect of induced currents in plates of iron has been dealt with theoretically by Professor J. J. Thomson,[*] and Professor J. A. Ewing.[†] The subject has also been dealt with experimentally in the case of an iron cylinder, 4 inches diameter,[‡] with alternating magnetising force and with simple reversal of the magnetising force. A cylinder, 12 inches diameter, has been experimented upon with simple reversal of magnetising force,[§] and the shielding effect of induced currents studied. As the exploring coils enclosing elements of the cross-section of this 12-inch magnet are well suited to give the average induction density at four mean radii, the author thought the subject worth further investigation with regard to alternate currents. The magnet is of cast steel, and is shown in sectional elevation in fig. 1. A section of the 12-inch core on the line AA is given in fig. 2. Wires have been threaded through the holes drilled in the plane AA, enclosing the areas numbered 1, 2, 3, 4 (fig. 2), and another coil (No. 5) surrounds the core. A D'Arsonval galvanometer was placed in each of these five circuits with an adjustable resistance to control the maximum deflection. The deflections of the needles of the five galvanometers were noted simultaneously every four seconds, and were ultimately plotted in terms of time. The magnetising current in the copper coil of the magnet was observed simultaneously with the above on a Weston ampere meter. The current was made to alternate

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[*] 'The Electrician,' vol. 28, p. 599.

[†] 'The Electrician, vol. 28 p. 631.

[‡] Hopkinson and Wilson, 'Phil. Trans.' A, vol. 186 (1895), pp. 93–121.

[§] Hopkinson and Wilson, 'Journal of the Inst. Elec. Eng.,' vol. 24, p. 195.

by means of a liquid ($CuSO_4$ dil.) reverser consisting of two oppositely fixed copper plates, each embracing a quadrant of a circle, and two similarly shaped copper plates fixed to a vertical spindle and capable

FIG. 1.

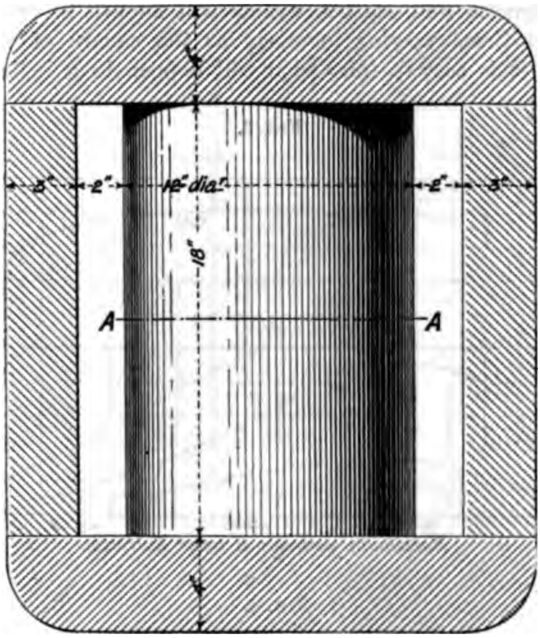
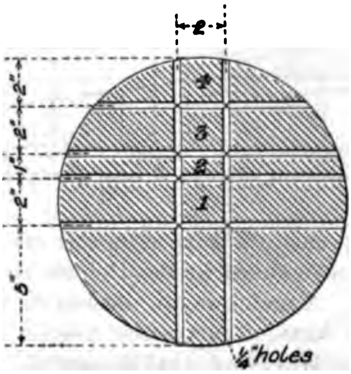


FIG. 2.



of rotating concentrically within the fixed plates. The operator at this liquid reverser counted seconds aloud whilst listening to the ticks of a seconds pendulum. In this way the epoch for all the observations could be noted. The speed of rotation was varied, from one revolution in ten to one revolution in two and a half minutes.

The electromotive force curves have been integrated, and therefrom the maximum average induction per sq. cm. of the area considered has been obtained. The data are set forth in the appended table. Since similar magnetic and electric events will happen in different sized cylinders at times varying inversely as the square of their linear dimensions, it is easy to infer what will happen in a cylinder 1 mm. diameter. Similar events will happen in this wire at 150 periods per second, as have been observed in the 12-inch core with a periodic time of ten minutes. A useful way of illustrating the results obtained is to express in the form of curves the relation between the maximum average B over Area No. 4, that is, near the surface of the core. and the percentage amounts by which this maximum has to be reduced to give (1) the maximum average over Area No. 1, and (2) the maximum average over the whole core as given by coil No. 5. This is done in figs. 3 and 4, in which the number on each curve refers to the

FIG. 3.

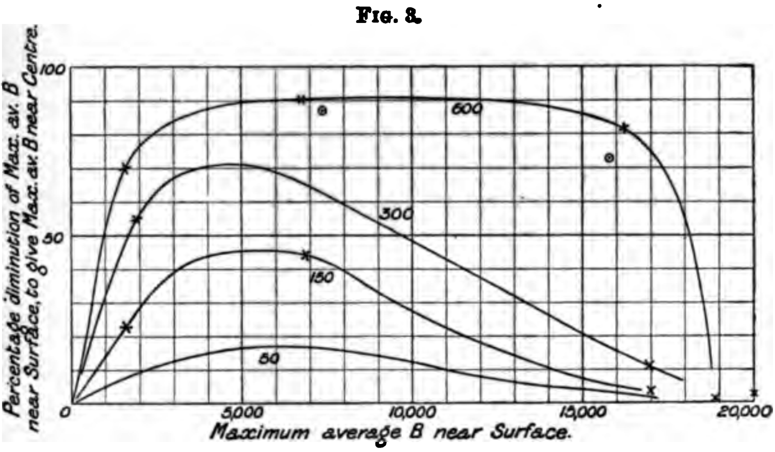
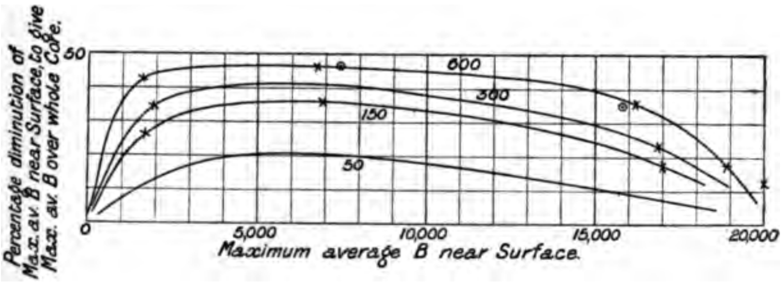


FIG. 4.



frequency with a 1 mm. wire. Figs. 5 and 6 show the relation between the frequency in complete periods per second for a 1 mm. wire and the same two quantities respectively. Since a plate, with regard to

FIG. 5.

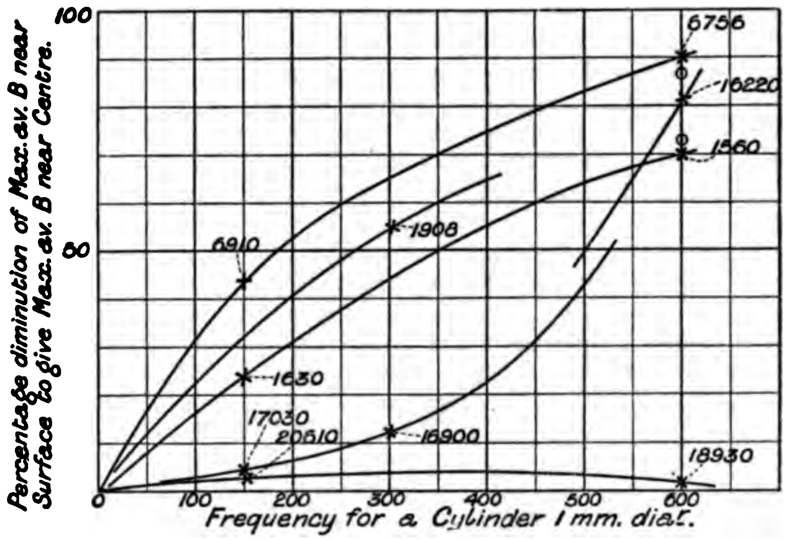
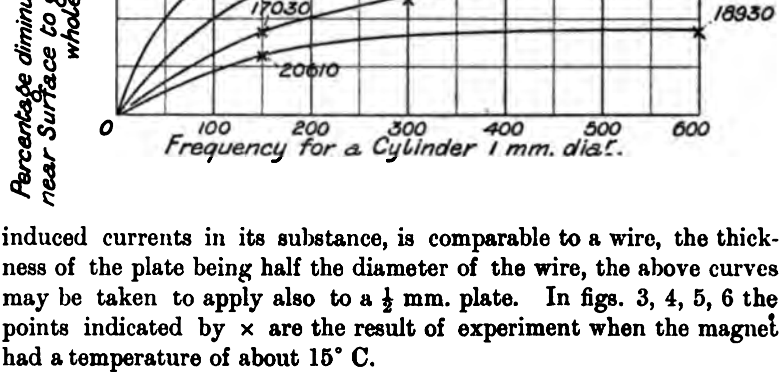


FIG. 6.



induced currents in its substance, is comparable to a wire, the thickness of the plate being half the diameter of the wire, the above curves may be taken to apply also to a ½ mm. plate. In figs. 3, 4, 5, 6 the points indicated by × are the result of experiment when the magnet had a temperature of about 15° C.

Suppose a transformer core to be built up of 1 mm. wires, or ½ mm. plates, insulated from one another, the transformer being in action with no currents in its secondary circuit. The reaction of the core upon the primary or magnetising coil will be the rate of change of the average induction over the whole core. The average induction per sq. cm. of a particular wire or plate will differ from the induction per sq. cm. at the surface of such wire or plate by an amount varying with the frequency and with the value of B at the surface. For high and low values of the surface B and a given frequency the average over the whole wire or plate differs less from the maximum at the surface than for intermediate values of the surface B. The relation between the permeability of the iron and the rate of propagation of magnetism in the iron has been explained in the case of simple reversals,[*] and agrees with what we have just observed. When the limits of B are small, that is, the permeability is small, the magnetism is propagated rapidly. For intermediate values of the limits of B, that is, when the average permeability is large, the rate of propagation is small. With the high limits of B the average permeability is small and the magnetism is propagated more rapidly. Setting aside the subject of magnetic viscosity, we should expect the average B over the whole wire or plate to be equal to the surface B if these induced currents did not exist. The curves show that for a given frequency there is an effect which increases the extent to which equalisation of the induction density over the core may be carried according as the maximum limits of B at the surface are on the lower or higher part of the curve of induction of the material. The dissipation of energy, due to magnetic hysteresis and induced currents, will likewise be affected since uniform distribution gives minimum dissipation for the same maximum average induction over the whole core.

Not only have we to consider the maximum value of the induction density at different parts of the core, but the phase of such induction density. It is not necessary to publish all the curves obtained, but as an example one might contrast in figs. 7 and 8 the curves of E.M.F. obtained with periodic times of 10·3 and 2·6 minutes for about the same maximum magnetising force, namely, 9·6 and 9·5. In figs. 7 and 8 the E.M.F. curves are plotted to a scale giving C.G.S. units per sq. cm. of the area embraced by the respective coils, the curve number corresponding with the coil number in fig. 2. With 10 minutes' periodic time the induction is practically reversed over the whole core by the time the current has attained its maximum value; whereas with 2·6 minutes' periodic time the current is again zero when the innermost coil (No. 1) is experiencing its maximum E.M.F. In the first case nearly the whole of the change for each coil aids the average

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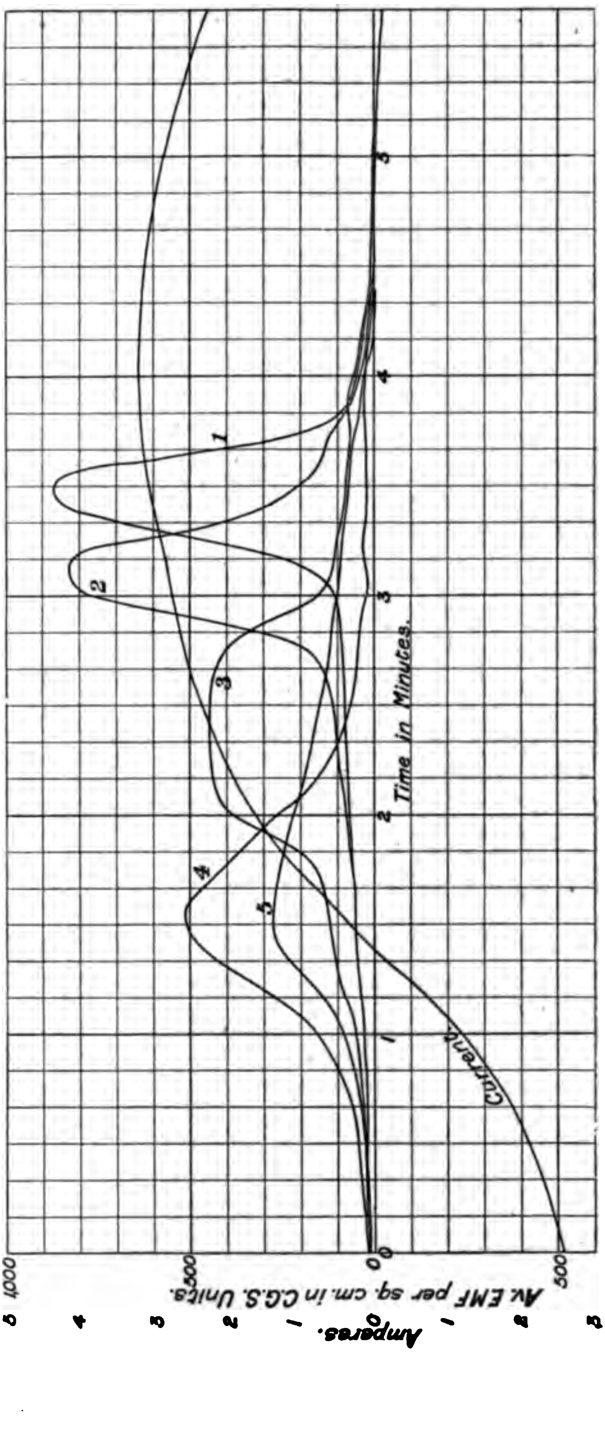
[*] Hopkinson and Wilson, 'Journal of the Inst. Elec. Eng.,' vol. 24, p. 195.

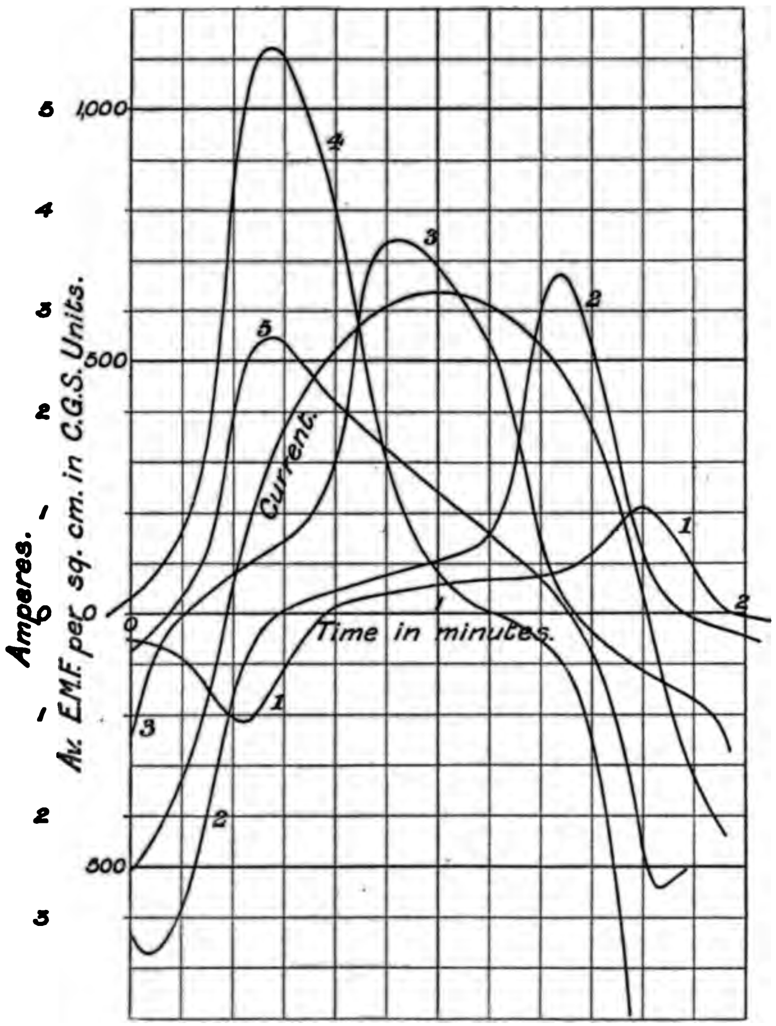
FIG. 7.


Time in Minutes.
0
1
2
3
4
5
Av. EMF per sq. cm. in C.G.S. Units.
1000
500
0
500
Amperes.
5
4
3
2
1
0
1
2
3
Current
1
2
3
4
5

(No. 5) E.M.F. In the second case the areas inclosed by Nos. 1 and 2 coils oppose, and the average suffers accordingly.

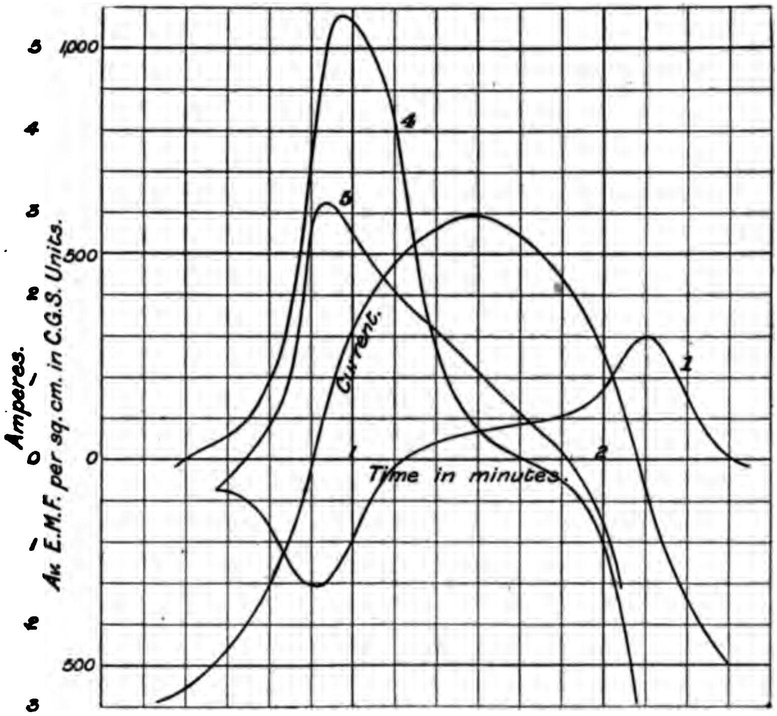
It is of interest to see what effect raising the temperature of the magnet would have upon these induced currents. The magnet was heated by placing Fletcher gas furnaces around it. The heat was applied for about 1½ hours, and the magnet allowed to cool. The electrical resistance of the No. 1 coil was measured, and when it

FIG. 8.



became steady, indicating a temperature of about 53° C., two sets of curves were taken. The points obtained with the heated magnet are indicated by ⊙ in figs. 3, 4, 5, 6. In fig. 9 the curves obtained at

FIG. 9.



53° C. with a maximum magnetising force H of 8·85, and periodic time 2·6 minutes, are given in order to enable a comparison to be made with fig. 8. It will be seen that coil No. 1 has an E.M.F. somewhat retarded at the higher temperature. The E.M.F. of this coil also suffers retardation of phase in the experiment with the lower force 2·85, when the magnet is at the higher temperature.

Heating the magnet has had the effect of increasing the maximum average value of B at the centre for the same frequency and slightly smaller magnetising force of the same wave-form. The relation between the surface density (No. 4 coil) and the average obtained from coil No. 5 remains practically the same. In this connection it should be remembered that for the same average over the whole core, a considerable increase in the induction density at the centre is compensated by a small decrease at the surface. It appears, then, that raising the temperature of the magnet tends to equalise the maximum

Coil.	Average radius in cms.	Maximum average Induction per sq. cm. in C.G.S. units.											
		Temperature of Magnet about 15° C.										Temperature of magnet about 53° C.	
1	0	1,260	863	472	3,847	653	16,460	15,020	3,010	20,000	18,800	951	4,305
		874	*600*	*328*	*2,670*	*474*	*11,400*	*10,400*	*2,090*	*13,880*	*13,050*	*660*	*2,990*
2	3·97	—	—	—	5,555	1,040	18,200	17,050	7,950	22,000	21,100	—	—
					2,640	*495*	*8,660*	*8,120*	*3,780*	*10,500*	*10,050*		
3	6·72	—	—	—	6,710	2,520	19,110	17,900	13,930	21,900	20,100	—	—
					4,660	*1,750*	*13,300*	*12,400*	*9,670*	*15,200*	*14,000*		
4	12·7	1,630	1,908	1,560	6,910	6,756	17,030	16,900	16,220	20,610	18,930	7,330	15,780
		1,271	*1,488*	*1,217*	*5,390*	*5,270*	*13,280*	*13,200*	*12,650*	*16,080*	*14,770*	*5.720*	*12,310*
5	—	1,200	1,260	884	5,085	3,617	14,140	13,020	10,420	17,870	15,500	3,910	10,240
Periodic time in minutes........		10·3	5·2	2·6	10·3	2·6	10·3	5·1	2 6	10 3	2 6	2·6	2·6
Max. H due to magnetising current in copper coils.......		1·1	1·1	1·1	2·82	2·88	9·6	9·45	9·51	16·7	16·9	2·85	8·85
Frequency for a wire 1 mm. diameter.....................		150	300	600	150	600	150	300	600	150	600	600	600
Percentage diminution of max. av. B in Coil 4 to give max. av. B over whole area—Coil 5....		26 *5·6*	34 *15·3*	43 *27·4*	36 *5·7*	46·5 *31·7*	17 *−6·5*	23 *1·4*	36 *17·6*	13 *−11*	18 *−4·9*	46·7 *31·6*	35 *16·8*
Percentage diminution of max. av. B in Coil 4 to give max. av. B at centre of core—Coil 1...		23 *31·2*	55 *59·7*	70 *73·1*	44 *50·5*	90 *91*	3·3 *14·2*	11 *21*	81 *83·5*	3·0 *13·7*	0·7 *11·6*	87 *88·4*	72·7 *75·7*
							Fig. 7.		Fig. 8.				Fig. 9.

induction density over its section. On account of the increased lag of phase of induction as the centre is approached, the maximum average over the whole core is not materially altered for the same surface density. The force due to the current in the magnetising coils is smaller at 53° C. for the same maximum average induction density over the whole core. For a given permeability and hysteresis loss the higher the specific resistance and temperature coefficient the better.

It should be mentioned that the potential difference employed in these experiments was 200 volts, the excess over the magnet and liquid reverser being taken up by non-inductive resistance. The area taken for each coil is the actual area of iron in the plane of section, fig. 2. The areas taken for coils 1, 2, 3, and 4 are 19·8, 8·465, 19·8, and 21·16 sq. cm. respectively. If, instead of these, we take the areas bounded by the centre lines of the ¼-inch holes, the diminution of induction density would be 30·6, 52·4, 30·6, and 22 per cent. respectively. The true correction will not alter the general conclusions arrived at in the paper, and is a function of the permeability of the iron. The figures in the table in italics are the result of taking the increased areas, so that a comparison can be made. The D'Arsonval galvanometers used have slightly different dead-beatness. The least and most dead-beat instruments were placed in series in the No. 1 circuit, when the changes of E.M.F. were most rapid. The instruments gave the same result within the limits of error in observation. A variable still to be dealt with is the wave-form of the magnetising currents.

I wish to express my thanks to Mr. Wm. Marden for the assistance he has given me in the work connected with this paper. Mr. F. S. Robertson, Mr. Nunes, and Mr. Browne have also helped me. To these gentlemen I tender my thanks. I have also to thank Messrs. Elliott Bros. for the loan of three out of the five D'Arsonval galvanometers used in the experiments. The experiments were made at King's College, London.

[redacted]

"On the Electrical Conductivity of Air and Salt Vapours."

By Harold A. Wilson, D.Sc., M.Sc., B.A., Allen Scholar, Cavendish Laboratory, Cambridge.

Communicated by Professor J. J. Thomson, F.R.S. Received March 14,—Read March 28, 1901.

(Abstract.)

The experiments described in this paper were undertaken with the object of obtaining information on the variation of the conductivity of air and of salt vapours with change of temperature, and on the maximum current which a definite amount of salt in the form of vapour can carry. They are a continuation of the two researches* on the same subject published in 1899.

In the paper on the Electrical Conductivity and Luminosity of Flames (*loc. cit.*) some observations on the variation of the conductivity with the temperature at different heights in the flame are given. They indicate a rapid increase in the conductivity with rise of temperature.

The method employed in the experiments described in the present paper was the following:—

A current of air containing a small amount of a salt solution in suspension in the form of spray was passed through a platinum tube heated in a gas furnace; this tube served as one electrode, and the other was fixed along its axis. The temperature of the tube was measured by means of a platinum platinum-rhodium thermo-couple, and the amount of salt passing through the tube was estimated by collecting the spray in a glass-wool plug.

From the temperature variation of the conductivity the energy required to produce the ionization can be calculated, and this compared with the energy required to ionize bodies in solutions.

Since the publication of the researches just referred to, several papers† on the conductivity of salt vapours in flames by Dr. E. Marx have appeared. The first part of the present paper contains a discussion of some of Marx's conclusions, which bear on my previous work.

The rest of the paper is divided into the following sections:—

(1.) Description of the apparatus used.

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* "The Electrical Conductivity and Luminosity of Flames containing Vaporised Salts," by A. Smithells, H. M. Dawson, and H. A. Wilson, 'Phil. Trans.,' A, 1899; "On the Electrical Conductivity of Flames containing Salt Vapours," by Harold A. Wilson, 'Phil. Trans.,' A, 1899.

† "Ueber den Potentialfall und die Dissociation in Flammengasen," Von Erich Marx, 'Gesellschaft der Wissenschaften zu Göttingen,' 1900, heft 1; 'Annalen der Physik,' 1900, No. 8. "Ueber das Hall'sche Phänomen in Flammengasen," Von E. Marx, 'Annalen der Physik,' 1900, No. 8.

(2.) Variation of the current with the E.M.F.
(3.) Variation of the current through air with the temperature.
(4.) Variation of the current through salt vapours with the temperature.
(5.) Summary of results.

The relation between the current and E.M.F. in air was found to depend very much on the direction of the current. When the outer electrode was negative the current attained a saturation value with an E.M.F. of about 200 volts, but when the outer tube was positive it increased rapidly with the current, even with an E.M.F. of 800 volts, so that a much greater E.M.F. would be necessary to produce saturation, that is, assuming that saturation can be produced at all.

With salt vapours the relation between the current and E.M.F. was not much affected by reversing the current. The current was always greater when the outer tube was negative, the reverse being the case with air alone. At low temperatures the current attained a saturation value, but above 1000° C. it was found to increase more nearly proportionally to the E.M.F.

The variation of the current at constant E.M.F. with the temperature for air was found to be approximately capable of being represented by a formula of the type $C = A\theta^n$, where C is the current, θ the absolute temperature, and A and n constants. The constant n depends on the E.M.F. used. With 240 volts it was 17, and with 40 volts 13. The current, therefore, does not begin suddenly when the temperature is raised, but always increases regularly with the temperature, so that the lowest temperature at which the current can be detected depends entirely on the sensitiveness of the galvanometer.

The energy required to ionize 1 gramme molecular weight of air was estimated by supposing that the fraction of the gas dissociated into ions is proportional to the current at small E.M.F's. By means of the ordinary thermo-dynamical formula giving the variation of the dissociation with the temperature, the energy in question can then be obtained. The result for air is 60,000 calories between 1000° and 1300° C. This amount of energy is of the same order of magnitude as the energy set free when H and OH ions combine to form water in a solution.

The relation between the current and temperature for salt vapours was found to be rather complicated. With KI, using an E.M.F. of 800 volts, the current had the following values ($1 = 10^{-4}$ ampere):—

Temperature ……	500°	600°	700°	800°	900°	1000°	1100°	1150°	1200°	1300°
Current …………	0·7	1·8	3·0	4·0	4·5	4·0	3·5	3·6	7·0	7·0

[redacted]

Using an E.M.F. of 100 volts, the following values of the current were obtained ($1 = 10^{-5}$ ampere):—

Temperature	300°	400°	500°	600°	700°	800°
Current	0·2	1·9	5·1	5·4	5·5	5·5

Temperature	900°	1000°	1100°	1200°	1300°
Current	5·5	5·3	6·8	8·2	9·2

Thus the current has a maximum value near 900° C., and rises very rapidly near 1150°. Similar results were obtained with other salts.

The energy required to ionize 1 gramme molecular weight of KI at about 300° C. was estimated to be 15,000 calories in the same way as was done for air.

The maximum current carried by the salt vapour (at 1300° with 800 volts) was found to be nearly equal to that required to electrolyse the same amount of salt in a solution.

This fact must be regarded as considerable evidence in favour of the view that the ions are of the same nature in the two cases.

"Further Observations on Nova Persei, No. 2." By Sir NORMAN LOCKYER, K.C.B., F.R.S. Received and Read March 28, 1901.

In continuation of two previous papers, I now bring the observations of the Nova made at Kensington to midnight of March 25. Since the last paper* of March 7th, estimates of the magnitude of the Nova have been made on ten evenings, visual observations of the spectrum on eight evenings, and photographs of the spectrum on four evenings up to the evening of the 25th.

In consequence of the greater faintness of the Nova, the 6-inch prismatic camera has not been utilised, but the 10-inch refractor to which it is attached has been used for eye observations of the spectrum with a McClean spectroscope.

With the 30-inch reflector four photographs have been secured on the evenings of the 6th, 10th, 24th, and 25th by Dr. Lockyer, and with the 9-inch prismatic reflector seven photographs on the nights of 10th, 21st, and 25th by Messrs. Butler and Hodgson.

Change of Brightness.

Since March 5th the magnitude of the star has been gradually decreasing, but between the nights of the 24th and 25th the light of

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* *Supra*, p. 142.

the Nova decreased very suddenly, dropping from 4·2 to 5·5 in twenty-four hours, and becoming only just visible as a naked-eye star.

The following gives a summary of the eye estimates made by (1) Dr. Lockyer, (2) Mr. Fowler, and (3) Mr. Butler:—

	(1.)	(2.)	(3.)
March 5......	2·7	2·7	--
6......	2·9	—	—
9......	—	3·5	3·5
10......	3·7	—	—
11......	—	—	<4·0
12......	—	3·8	—
21......	—	4·0	4·2
22......	—	—	—
23......	4·2	4·2	4·5
24......	4·2	4·2	4·5
25......	5·5	5·5	5·5

Colour.

The colour of the Nova has undergone some distinct changes since the observation on March 5th last, when it was shining with a clarety-red hue. On the 9th and 10th it was observed to be much redder, due probably to the great development of the red C line of hydrogen.

On the 23rd and 24th, the star was noted as yellowish-red, while on the 25th (after the sudden drop in magnitude) it was very red, with, perhaps, a yellow tinge.

The Visual Spectrum.

Since March 5th the spectrum from C to F has become very much fainter, the bright lines of hydrogen being relatively more prominent than they were before; indeed, C and F throughout this period have been the most conspicuous lines, especially the former, while the bright lines λλ 5169, 5018, and 4924, and the line in the yellow near D, were the most prominent of the others.

All these lines have been gradually becoming weaker, but there is an indication that λ 5018* has been brightening relatively to λ 5169.

Accompanying the great diminution in the light of the Nova observed on the evening of the 25th, the spectrum was found to have undergone a great change: the continuous spectrum had practically disappeared, and a line near D (probably helium, D_3) became more distinct. The other lines were hardly visible.

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* The line near this wave-length in later observations is probably the chief nebular line 5007, which accounts for the apparent brightening of 5018.

The Photographic Spectrum.

On March 6th the photographs were very similar to those obtained in the earlier stages, the only apparent difference being in the relative intensity of the bright hydrogen lines as opposed to those having other origins, most of which have been shown to be probably due to iron and calcium. The hydrogen lines have sensibly brightened, while the others have become much feebler.

The photograph of March 10th shows a further dimming of the bright lines other than those of hydrogen.

On March 25th, when the next good photograph was taken, the spectrum had undergone great modifications. The hydrogen lines are still very bright, though they do not show the structure which they did in the photographs taken between February 25th and March 10th. The bright lines other than those of hydrogen, which are seen in the earlier photographs, have now disappeared, and other lines become visible. The continuous spectrum has also greatly diminished.

Approximate determinations of the wave-length of these new lines have been made by Mr. Baxandall by comparison with lines of known wave-length in the spectra of α and ϵ Persei photographed with the same instrument. They are as follows:—

λ

3870. Broad, and merging into Hζ (3889).
4367. Weak.
4472. Not very strong. Probably helium (λ 4471·6).
4565. Weak.
4650. Very strong broad line. Possibly the 465 line of the bright-line stars and the belt stars of Orion.
4690. Moderately strong. Possibly new hydrogen (λ 4687·88) seen in bright-line stars and some Orion stars.
471. Weak. Probably helium (λ 4713).

The hydrogen lines in the spectra are Hζ, Hϵ, Hδ, Hγ, and Hβ.

The lines at λ 3870 and 4650 are perhaps identical with those observed by von Gothard* in the spectrum of Nova Aurigæ after it had become nebular, but associated with these lines in his record is the chief nebular line at 5007, no trace of which is yet visible in the photographs of the spectrum of Nova Persei. On the other hand, Hβ, which is the brightest line in the present spectrum of Nova Persei, does not appear at all in von Gothard's spectrum of Nova Aurigæ.

Characteristics of the Hydrogen Lines.

In my former paper I referred to the structure of the broad bright lines of hydrogen. A more detailed examination of the lines as photo-

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* 'Ast.-Phys. Jour.,' vol. 12, 1893, p. 51.

graphed on several evenings shows that this structure has been undergoing changes.

The annexed figure (fig. 1) gives light curves showing the variation

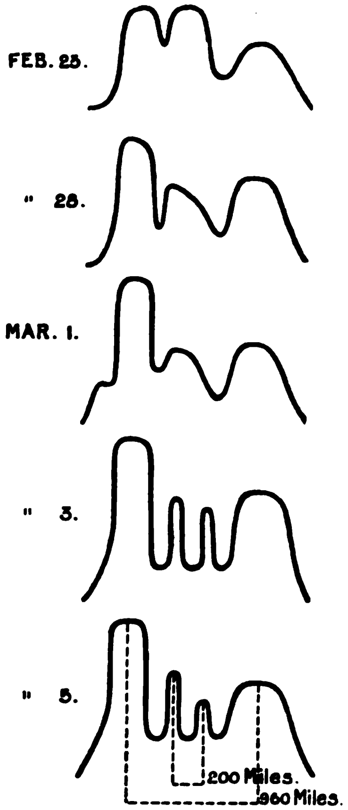

Fig. 1.—Light curve of Hβ (6-inch objective prism).

in the loci of intensity of the line Hβ, as photographed with the 6-inch prismatic camera. These curves were plotted by Messrs. Baxandall and Shaw independently of each other, and I have satisfied myself of their accuracy. It will be seen that on February 25th there were three points of maximum luminosity, the two maxima on the blue side being of equal intensity, and greater than the third on the red side. By March 1 the centre one had been greatly reduced in intensity, and on the 3rd it had been broken up into two portions, thus making four distinct maxima.

Rough measures made on the relative positions of these points of maxima show that the difference of velocity indicated between the two external maxima is nearly 1,000 miles per second, while that between the two inner maxima is 200 per second. We thus have indications of possible rotations or spiral movements of two distinct sets of particles travelling with velocities of 500 and 100 miles per second.

A similar examination of the F and G lines of hydrogen in the photographs obtained with the 30-inch reflector has also been made by Dr. Lockyer, and the light curves for the G line are here illustrated (fig. 2). In this longer series the most important point comes out that

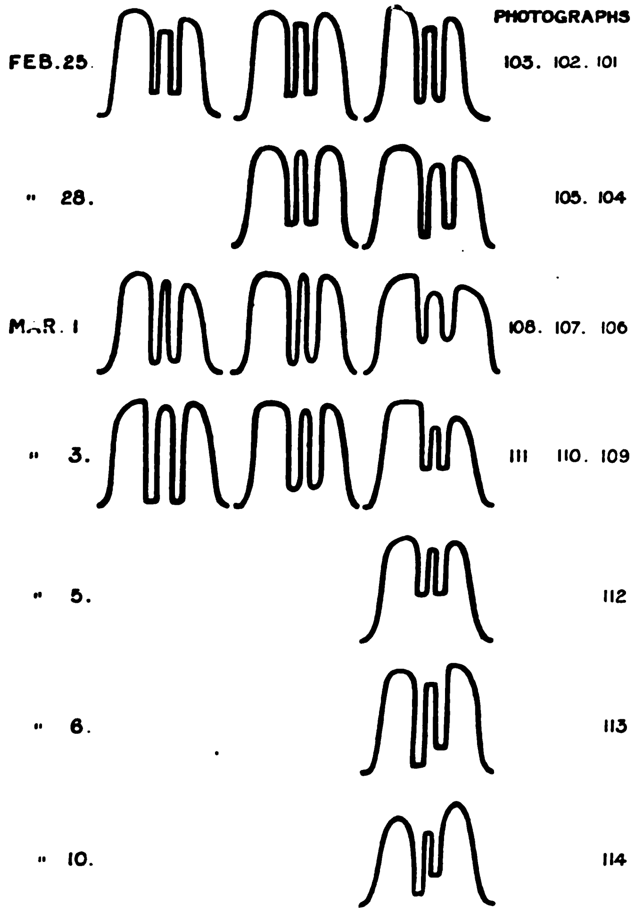

Fig. 2.—Light curve of Hγ (30-inch reflector).

the maximum intensity changes from the more to the less refrangible side of the bright hydrogen line.

The small dispersion given by the 30-inch prevents some of the details recorded by Messrs. Baxandall and Shaw from being seen.

So far as the observations have gone, they strongly support, in my opinion, the view I put forward in 1877 that "new stars" are produced by the clash of meteor-swarms; and they have suggested some further tests of its validity.

We may hope since observations were made at Harvard and Potsdam very near the epoch of maximum brilliancy, that a subsequent complete discussion of the results obtained will very largely increase our knowledge. The interesting question arises whether we may not regard the changes in spectrum as indicating that the very violent intrusion of the denser swarm has been followed by its dissipation, and that its passage has produced movements in the sparser swarm which may eventuate in a subsequent condensation.

My best thanks are due to those I have named for assistance in this inquiry.

"Elastic Solids at Rest or in Motion in a Liquid." By C. CHREE, Sc.D., LL.D., F.R.S. Received November 19,—Read December 13, 1900.

§ 1. The problems dealt with in the present paper are probably of little practical importance; but they seem of considerable interest from the standpoint of dynamical theory. The hard and fast line which it is customary to draw between Rigid Dynamics and Elastic Solids has been discarded, and a more direct insight is thus obtained into the modes of transmission of force in solids.

Let us consider a solid of any homogeneous elastic material, possessed only of such symmetry of shape as will ensure that if it falls under gravity in a liquid, each element will move vertically. Take the origin of rectangular Cartesian co-ordinates at the centre of gravity, the axes of x and y being horizontal, and the axis of z being drawn vertically downwards. At time t let ζ be the depth of the C.G. below a horizontal plane in the liquid, the pressure on which is uniform and equal to Π. The existence of gaseous pressure on the liquid surface would only contribute to Π without modifying the general conditions of the problem.

Consider first the elementary hydrostatical theory, according to which the liquid pressure at any point x, y, z on the surface of the solid acts along the normal, and is equal to

$$\Pi + g\rho'(\zeta + z),$$

where ρ' is the density of the liquid, supposed uniform.

If the solid fall or rise very slowly, and the viscosity of the liquid is very small, the results based on the hydrostatical theory ought to give a close approximation to the truth.

If α, β, γ represent the elastic displacements, $\widehat{xx}$, $\widehat{xy}$, &c., the stresses in the notation of Todhunter and Pearson's 'History of Elasticity,' the body stress equations are of the type

$$\left.\begin{aligned}
&\frac{d\widehat{xx}}{dx}+\frac{d\widehat{xy}}{dy}+\frac{d\widehat{xz}}{dz}-\rho\frac{d^2\alpha}{dt^2}=0,\\
&\frac{d\widehat{xy}}{dx}+\frac{d\widehat{yy}}{dy}+\frac{d\widehat{yz}}{dz}-\rho\frac{d^2\beta}{dt^2}=0,\\
&\frac{d\widehat{xz}}{dx}+\frac{d\widehat{yz}}{dy}+\frac{d\widehat{zz}}{dz}+\rho\left\{g-\frac{d^2(\zeta+\gamma)}{dt^2}\right\}=0
\end{aligned}\right\}\quad\ldots\ldots\ldots\ldots\quad(1);$$

where ρ represents the density of the solid, g the acceleration of gravity.

The equations treat x, y, z as constants for each element of the solid, and so assume that the motion, if motion takes place, is purely translational.

If λ, μ, ν be the direction cosines of the outwardly directed normal at a point x, y, z, the surface equations are

$$\begin{aligned}(\lambda\widehat{xx}+\mu\widehat{xy}+\nu\widehat{xz})/\lambda &= (\lambda\widehat{xy}+\mu\widehat{yy}+\nu\widehat{yz})/\mu = (\lambda\widehat{xz}+\mu\widehat{yz}+\nu\widehat{zz})/\nu\\
&= -\Pi-g\rho'(\zeta+z)\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\quad(2).\end{aligned}$$

The equations (2) are satisfied by the assumption

$$\left.\begin{aligned}
&\widehat{xx}=\widehat{yy}=\widehat{zz}=-\Pi-g\rho'(\zeta+z),\\
&\widehat{xy}=\widehat{xz}=\widehat{yz}=0
\end{aligned}\right\}\quad\ldots\ldots\ldots\ldots\quad(3).$$

Also the values (3) satisfy the body stress equations (1), provided

$$\begin{aligned}
&\frac{d^2\alpha}{dt^2}=\frac{d^2\beta}{dt^2}=0,\\
&\rho\left\{\frac{d^2(\zeta+\gamma)}{dt^2}-g\right\}=-g\rho'\quad\ldots\ldots\ldots\ldots\ldots\ldots\quad(4).
\end{aligned}$$

We can satisfy (4) by assuming

$$\begin{aligned}
&\frac{d^2\gamma}{dt^2}=0,\\
&\zeta=\text{const.}+\tfrac{1}{2}g\frac{\rho-\rho'}{\rho}t^2\quad\ldots\ldots\ldots\ldots\ldots\ldots\quad(5).
\end{aligned}$$

For brevity, the constant in (5) will be supposed to be zero.

The result (5) is of course that given by ordinary elementary methods for the accelerated motion of a solid rising or falling in a *liquid of different* density.

On looking more closely into the matter an inconsistency manifests itself. Supposing for mathematical simplicity that the solid is isotropic, of bulk modulus k, we find that the displacements answering to (3) are given by

$$\left.\begin{aligned} \alpha/x = \beta/y &= -\{\Pi + g\rho'(\zeta+z)\}/3k, \\ \gamma &= -[\Pi z + g\rho'\{z(\zeta+z) - \tfrac{1}{2}(x^2+y^2+z^2)\}]/3k \end{aligned}\right\} \quad \ldots\ldots \quad (6).$$

The inconsistency consists in the fact that, by (6), α, β, γ contain terms in ζ, and so by (5) terms in t^2, while above it was assumed that $d^2\alpha/dt^2$, &c., vanished. It thus appears that the solution embodied in (3) and (6) is valid and complete only when ζ does not vary as t^2, *i.e.*, only when the solid is at rest or moving with uniform velocity in the liquid.

Though thus restricted, the solution is notable from its simplicity and generality, as applicable to any homogeneous solid (free from cavities) at rest in a liquid of equal density.

The values (3) for the stresses apply irrespective of the species of elasticity. The displacements are given by (6) only when the material is isotropic, but corresponding expressions are immediately obtainable for materials of greater complexity. If for instance we have material symmetrical with respect to the co-ordinate planes, we have

$$\left.\begin{aligned} \alpha &= -x\{\Pi + g\rho'(\zeta+z)\}(1-\eta_{12}-\eta_{13})/E_1, \\ \beta &= -y\{\Pi + g\rho'(\zeta+z)\}(1-\eta_{21}-\eta_{23})/E_2, \\ \gamma &= -z\{\Pi + g\rho'(\zeta+\tfrac{1}{2}z)\}(1-\eta_{31}-\eta_{32})/E_3 \\ &\quad + \tfrac{1}{2}g\rho'\left\{\frac{x^2}{E_1}(1-\eta_{12}-\eta_{13}) + \frac{y^2}{E_2}(1-\eta_{21}-\eta_{23})\right\} \end{aligned}\right\} \quad \ldots \quad (7).$$

Here E_1, E_2, E_3 are the three principal Young's moduli, while η_{12}, η_{13}, &c., are the corresponding Poisson's ratios.

§ 2. Presently we shall consider the equilibrium problem in greater detail. Meanwhile, in the case of uniformly accelerated motion, we shall obtain a self-consistent solution for a sphere, or any form of solid ellipsoid, under the conditions assumed in § 1.

The procedure to be adopted is the same for all species of elastic material. If for definiteness we suppose the material symmetrical with respect to the three co-ordinate planes, we first assume that the stresses (3) and displacements (7) form part—but only part—of the complete solution, ζ being given by (5). Then substituting from (7) in the body stress equations (1), we find that the stresses of the *supplementary* solution, as we may call it, must satisfy

$$\left.\begin{aligned} \frac{d\widehat{xx}}{dx}+\frac{d\widehat{xy}}{dy}+\frac{d\widehat{xz}}{dz} &= -\mathrm{P}\rho x, \\ \frac{d\widehat{xy}}{dx}+\frac{d\widehat{yy}}{dy}+\frac{d\widehat{yz}}{dz} &= -\mathrm{Q}\rho y, \\ \frac{d\widehat{xz}}{dx}+\frac{d\widehat{yz}}{dy}+\frac{d\widehat{zz}}{dz} &= -\mathrm{R}\rho z \end{aligned}\right\} \quad\ldots\ldots\ldots\ldots\ldots\ldots (8);$$

where

$$\left.\begin{aligned} \mathrm{P}\rho &\equiv g^2\rho'(\rho-\rho')(1-\eta_{12}-\eta_{13})/\mathrm{E}_1, \\ \mathrm{Q}\rho &\equiv g^2\rho'(\rho-\rho')(1-\eta_{21}-\eta_{23})/\mathrm{E}_2, \\ \mathrm{R}\rho &\equiv g^2\rho'(\rho-\rho')(1-\eta_{31}-\eta_{32})/\mathrm{E}_3 \end{aligned}\right\} \quad\ldots\ldots\ldots\ldots (9).$$

The surface equations to be satisfied by the supplementary solution are

$$\lambda\widehat{xx}+\mu\widehat{xy}+\nu\widehat{xz} = \lambda\widehat{xy}+\mu\widehat{yy}+\nu\widehat{yz} = \lambda\widehat{xz}+\mu\widehat{yz}+\nu\widehat{zz} = 0 \ldots \quad (10).$$

The problem thus resolves itself into that of an ellipsoid acted on solely by bodily forces derivable from the potential

$$\tfrac{1}{2}(\mathrm{P}x^2+\mathrm{Q}y^2+\mathrm{R}z^2).$$

This problem was solved by me in 1894 for isotropic* materials, and in 1899 I extended the solution to æolotropic† ellipsoids. We can thus derive a satisfactory supplementary solution from the sources specified. Finally adding the stresses of the supplementary solution to the stresses (3), and the displacements to the displacements (7), we have a consistent and complete solution of the problem presented by a heavy ellipsoid in a homogeneous liquid, when the action of the liquid is supposed that given by elementary hydrostatics.

§ 3. The supplementary solution, though simple in type, contains terms which are of great length when the ellipsoid has three unequal axes, and is of a complex kind of æolotropy. It will thus perhaps suffice to select for illustration the simple case of an isotropic sphere of radius a.

Denoting Young's modulus by E, Poisson's ratio by η, and writing r^2 for $x^2 + y^2 + z^2$, we have in full

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* 'Roy. Soc. Proc.,' vol. 58, p. 39; 'Quarterly Journal of Pure and Applied Mathematics,' vol. 27, p. 338.

† '*Camb. Phil. Soc. Trans.*,' vol. 17, p. 201.

$$\left.\begin{aligned}
\widehat{xx} &= -\Pi - g\rho'\left(z + \tfrac{1}{2}g\frac{\rho-\rho'}{\rho}t^2\right) \\
&\quad + \frac{g^2\rho'(\rho-\rho')(1-2\eta)}{10\mathrm{E}(1-\eta)}\{(3-\eta)(a^2-x^2)-(1+3\eta)(y^2+z^2)\}, \\
\widehat{yy} &= -\Pi - g\rho'\left(z + \tfrac{1}{2}g\frac{\rho-\rho'}{\rho}t^2\right) \\
&\quad + \frac{g^2\rho'(\rho-\rho')(1-2\eta)}{10\mathrm{E}(1-\eta)}\{(3-\eta)(a^2-y^2)-(1+3\eta)(x^2+z^2)\}, \\
\widehat{zz} &= -\Pi - g\rho'\left(z + \tfrac{1}{2}g\frac{\rho-\rho'}{\rho}t^2\right) \\
&\quad + \frac{g^2\rho'(\rho-\rho')(1-2\eta)}{10\mathrm{E}(1-\eta)}\{(3-\eta)(a^2-z^2)-(1+3\eta)(x^2+y^2)\}, \\
\widehat{xy}/xy &= \widehat{xz}/xz = \widehat{yz}/yz = -g^2\rho'(\rho-\rho')(1-2\eta)^2 \div \{5\mathrm{E}(1-\eta)\}
\end{aligned}\right\} \dots (11);$$

$$\left.\begin{aligned}
\alpha/x = \beta/y &= -\frac{1-2\eta}{\mathrm{E}}\left\{\Pi + g\rho'\left(z+\tfrac{1}{2}g\frac{\rho-\rho'}{\rho}t^2\right)\right\} \\
&\quad + \frac{g^2\rho'(\rho-\rho')(1-2\eta)^2}{10\mathrm{E}^2(1-\eta)}\{(3-\eta)a^2-(1+\eta)r^2\}, \\
\gamma &= -\frac{1-2\eta}{\mathrm{E}}\left\{\Pi z + g\rho' z\left(z+\tfrac{1}{2}g\frac{\rho-\rho'}{\rho}t^2\right) - \tfrac{1}{2}g\rho' r^2\right\} \\
&\quad + \frac{g^2\rho'(\rho-\rho')(1-2\eta)^2 z}{10\mathrm{E}^2(1-\eta)}\{(3-\eta)a^2-(1+\eta)r^2\}
\end{aligned}\right\} \dots (12).$$

The terms in g^2 constitute what has been called above the supplementary solution. In the case alike of the stresses and of the displacements they are exactly the same as if the sphere were under a self-gravitative force which followed the ordinary gravitational law, and which had for its accelerative value at the surface of the sphere

$$\frac{g^2\rho'(\rho'-\rho)}{\rho}\,\frac{1-2\eta}{\mathrm{E}}\,a.$$

This imaginary gravitative action represents attraction or repulsion between elements of the solid according as $\rho-\rho'$ is negative or positive. It is thus an attraction when the sphere rises in a heavier liquid, a repulsion when it sinks in a lighter. The smaller $1 - 2\eta$, or in general the less compressible the solid, the smaller is the effect of this imaginary gravitative force relative to that of the hydrostatic pressure $\Pi + g\rho'(z+\zeta)$; on the other hand its relative importance increases rapidly with the size of the sphere.

Representing by dashed letters the parts of the displacements depending on $\rho-\rho'$, we have

$$\alpha'/x = \beta'/y = \gamma'/z$$

$$= \frac{g^2\rho'(\rho-\rho')}{2\rho\mathrm{E}}(1-\eta)\left[\frac{\rho(1-2\eta)}{5\mathrm{E}}\{(3-\eta)a^2-(1+\eta)r^2\}-t^2\right] \ldots (13).$$

At the very beginning of the motion, the expression inside the square bracket is positive for all values of r; but as t increases it changes sign, first at the surface, last close to the centre of the sphere. If ζ_a, ζ_0 represent the distances fallen when the expression vanishes at the surface and at the centre respectively, we have

$$\left.\begin{aligned} \zeta_a/a &= (1-\eta)g(\rho-\rho')a/15k, \\ \zeta_0/a &= (3-\eta)g(\rho-\rho')a/30k \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots (14).$$

Unless a is enormously large, ζ_a and ζ_0 must be extremely small for any ordinary elastic material.

In reality, in order to be instantaneously at rest, the sphere would require to be supported or acted on by some suddenly suppressed force, or to be in the act of reversing some previously impressed motion. The elastic strains and stresses might initially retain the impress of the pre-existing state of matters, and there are thus special sources of uncertainty affecting the applicability of (14) to actual conditions, which should not be lost sight of.

§ 4. The problem just considered has been advanced as showing how under a consistent dynamical system, producing uniform acceleration in a straight line, there appear elastic strains and stresses which simulate the action of self-gravitation in the material in motion. The conditions postulated do not answer exactly to what happens when a real solid moves through real liquid at the earth's surface. Under such circumstances the action between solid and liquid is not fully represented by the hydrostatic pressure. If the fluid be "perfect," ordinary hydrodynamical theory* gives for the pressure p on the surface of the sphere, supposing u the velocity,

$$p = \Pi + g\rho'(\zeta+z) + \rho'(\tfrac{1}{2}a\dot{u}\mathrm{P}_1 + \tfrac{3}{4}u^2\mathrm{P}_2 - \tfrac{1}{4}u^2) \ldots\ldots\ldots\ldots (15),$$

where P_1, P_2 are zonal harmonics, whose axis is the vertical diameter. We shall now consider this case, on the hypothesis that the velocity is so small that terms in u^2 are negligible. Instead of (3) and (6) we find for the stresses and displacements, the material being supposed isotropic,

$$\left.\begin{aligned} \widehat{xx} = \widehat{yy} = \widehat{zz} &= -\Pi - g\rho'(\zeta+z) - \tfrac{1}{2}\dot{u}\rho' z, \\ \widehat{xy} = \widehat{xz} = \widehat{yz} &= 0 \end{aligned}\right\} \ldots\ldots\ldots (16);$$

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* *Cf.* Lamb's 'Hydrodynamics,' Art. 91.

$$\left.\begin{aligned} \alpha/x = \beta/y &= -\frac{1-2\eta}{\mathrm{E}}\{\Pi + g\rho'(\zeta+z) + \tfrac{1}{2}\dot{u}\rho' z\}, \\ \gamma &= -\frac{1-2\eta}{\mathrm{E}}[\Pi z + g\rho' z\zeta + \tfrac{1}{2}\rho'(g+\tfrac{1}{2}\dot{u})(z^2 \quad x^2 - y^2)] \end{aligned}\right\} \ldots (17).$$

Instead of (4) we have

$$\rho\left\{\frac{d^2(\zeta+\gamma)}{dt^2} - g\right\} = -g\rho' - \tfrac{1}{2}\dot{u}\rho'.$$

Also $$\dot{u} \equiv d^2\zeta/dt^2,$$

thus, if $d^2\gamma/dt^2$ be omitted, we have

$$(\rho + \tfrac{1}{2}\rho')\frac{d^2\zeta}{dt^2} = g(\rho - \rho'),$$

or $$\zeta = \text{constant} + \tfrac{1}{2}g\frac{\rho-\rho'}{\rho+\tfrac{1}{2}\rho'}t^2 \ldots\ldots\ldots\ldots\ldots\ldots (18).$$

This is, of course, only the well-known result, that the dynamical action of the liquid may be regarded as adding to the mass of the sphere that of a hemisphere of the liquid.* We may suppose the constant in (18) to be zero, suitably interpreting Π.

As in the first case considered, the existence of t^2 in ζ and, consequently, in α, β, γ, makes a supplementary solution necessary. The stresses of the supplementary solution must satisfy the surface equations (10) as well as the following body stress equations:

$$\left(\frac{d\widehat{xx}}{dx} + \frac{d\widehat{xy}}{dy} + \frac{d\widehat{xz}}{dz}\right)\Big/x = \left(\frac{d\widehat{xy}}{dx} + \frac{d\widehat{yy}}{dy} + \frac{d\widehat{yz}}{dz}\right)\Big/y$$

$$= \left(\frac{d\widehat{xz}}{dx} + \frac{d\widehat{yz}}{dy} + \frac{d\widehat{zz}}{dz}\right)\Big/z = -\frac{1-2\eta}{\mathrm{E}}\,\frac{2g^2\rho\rho'(\rho-\rho')}{2\rho+\rho'} \ldots\ldots\ldots (19).$$

It will be observed that the retention of the term in $\dot{u}$ in the pressure has only modified (reduced) the acceleration without altering the type of the supplementary solution. It will thus suffice to record the complete expressions for the displacements, viz.,

$$\left.\begin{aligned} \alpha/x = \beta/y = &-\frac{1-2\eta}{\mathrm{E}}\left[\Pi + \frac{3g\rho\rho' z}{2\rho+\rho'} + g^2\frac{\rho'(\rho-\rho')}{2\rho+\rho'}t^2\right] \\ &+ \frac{(1-2\eta)^2}{5(1-\eta)\mathrm{E}^2}\,\frac{g^2\rho\rho'(\rho-\rho')}{2\rho+\rho'}[(3-\eta)a^2 - (1+\eta)r^2], \\ \gamma = &-\frac{1-2\eta}{\mathrm{E}}\left[\Pi z + \frac{3g\rho\rho'}{2(2\rho+\rho')}(z^2 - x^2 - y^2) + \frac{g^2\rho'(\rho-\rho')}{2\rho+\rho'}zt^2\right] \\ &+ \frac{(1-2\eta)^2}{5(1-\eta)\mathrm{E}^2}\,\frac{g^2\rho\rho'(\rho-\rho')}{2\rho+\rho'}z[(3-\eta)a^2 - (1+\eta)r^2] \end{aligned}\right\} (20).$$

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* *Cf.* Lamb's 'Hydrodynamics,' Art. 91; or Basset's 'Treatise on Hydrodynamics,' Art. 182.

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In obtaining this solution we have neglected terms in u^2, *i.e.*, terms in $(d\zeta/dt)^2$ or $g^2t^2(\rho-\rho')^2/(\rho+\frac{1}{2}\rho')^2$, in the expression (15), while there appear in the solution terms containing $g^2t^2(\rho-\rho')/(2\rho+\rho')$. Thus our work is consistent only when $(\rho-\rho')/\rho$ is small, and even when this is the case the fact that u^2 increases as t^2 involves a restriction which should not be overlooked. It would not, I think, be a very difficult matter to obtain a complete solution answering to the full value (15) of p. Treating u^2 at first as a constant, we could at once write down, from my general solution* for the isotropic elastic sphere, the displacements answering to the surface pressure $\frac{1}{4}\rho'u^2(3P_2-1)$; but the explicit determination of the corresponding supplementary solution would be much more laborious than in the first case treated above.

§ 5. When ρ' and ρ are equal, and u^2 is thus really constant, the complete values of the stresses and displacements answering to the surface pressure (15) are as follows:—

$$\left.\begin{aligned}
\widehat{xx} &= -\Pi - g\rho'(z+ut) + \tfrac{1}{4}\rho'u^2 + \tfrac{3}{8}\frac{\rho'u^2a^{-2}}{7+5\eta}\big[(7+2\eta)a^2 \\
&\qquad + 3\eta(x^2+5y^2) - 3(7+6\eta)z^2\big], \\
\widehat{yy} &= -\Pi - g\rho'(z+ut) + \tfrac{1}{4}\rho'u^2 + \tfrac{3}{8}\frac{\rho'u^2a^{-2}}{7+5\eta}\big[(7+2\eta)a^2 \\
&\qquad + 3\eta(5x^2+y^2) - 3(7+6\eta)z^2\big], \\
\widehat{zz} &= -\Pi - g\rho'(z+ut) + \tfrac{1}{4}\rho'u^2 - \tfrac{3}{8}\frac{\rho'u^2a^{-2}}{7+5\eta}\big[2(7+2\eta)a^2 \\
&\qquad - 3(7+\eta)(x^2+y^2) + 6\eta z^2\big], \\
\widehat{xy} &= -9\rho'u^2\eta xya^{-2} \div [2(7+5\eta)], \\
\widehat{xz}/xz &= \widehat{yz}/yz = 9\rho'u^2\eta a^{-2} \div [4(7+5\eta)]
\end{aligned}\right\} \ldots (21);$$

$$\left.\begin{aligned}
\alpha/x = \beta/y &= -\frac{1-2\eta}{E}\big[\Pi - \tfrac{1}{4}\rho'u^2 + g\rho'(z+ut)\big] \\
&\quad + \tfrac{3}{8}\frac{\rho'u^2(1+\eta)a^{-2}}{E(7+5\eta)}\big[(7+2\eta)a^2 - 6\eta(x^2+y^2) - 3(7-8\eta)z^2\big], \\
\gamma &= -\frac{1-2\eta}{E}\big[(\Pi - \tfrac{1}{4}\rho'u^2)z + g\rho'\{utz + \tfrac{1}{2}(z^2-x^2-y^2)\}\big] \\
&\quad - \tfrac{3}{8}\frac{\rho'u^2(1+\eta)za^{-2}}{E(7+5\eta)}\big[2(7+2\eta)a^2 - 3(7-6\eta)(x^2+y^2) - 12\eta z^2\big]
\end{aligned}\right\} (22).$$

§ 6. In real liquids viscosity is more or less present, and as the hydrodynamical equations have been solved for the case of an ellipsoid

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* 'Camb. Phil. Soc. Trans.,' vol. 14, p. 250.

when the retarding action of viscosity neutralises the acceleration due to gravity, it is worth considering. The hydrodynamical solution really assumes the velocity to be small, and the ellipsoid to be so remote from the surface and other boundaries as to be practically in an infinite liquid.

It is not very difficult to deduce from the formulæ in Lamb's 'Hydrodynamics,' Art. 296,—though I have not seen the result noticed —that the viscous surface action reduces to a force $f\varpi$ per unit surface, opposite to the direction of motion, ϖ being the perpendicular from the centre on the tangent plane, and f a constant. The recognition of this fact saves us from the labour of considering the general expressions for the hydrodynamical pressures, which are of a very complicated nature.

As the motion is steady, the body stress equations are

$$\frac{d\widehat{xx}}{dx}+\frac{d\widehat{xy}}{dy}+\frac{d\widehat{xz}}{dz} = \frac{d\widehat{xy}}{dx}+\frac{d\widehat{yy}}{dy}+\frac{d\widehat{yz}}{dz} = \frac{d\widehat{xz}}{dx}+\frac{d\widehat{yz}}{dy}+\frac{d\widehat{zz}}{dz}+g\rho = 0 \ldots(23);$$

while the surface equations are—a, b, c being the semi-axes of the ellipsoid—

$$\left.\begin{aligned} a^{-2}x\widehat{xx}+b^{-2}y\widehat{xy}+c^{-2}z\widehat{xz} &= -a^{-2}x\{\Pi+g\rho'(\zeta+z)\}, \\ a^{-2}x\widehat{xy}+b^{-2}y\widehat{yy}+c^{-2}z\widehat{yz} &= -b^{-2}y\{\Pi+g\rho'(\zeta+z)\}, \\ a^{-2}x\widehat{xz}+b^{-2}y\widehat{yz}+c^{-2}z\widehat{zz} &= -c^{-2}z\{\Pi+g\rho'(\zeta+z)\}-f \end{aligned}\right\} (24).$$

The surface equations are satisfied by

$$\left.\begin{aligned} \widehat{xx} &= -\Pi-g\rho'(\zeta+z)+(a^2/c^2)fz, \\ \widehat{yy} &= -\Pi-g\rho'(\zeta+z)+(b^2/c^2)fz, \\ \widehat{zz} &= -\Pi-g\rho'(\zeta+z)-fz, \\ \widehat{xy} &= 0, \\ \widehat{xz}/x &= \widehat{yz}/y = -f \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots (25).$$

The values (25) also satisfy the body stress equations (23), provided

$$-3f+g(\rho-\rho') = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (26).$$

As
$$\iint f\varpi dS = 3f\,.\,\tfrac{4}{3}\pi abc,$$

when the integral is taken over the surface of the ellipsoid, (26) is simply equivalent to the condition that the motion is not accelerated, or that

$$\zeta = vt.$$

[redacted]

where u is a constant. As to the value of u, it has been proved that the total viscous resistance to the motion is*

$$16\pi\mu' uabc/(\chi_0 + c^2\gamma_0),$$

where μ' is the viscosity, and

$$\chi_0 \equiv abc\int_0^\infty [(a^2+\lambda)(b^2+\lambda)(c^2+\lambda)]^{-\frac{1}{2}}d\lambda,$$

$$\gamma_0 \equiv abc\int_0^\infty [(a^2+\lambda)(b^2+\lambda)(c^2+\lambda)^3]^{-\frac{1}{2}}d\lambda.$$

But this resistance is also equal to $g(\rho - \rho')\frac{4}{3}\pi abc$ [or to $\iint f\varpi dS$], thus

$$u = g(\rho-\rho')(\chi_0 + c^2\gamma_0)/12\mu'.$$

Substituting for ζ and f in (25), we have

$$\left.\begin{aligned}
\widehat{xx} &= -\Pi - g\rho'(z+ut) + \tfrac{1}{3}g(\rho-\rho')a^2z/c^2,\\
\widehat{yy} &= -\Pi - g\rho'(z+ut) + \tfrac{1}{3}g(\rho-\rho')b^2z/c^2,\\
\widehat{zz} &= -\Pi - g\rho'(z+ut) - \tfrac{1}{3}g(\rho-\rho')z,\\
\widehat{xy} &= 0,\\
\widehat{xz}/x = \widehat{yz}/y &= -\tfrac{1}{3}g(\rho-\rho')
\end{aligned}\right\} \quad\ldots\ldots\ldots\ldots(27).$$

The corresponding displacements, supposing the material isotropic, are

$$\left.\begin{aligned}
\alpha &= -\frac{1-2\eta}{E}x[\Pi + g\rho'(z+ut)] + \frac{g(\rho-\rho')}{3E}xz\left[\frac{a^2}{c^2} + \eta\left(1-\frac{b^2}{c^2}\right)\right],\\
\beta &= -\frac{1-2\eta}{E}y[\Pi + g\rho'(z+ut)] + \frac{g(\rho-\rho')}{3E}yz\left[\frac{b^2}{c^2} + \eta\left(1-\frac{a^2}{c^2}\right)\right],\\
\gamma &= -\frac{1-2\eta}{E}[\Pi z + g\rho' utz + \tfrac{1}{2}g\rho'(z^2-x^2-y^2)]\\
&\qquad - \frac{g(\rho-\rho')z^2}{6E}\left(1+\eta\frac{a^2+b^2}{c^2}\right)\\
&\quad - \frac{g(\rho-\rho')}{6E}\left[x^2\left(2+3\eta+\frac{a^2-\eta b^2}{c^2}\right) + y^2\left(2+3\eta+\frac{b^2-\eta a^2}{c^2}\right)\right]
\end{aligned}\right\} (28).$$

§ 7. The terms inside the first brackets in (28) contain Π or $g\rho'$, and represent displacements which vary only with the depth of the element or its distance from the centre of the ellipsoid. The terms containing

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* *Cf.* Lamb's 'Hydrodynamics,' Art. 296.

$g(\rho-\rho')$, on the other hand, depend largely on the shape of the ellipsoid.

Thus, denoting them by α', β', γ', we have approximately, in the case of a very elongated ellipsoid, whose long axis is vertical,

$$\left.\begin{aligned} \alpha'/x = \beta'/y &= g(\rho-\rho')\eta z/3\mathrm{E}, \\ \gamma' &= -g(\rho-\rho')\left[z^2+(2+3\eta)(x^2+y^2)\right]/6\mathrm{E} \end{aligned}\right\} \quad \ldots\ldots(29);$$

and, except in the immediate vicinity of the central section $z=0$, we may take in place of (29)

$$\alpha'/x\eta = \beta'/y\eta = -\gamma'/(\tfrac{1}{2}z) = g(\rho-\rho')z/3\mathrm{E} \ldots\ldots\ldots\ldots(30).$$

In a very flat ellipsoid, approximating to a disc, with the short axis vertical, we have approximately

$$\left.\begin{aligned} \alpha' &= g(\rho-\rho')xz(a^2-\eta b^2)/(3\mathrm{E}c^2), \\ \beta' &= g(\rho-\rho')yz(b^2-\eta a^2)/(3\mathrm{E}c^2), \\ \gamma' &= -g(\rho-\rho')\left[(a^2-\eta b^2)x^2+(b^2-\eta a^2)y^2+\eta(a^2+b^2)z^2\right]\div(6\mathrm{E}c^2) \end{aligned}\right\} (31).$$

Except close to the vertical diameter, the terms in z^2 in γ' would be relatively negligible, while, in general, α' and β' would be small compared to γ'.

In the case of the sphere it is perhaps more convenient to record the complete solution, viz.,

$$\left.\begin{aligned} \widehat{xx} = \widehat{yy} &= -\Pi - g\rho' ut + \tfrac{1}{3}g(\rho-4\rho')z, \\ \widehat{zz} &= -\Pi - g\rho' ut - \tfrac{1}{3}g(\rho+2\rho')z, \\ \widehat{xy} &= 0, \\ \widehat{xz}/x = \widehat{yz}/y &= -\tfrac{1}{3}g(\rho-\rho') \end{aligned}\right\} \quad \ldots\ldots(32);$$

$$\left.\begin{aligned} \alpha/x = \beta/y &= -\frac{1-2\eta}{\mathrm{E}}\left[\Pi+g\rho'(z+ut)\right]+\tfrac{1}{3}g(\rho-\rho')z/\mathrm{E}, \\ \gamma &= -\frac{1-2\eta}{\mathrm{E}}\left[(\Pi+g\rho' ut)z+\tfrac{1}{2}g\rho'(z^2-x^2-y^2)\right] \\ &\quad -\frac{g(\rho-\rho')}{6\mathrm{E}}\left[(3+2\eta)(x^2+y^2)+(1+2\eta)z^2\right] \end{aligned}\right\} \ldots(33).$$

[*March* 13, 1901.]—The paper as originally presented to the Society dealt briefly with two or three other details. It showed how the solution in § 6 depended not on the viscous resistance varying as the first power of the velocity in the final state, but on its varying over the

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surface as the perpendicular on the tangent plane. In particular, if, in accordance with Mr. Allen's experiments,* there be possible forms of final uniform motion for a sphere in which the resistance varies as $u^{\frac{3}{2}}$ or u^2 (u being the velocity), it was shown that the solution would still be of the form of (32) and (33), provided the distribution of the viscous resistance happens to remain unchanged.

It was pointed out that in an isotropic solid, free of cavities, at rest in a liquid, the *stresses* are everywhere the same as if each element were separately subjected to the pressure answering to its depth; but that when cavities exist in the solid the state of matters is altered. As an example, a complete solution was given for a hollow spherical shell fully immersed.

It was shown that, in a completely solid body, the greatest strain and maximum stress-difference theories agreed in indicating no tendency to rupture, but that when cavities existed, it was otherwise; in particular, that in the spherical shell there is on either theory a tendency to rupture, greatest at the lowest point, which approximately in a thin shell varies directly as the depth and inversely as the thickness of the shell.

"On the Heat dissipated by a Platinum Surface at High Temperatures. Part IV.†—High-pressure Gases."

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Communicated by Professor SCHUSTER, F.R.S. Received February 7,—Read March 7, 1901.

(Abstract.)

The rate of cooling of a hot body in gases at pressures up to one atmosphere has received considerable attention, but with regard to gases at high pressures practically no data were up to the present available. It was thought therefore that an experimental investigation of the subject might prove of some interest.

The experiments were carried out with a horizontal cylindrical radiator contained in a strong steel enclosure, the enclosure being maintained at about 18° C. by a water circulation.

It is shown that the rate at which heat is dissipated by the radiator may be expressed by the following formula—

$$E = ap^{\alpha} + bp^{\beta}\vartheta,$$

where E = emissivity in C.G.S. units = total amount of heat dissi-

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* 'Phil. Mag.,' September and November, 1900.

† For Parts I, II and III see 'Phil., Trans.,' A, vol. 191, p. 501, 1898.

pated expressed in therms (water-grammes-degrees) per square centimetre of surface of radiator per second,

p = pressure in atmospheres,

ϑ = the temperature of the radiator minus the temperature of the enclosure, or in other words the temperature interval in degrees Centigrade.

The limits between which the formula may be considered to hold good, and the numerical value of the constants for the various gases studied, are given by the following table:—

	$a \times 10^6$.	$b \times 10^6$.	α.	β.	The formula holds good			
					from ϑ =	to ϑ =	and from p =	to p =
Air	403	1·63	0·56	0·21	100	1100	7	170
Oxygen	387	1·39	0·58	0·28	100	1100	15	115
Hydrogen.....	2705	1·88	0·35	0·36	300	1100	7	113
Nitrous oxide..	276	1·70	0·74	0·28	100	800	5	40
Carbon dioxide.	207	1·50	0·82	0·33	100	1100	10	35

The question as to what proportion of the total loss of heat is due respectively to convection, conduction, and radiation is treated at some length. The influence of experimental conditions, such as the temperature of the gas and the dimensions of the radiator and enclosure, is also studied.

All gases show a rapid increase of the effective conductivity with the pressure. In air, for instance, the rate of cooling is six times greater at 100 atmospheres than it is at atmospheric pressure. The effect of the high rate at which heat is transmitted through compressed gases is discussed, both from a theoretical and a practical point of view, and the bearing of the results on some problems of modern engineering is considered.

[redacted]

May 2, 1901.

Sir WILLIAM HUGGINS, K.C.B., D.C.L., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

In pursuance of the Statutes, the names of the Candidates recommended for election into the Society were read, as follows:—

Alcock, Professor Alfred William, M.B.
Dyson, Frank Watson, M.A.
Evans, Arthur John, M.A.
Gregory, Professor John Walter, D.Sc.
Jackson, Henry Bradwardine, Captain, R.N.
Macdonald, Hector Munro, M.A.
Mansergh, James, M.Inst.C.E.
Martin, Prof. Charles James, M.B.
Ross, Ronald, Major (I.M.S., retired).
Schlich, Professor William, C.I.E.
Smithells, Professor Arthur, B.Sc.
Thomas, Michael R. Oldfield, F.Z.S.
Watson, William, B.Sc.
Whetham, William C. Dampier, M.A.
Woodward, Arthur Smith, F.G.S.

The following Papers were read:—

I. "On the Variation in Gradation of a Developed Photographic Image when impressed by Monochromatic Light of different Wave-lengths." By Sir W. DE W. ABNEY, K.C.B., F.R.S.

II. "Ellipsoidal Harmonic Analysis." By G. H. DARWIN, F.R.S.

III. "On the Small Vertical Movements of a Stone laid on the Surface of the Ground." By HORACE DARWIN. Communicated by CLEMENT REID, F.R.S.

"Ellipsoidal Harmonic Analysis."

By G. H. DARWIN, F.R.S., Plumian Professor and Fellow of Trinity College in the University of Cambridge. Received March 23,—Read May 2, 1901.

(Abstract.)

Lamé's functions have been used in many investigations, but the form in which they have been presented has always been such as to render numerical calculation so difficult as to be practically impossible. The object of this paper is to remove the imperfection in question by

giving to the functions such forms as shall render numerical results accessible.

Throughout the work I have enjoyed the immense advantage of frequent discussions with Mr. E. W. Hobson, and I have to thank him not only for many valuable suggestions but also for assistance in obtaining various specific results.

My object in attacking this problem was the hope of being thereby enabled to obtain exact numerical results as to M. Poincaré's pear-shaped figure of equilibrium of rotating liquid. But it soon became clear that partial investigation with one particular object in view was impracticable, and I was led on to cover the whole field, leaving the consideration of the particular problem to some future occasion.

The usual symmetrical forms of the three functions whose product is a solid ellipsoidal harmonic are such as to render purely analytical investigations both elegant and convenient. But it seemed that facility for computation might be gained by the surrender of symmetry, and this idea is followed out in the paper.

The success attained in the use of spheroidal analysis suggested that it should be taken as the point of departure for the treatment of ellipsoids with three unequal axes. In spheroidal harmonics we start with a fundamental prolate ellipsoid of revolution, with imaginary semi-axes $k\sqrt{-1}$, $k\sqrt{-1}$, 0. The position of a point is then defined by three co-ordinates; the first of these, ν, is such that its reciprocal is the eccentricity of a meridional section of an ellipsoid confocal with the fundamental ellipsoid and passing through the point. Since that eccentricity diminishes as we recede from the origin, ν plays the part of a reciprocal to the radius vector. The second co-ordinate, μ, is the cosine of the auxiliary angle in the meridional ellipse measured from the axis of symmetry. It therefore plays the part of sine of latitude. The third co-ordinate is simply the longitude ϕ. The three co-ordinates may then be described as the radial, latitudinal, and longitudinal co-ordinates. The parameter k defines the absolute scale on which the figure is drawn.

It is equally possible to start with a fundamental oblate ellipsoid with real semi-axes k, k, 0. We should then take the first co-ordinate, ζ, as such that $\zeta^2 = -\nu^2$. All that follows would then be equally applicable; but in order not to complicate the statement by continual reference to alternate forms, the first form is taken as a standard.

In the paper a closely parallel notation is adopted for the ellipsoid of three unequal axes. The squares of the semi-axes of the fundamental ellipsoid are taken to be $-k^2\frac{1+\beta}{1-\beta}$, $-k^2$, 0, and the three co-ordinates are still ν, μ, ϕ. As before, we might equally well start with a fundamental ellipsoid whose squares of semi-axes are $k^2\frac{1+\beta}{1-\beta}$, k^2, 0, and replace ν^2 by ζ^2 where $\zeta^2 = -\nu^2$. All possible

[redacted]

ellipsoids are comprised in either of these types by making β vary from zero to infinity. But it is shown that, by a proper choice of type, all possible ellipsoids are comprised in a range of β from zero to one-third. When β is zero we have the spheroids for which harmonic analysis already exists, and when β is equal to one-third the ellipsoid is such that the mean axis is the square root of mean square of the extreme axes. We may then regard β as essentially not greater than one-third, and may conveniently make developments in powers of β.

In spheroidal analysis, for space internal to an ellipsoid ν_0, two of the three functions are the same P-functions that occurs in spherical analysis; one P being a function of ν, the other of μ. The third function is a cosine or sine of a multiple of the longitude ϕ. For external space the P-function of ν is replaced by a Q-function, being a solution of the differential equation of the second kind.

The like is true in ellipsoidal analysis, and we have P- and Q-functions of ν for internal and external space, a P-function of μ, and a cosine- or sine-function of ϕ. For the moment we will only consider the P-functions, and will consider the Q-functions later.

There are eight cases which are determined by the evenness or oddness of the degree i and of the order s of the harmonic, and by the alternative of whether they correspond with a cosine- or sine-function of ϕ. These eight types are indicated by the initials E, O, C, or S; for example, EOS means the type in which i is even, s is odd, and that there is association with a sine-function.

It appears that the new P-functions have two forms. The first form, written $\mathfrak{P}$, is found to be expressible in a finite series in terms of $P_i^{s\pm 2k}$, when the P's are ordinary functions of spherical analysis. The terms in this series are arranged in powers of β, so that the coefficient of $P_i^{s\pm 2k}$ has β^k as part of its coefficient. The second form, written P_i^s, is such that $\sqrt{\dfrac{\nu^2-1}{\nu^2-\frac{1+\beta}{1-\beta}}}\,\mathsf{P}_i(\nu)$ or $\sqrt{\dfrac{1-\mu^2}{\frac{1+\beta}{1-\beta}-\mu^2}}\,\mathsf{P}_i^s(\mu)$ is expressible by a series of the same form as that for $\mathfrak{P}_i^s$. Amongst the eight types four involve $\mathfrak{P}$-functions and four P-functions; and if for given s a $\mathfrak{P}_i^s$-function is associated with a cosine-function, the corresponding P_i is associated with a sine-function, and *vice versâ*.

Lastly, a $\mathfrak{P}$-function of ν is always associated with a $\mathfrak{P}$-function of μ; and the like is true of the P's.

Again, the cosine- and sine-functions have two forms. In the first form s and i are either both odd or both even, and the function written $\mathfrak{C}_i^s$ or $\mathfrak{S}_i^s$ is expressed by a series of terms consisting of a coefficient multiplied by β^k cos or sin $(s \pm 2k)\phi$. In the second form, s and i differ as to evenness and oddness, and the function written C_i^s or S_i is expressed by a similar series multiplied by $(1-\beta\cos 2\phi)^{\frac{1}{2}}$.

The combination of the two forms of P-function with the four forms cosine- and sine-function gives the eight types of harmonic.

Corresponding to the two forms of P-function there are two forms of Q-function, such that $\mathfrak{Q}_i^s$ and $\mathsf{Q}_i^s \sqrt{\dfrac{\nu^2 - 1}{\nu^2 - \frac{1+\beta}{1-\beta}}}$ are expressible in a series of ordinary Q-functions; but whereas the series for $\mathfrak{P}_i^s$ and P_i^s are terminable, because P_i^s vanishes when s is greater than i, this is not the case with the Q-functions.

In spherical and spheroidal analysis the differential equation satisfied by P_i^s involves the integer s, whereby the order is specified. So here also the differential equations, satisfied by $\mathfrak{P}_i^s$ or P_i^s and by $\mathfrak{C}_i^s$, $\mathfrak{S}_i^s$, C_i^s, or S_i^s, involve a constant; but it is no longer an integer. It seemed convenient to assume $s^2 - \beta\sigma$ as the form for this constant, where s is the known integer specifying the order of harmonic, and σ remains to be determined from the differential equations.

When the assumed forms for the P-function and for the cosine- and sine-functions are substituted in the differential equations, it is found that, in order to satisfy the equations, $\beta\sigma$ must be equal to the difference between two finite continued fractions, each of which involves $\beta\sigma$. We thus have an equation for $\beta\sigma$, and the required root is that which vanishes when β vanishes.

For the harmonics of degrees 0, 1, 2, 3 and for all orders σ may be found rigorously in algebraic form, but for higher degrees the equation can only be solved approximately, unless β should have a definite numerical value.

When $\beta\sigma$ has been determined either rigorously or approximately, the successive coefficients of the series are determinable in such a way that the ratio of each coefficient to the preceding one is expressed by a continued fraction, which is in fact portion of one of the two fractions involved in the equation for $\beta\sigma$.

Throughout the rest of the paper the greater part of the work is carried out with approximate forms, and, although it would be easy to attain to greater accuracy, it seemed sufficient in the first instance to limit the development to β^2. With this limitation the coefficients of the series assume simple forms, and we thus have definite, if approximate, expressions for all the functions which can occur in ellipsoidal analysis.

In rigorous expressions $\mathfrak{P}_i^s$ and P_i^s are essentially different from one another, but in approximate forms, when s is greater than a certain integer dependent on the degree of approximation, the two are the same thing in different shapes, except as to a constant factor.

The factor whereby P_i^s is convertible into $\mathfrak{P}_i^s$, and C_i^s or S_i^s into $\mathfrak{C}_i^s$ or $\mathfrak{S}_i^s$ are therefore determined up to squares of β. With the degree of approximation adopted there is no factor for converting the P's when $s = 3, 2, 1$. Similarly, down to $s = 3$ inclusive, the same factor serves for converting C_i^s into $\mathfrak{C}_i^s$ and S_i^s into $\mathfrak{S}_i^s$. But for $s = 2, 1, 0$ one form is needed for changing C into $\mathfrak{C}$, and another for changing $\mathbf{S}$ into $\mathfrak{S}$. It may be well to note that there is no sine-function when s is zero.

The use of these factors does much to facilitate the laborious reductions involved in the whole investigation.

It is well known that the Q-functions are expressible in terms of the P-functions by means of a definite integral. Hence $\mathfrak{Q}_i^s$ and $\mathbf{Q}_i^s$ must have a second form, which can only differ from the other by a constant factor. The factor in question is determined in the paper.

It is easy to form a function continuous at the surface ν_0 which shall be a solid harmonic both for external and for internal space. Poisson's equation then gives the surface density of which this continuous function is the potential, and it is found to be a surface harmonic of μ, ϕ multiplied by the perpendicular on to the tangent plane.

This result may obviously be employed in determining the potential of an harmonic deformation of a solid ellipsoid.

The potential of the solid ellipsoid itself may be found by the consideration that it is externally equal to that of a focaloid shell of the same mass. It appears that in order to express the equivalent surface density in surface harmonics it is only necessary to express the reciprocal of the square of the perpendicular on to the tangent plane in that form. This result is attained by expressing x^2, y^2, z^2 in surface harmonics. When this is done an application of the preceding theorem enables us to write down the external potential of the solid ellipsoid at once.

Since x^2, y^2, z^2 have been found in surface harmonics, we can also write down a rotation potential about any one of the three axes in the same form.

The internal potential of a solid ellipsoid does not lend itself well to elliptic co-ordinates, but expressions for it are given.

If it be desired to express any arbitrary function of μ, ϕ in surface harmonics, it is necessary to know the integrals, over the surface of the ellipsoid, of the squares of the several surface harmonics, each multiplied by the perpendicular on to the tangent plane. The rest of the paper is devoted to the evaluation of these integrals. No attempt is made to carry the developments beyond β^2, although the methods employed would render it possible to do so.

The necessary analysis is difficult, but the results for all orders and degrees are finally obtained.

"On the Small Vertical Movements of a Stone laid on the Surface of the Ground."

By **HORACE DARWIN**. Communicated by **CLEMENT REID**, F.R.S.

Received April 17,—Read May 2, 1901.

In my father's book on Vegetable Mould and Earthworms an estimate is given of the rate at which stones placed on the surface of the soil are buried by the action of earthworms. The estimate is rough, and as far as I know no attempt has been made to detect such movements when small, or to determine them accurately when they are large.

The experiments described in this paper were undertaken originally to measure accurately the downward movement of a stone caused by earthworms. The upward and downward movements due to varying moisture of the soil and to frost were found to be much larger than was expected. These movements, interesting in themselves, increase the difficulty of accurately determining the movement due to the action of earthworms.*

The experiment was begun on September 5, 1877, and the position selected is in a nearly level field which had probably been pasture for considerably more than fifty years. It is to the south of my father's house at Down, close to some railings separating the field from the lawn and under a large Spanish chestnut tree. He approved at the time of the selection of this position; at a later date he considered a mistake had been made, as he thought there were fewer worms under trees.†

It was necessary to have a fixed point from which the displacement might be measured; this was managed in the following way:—An iron rod was driven into the ground by means of a heavy hammer; it was then removed, and a copper rod, slightly larger (22 mm. in diameter), was driven into the hole; the bottom of the rod was about 2·63 metres from the surface. The top of this rod is the point from which all measurements were taken.

A circular stone about 460 mm. in diameter and about 57 mm. thick, weighing about 23 kilos., was placed on the ground with the rod projecting through a hole in its centre. A brass cylinder, slightly smaller than the hole in the stone, had previously been firmly fixed in the hole by running in melted lead. The brass cylinder had three projecting pieces at its top; three symmetrical radial right-angle grooves were cut, one in each of these projecting pieces. This gave the usual

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* See 'Vegetable Mould and Earthworms,' by C. Darwin, 1883, p. 121, where a short preliminary account of the experiment is given.

† *Ibid.*, p. 146. In Knowle Park, under beech trees, worm castings were almost wholly absent.

form of geometrical bearings for the three rounded feet of the stand which carried the micrometer used for measuring the relative positions of the stone and the top of rod.

The action of the earthworms would cause the stone to sink relatively to the top of the rod, but the following other causes should also be considered:—

1. *The Growth of the Roots of the Tree.*—The copper rod passed through about 2·63 metres of slightly sandy red clay which overlies the chalk, and contains many flints; some of these were broken or displaced by the passage of the iron rod. Great force was required to draw the rod out of the ground, and in doing so its sides became scored by the flints. It is, therefore, safe to assume that the flints were pressed with considerable force against the rod, and that their sharp edges gripped it tightly. The point where the rod was gripped, and where there was no relative movement between it and the clay, was unknown; probably, however, it was well below the level of the roots of the tree. The roots growing larger in diameter would raise the stone relatively to the top of the rod. The amount of this movement is quite uncertain.

2. *Dampness of the Ground.*—The clay and the surface soil both, no doubt, swell with increase of moisture. The swelling of the clay above the unknown point at which the rod is gripped will raise the stone, and the swelling of the surface soil will have the same effect.

3. *Expansion of the Rod from Change of Temperature.*—The effect of this is very small and is quite negligible when measurements, taken at the same time of year, are compared. If we take a high estimate and assume that the summer and winter temperature of the rod differed by 10° C., the relative movement of the stone and the top of the rod would be about 0·4 mm.; this is on the assumption that the rod is only gripped close to its lower end, and that the expansion practically of its whole length is taken into account. An attempt was made to eliminate this error by sinking two rods alongside of each other, one being of iron and one of copper, and by taking measurements from both rods. This attempt failed, and the results now given are the measurements from the copper rod only.*

The measuring apparatus is shown in fig. 1. It consists of a brass ring A, with three short rounded feet B, which rest in the radial grooves before mentioned. This annular base carries a vertical brass rod C, to which is soldered an arm with V-bearings D. Trunnions E were fixed to the usual form of micrometer screw gauge as shown in the figure, the trunnions were supported by the V-bearings in the arm,

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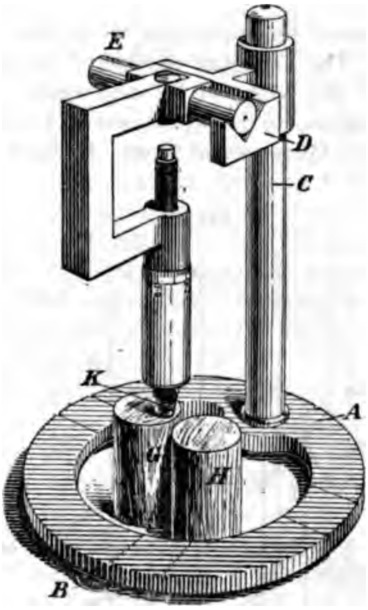
* Professor Judd pointed out that the clay with flints through which the rod passed probably contained small quantities of calcium carbonate which would be slowly dissolved by rain, and that this would produce a small error.—May 2, 1901. *H. D.*

and the micrometer screw was used for the measurement. G and H are the tops of the iron and copper rods; the micrometer screw is turned till its lower end K just touches one of the rods; the upper end of the screw is not used at all. The stand and micrometer were kept indoors till wanted.

Fig. 1.



The method of reading was as follows :—

The grooves for the feet of the stand were cleaned, and the stand placed with its feet resting in them. The trunnions of the micrometer gauge were placed in the V-bearings; the screw was then adjusted till the lower end just touched the top of one rod; by swinging the gauge, which hangs by its trunnions in the bearings, this adjustment could be done with great delicacy.

The gauge was moved sideways by sliding the trunnions along the bearings; this horizontal movement brought the screw over the centre of the second rod, and a second measurement was taken. This second measurement, however, was not used.

The tops of both rods were smooth, and a piece of copper was attached to the iron rod in order to give a surface which would not corrode. The micrometer screw was graduated to 0·01 mm., but as we had not realised the importance of making sure that there was not a small lateral displacement of the trunnions along the bearings, the last place

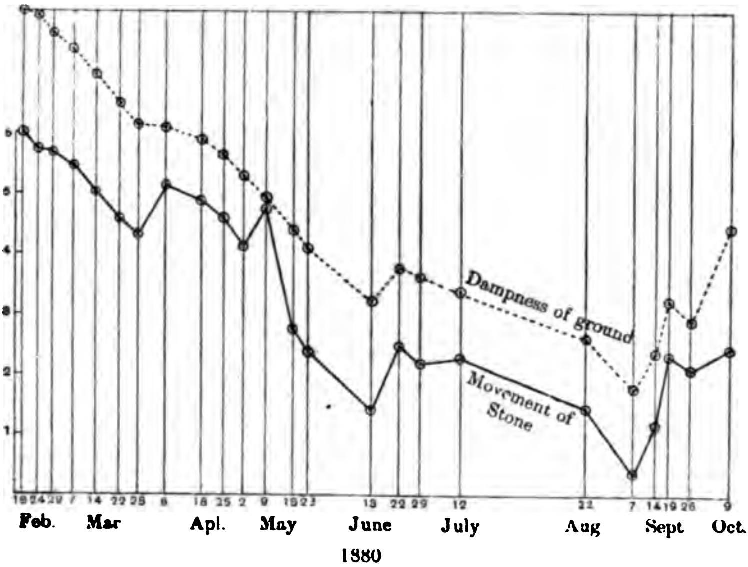
[redacted]

of the decimals was not reliable. This error existed because the horizontal movement of the trunnions along its bearings was not strictly parallel to the surface of the top of the rods from which the measurement was taken. As the readings from one rod only were used, it would have been better if this lateral displacement had been impossible. With care, however, consecutive measurements agreed within 0·01 mm., showing that the method was capable of far greater accuracy than was required.

During the experiment the stone sank more than the range of the micrometer screw. The arm was unsoldered, moved upwards sufficiently far to allow the screw to be used again, and was then resoldered. This operation, no doubt, introduced a small error.

The curve marked "Movement of Stone" in fig. 2 represents the up and down movements of the stone from February 19 to October 9, 1880, due to the varying dampness of the ground.

FIG. 2.



The points corresponding to each observation are surrounded by a small circle; their vertical distance apart is the movement of the stone magnified 8 times, each division of the scale representing 1 mm.; the horizontal distance apart is proportional time.

The following are the observations from which the curve is constructed. The numbers in the second column give the distance moved downward by the stone from its position on February 19, 1880:—

	mm.		mm.
Feb. 19	0·00	May 18	3·23
„ 24	0·28	„ 23	3·62
„ 29	0·43	June 13	4·59
Mar. 7	0·54	„ 22	3·53
„ 14	0·97	„ 29	3·81
„ 22	1·43	July 12	3·72
„ 28	1·69	Aug. 22	4·56
Apr. 6	0·89	Sept. 7	5·62
„ 18	1·11	„ 14	4·84
„ 25	1·43	„ 19	3·69
May 2	1·89	„ 26	3·91
„ 9	1·27	Oct. 9	3·58

The curve shown by the dotted line roughly represents the dampness of the soil. Mr. Baldwin Latham has most kindly supplied me with the rainfall during this period at Leaves Green, about 1 mile distant, and nearly at the same level as Down. I have assumed that the soil dries at a uniform rate; this assumption cannot be correct, but no other is possible. The varying rate of drying will, no doubt, depend on temperature, wind, and dryness of the air, as well as on the rate at which the water drains away.

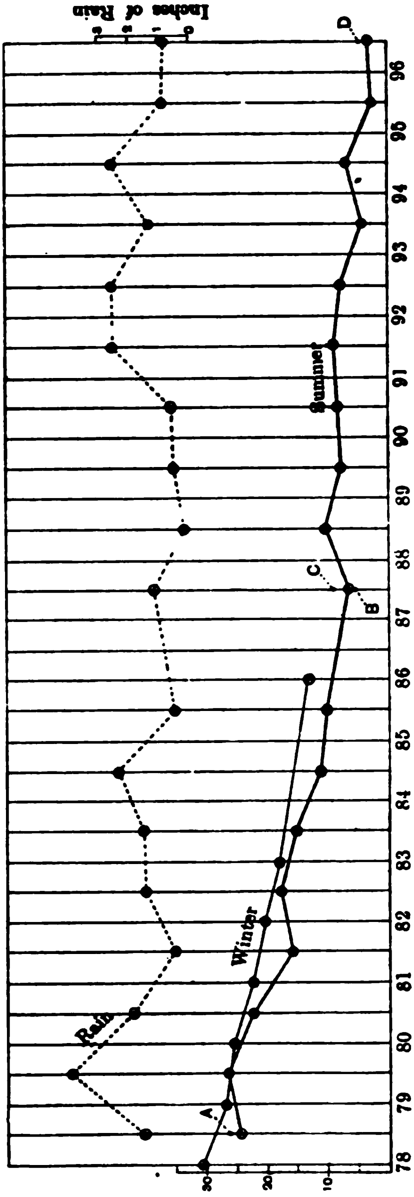
The ordinates are proportional to the amount of the rainfall, less the assumed amount which has evaporated or drained away; both quantities are calculated from February 19, the date of the beginning of the curve. The curves representing the dampness of the soil and the movement of the stone are 16 mm. apart on February 19, the beginning of the experiment, and the rate of drying has been assumed to be great enough to bring them again 16 mm. apart on October 9, at the end of the experiment.

The curves follow each other in a striking manner after May 18. On May 9 the stone-curve rises to a sharp peak when there was no corresponding rainfall, suggesting an error in reading the micrometer on that date; this is the most probable explanation. Mr. W. N. Shaw tells me that there was a thunderstorm on May 4 in the South and West of England with variation in the local rainfall; but this is unlikely to be the explanation, as the rainfall between May 1 and May 9 at Greenwich, 10½ miles distant, is the same as the Leaves Green, 1 mile distant. On April 6 there is again a discrepancy; the form of the curve does not on this date suggest an error in the micrometer reading, and no explanation is suggested.

The direct effect of artifically wetting the ground was tried on July 9, 1878. The ground was not dry, as there had been rain in the previous night. About one hour after the water had been poured on the ground near the stone it had risen 0·4 mm.; six hours later it had risen 0·1 mm. more.

Fig. 3 shows the permanent downward movement of the stone from

FIG. 3.



1878 to 1896. The curve is constructed from readings taken near the middle of January when the ground was free from frost. The points which correspond to these readings are surrounded by small circles and are joined by straight lines. The points are at equal distances apart in a horizontal direction, and their vertical distance apart is 4/5 of the actual displacement of the stone, the numbers on the scale representing mms. This curve is marked "Winter." There were no winter readings after 1886. The Summer curve is made in a similar manner; the dates of the observations are more irregular: the corresponding points, however, are equally spaced in a horizontal direction.

The measurements from which the curve is constructed are as follows; the second column gives the position of the stone measured in mm. :—

	mm.		mm.		mm.
1878, Jan. 26	30·91	... July 7	24·50	1887, Aug. 21	6·50
1879, „ 3	26·92	... „ 10	26·34	1888, Sept. 20	10·34
1880, „ 11	25·59	... „ 12	22·24	1889, „ 17	7·53
1881, „ 9	22·28	... „ 29	15·84	1890, „ 24	8·16
1882, „ 9	20·42	... „ 10	17·61	1891, Aug. 6	8·90
1883, Apr. 3	17·82	... Aug. 1	15·27	1892, Sept. 6	7·72
1884, no winter reading.		... Sept. 14	11·38	1893, Aug. 2	4·03
1885, „ „		... July 19	11·02	1894, Aug. 24	6·86
1886, Mar. 1	18·13	... No summer reading.		1895, Sept. 17	2·50
				1896, Aug. 2	3·14

The stone was accidentally removed and no readings were taken after 1896.

If we take the winter readings, we find that the stone sank 17·8 mm. in the eight years from January 1878 to March 1886, or at the average rate of 2·22 mm. per year, rather less than 1 inch in ten years. My father found* that small objects left on the surface of a field were buried 2·2 inches in ten years. This result is obtained from observations in a field near the stone. The large stone sank more slowly, a result we should expect.

The curve shows that the rate of sinking was greater at the beginning than at the end; this is probably due to the decaying of the grass; the turf was not removed, the stone resting directly on it.

The third curve, marked "Rain" on this diagram, roughly indicates the dampness of the ground. The ordinates of the curve are proportional to the rainfall at Greenwich Observatory during the twenty days before the date of the summer reading. The curve is only a very rough indication of the dampness of the soil, as no account is taken of the rainfall for a longer period than twenty days before the observation, and neither is the evaporation during this period allowed for. The rainfall at Down also is assumed to be the same as at Greenwich, although they are 10½ miles apart, and Down is 569 ft. above Ordnance datum, and Greenwich is 155.

The summer curve is far more irregular than the winter curve; this

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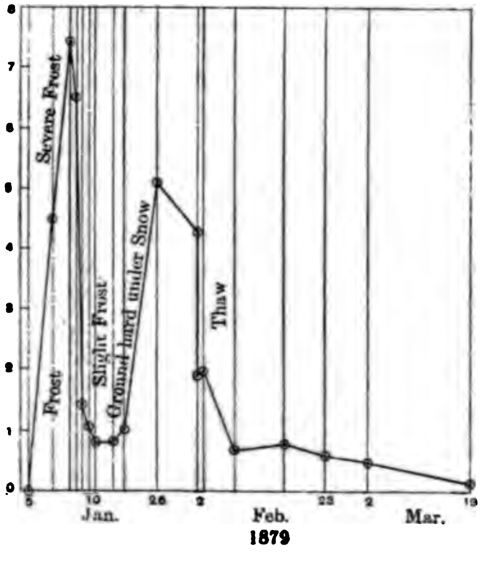
* 'Vegetable Mould,' 1883, p. 142.

no doubt is due to the greater variation in the dampness of the soil in summer than in winter. The rain-curve and stone-curve roughly follow each other. In 1888, however, the stone rises and the rain-curve shows very little rain for the twenty days before September 20, the date of this observation. During June, July, and August a great amount of rain fell; and although there was very little rain from September 1 to 20, the ground was probably damper than the rain-curve indicates. At Hayes, 3½ miles from Down, the rainfall on these days was greater than at Greenwich, but still very small.

If the points marked A and B are joined by a straight line, it will roughly represent the mean movement during the first nine years of the experiment. These points were selected so that the line joining them appeared to represent the mean movement to the best of my judgment. In the same manner the points C and D were selected, so that the line joining them represented the mean movement of the last nine years of the experiment. The movements deduced by this method are 2·3 mm. per year for the first nine years, and 0·36 mm. the last nine years. The slow movements for the latter period are surprising. The movement given above and obtained from the winter curve is 2·22 mm. per year.

FIG. 4.



During the last five years the rainfall on the twenty days before each observation was distinctly above the average; it was 2·09 inches, and the average for these twenty days during the whole experiment is

1·54 inches. This will perhaps partially explain the slow movement at the end of the experiment.

The curve, Fig. 4, shows the movement due to frost. It is constructed as before, and the ordinates represent the position of the stone magnified 8 times. On February 2, at 12.45 P.M., the thaw was beginning, but the ground was still hard; readings were also taken at 3.25 P.M. and 5.25 P.M. The stone fell 2·37 mm. in 4 hours 40 minutes.

May 9, 1901.

Meeting for Discussion.

Sir WILLIAM HUGGINS, K.C.B., D.C.L., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

Professor Franz von Leydig was balloted for and elected a Foreign Member of the Society.

The President stated from the Chair that the meeting was convened in pursuance of the following resolution of the Council, passed at their meeting on February 21, viz.:—"That a special meeting of the Fellows be called in order that the President and Council may have an opportunity of hearing the views of the Fellows on the questions raised in the Report of the British Academy Committee, it being understood that no vote will be taken."

The Report under reference was laid before the meeting, and a discussion ensued, in which the following Fellows took part:—Sir Norman Lockyer, Dr. Johnstone Stoney, Professor A. R. Forsyth, Professor S. P. Thompson, Professor E. Ray Lankester, Sir John Evans, Professor A. Schuster, the Right Hon. J. Bryce, Professor J. D. Everett, Sir Henry Howorth, Sir A. Geikie, Dr. J. H. Gladstone, and Mr. G. J. Burch.

May 23, 1901.

Sir WILLIAM HUGGINS, K.C.B., D.C.L., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

Professor James Gordon MacGregor was admitted into the Society.

The following Papers were read:—

I. "On the Presence of a Glycolytic Enzyme in Muscle." By Sir LAUDER BRUNTON, F.R.S., and HERBERT RHODES.

II. "On Negative After-images and their Relation to certain other Visual Phenomena." By S. BIDWELL, F.R.S.

III. "The Solar Activity 1833–1900." By Dr. W. J. S. LOCKYER. Communicated by Sir NORMAN LOCKYER, K.C.B., F.R.S.

IV. "A Comparative Crystallographical Study of the Double Selenates of the Series $R_2M(SeO_4)_2,6H_2O$.—Salts in which M is Magnesium." By A. E. TUTTON, F.R.S.

V. "On the Intimate Structure of Crystals. Part V.—Cubic Crystals with Octahedral Cleavage." By Professor W. J. SOLLAS, F.R.S.

VI. "Preliminary Statement on the Prothalli of *Ophioglossum pendulum*, L., *Helminthostachys zeylanica*, Hook., and *Psilotum sp.*" By Dr. W. H. LANG. Communicated by Professor BOWER, F.R.S.

The Society adjourned over the Whitsuntide Recess to Thursday, June 6.

"On Negative After-images, and their Relation to certain other Visual Phenomena." By SHELFORD BIDWELL, M.A., Sc.D., F.R.S. Received May 1,—Read May 23, 1901.

I. *Preliminary.*

In a former communication I described a curious phenomenon due to the formation of negative after-images following brief retinal excitation after a period of darkness.[*] The effect is conveniently demonstrated by the aid of a disc, partly black and partly white,

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[*] 'Roy. Soc. Proc.,' 1897, vol. 61, p. 268.

having an open sector, as shown in fig. 1. If such a disc is caused to turn five or six times in a second, while its surface is strongly illuminated, a coloured object placed behind it and viewed intermittently through the open sector, generally appears to assume an entirely different hue, which is approximately complementary to the true colour of the object: a piece of red ribbon, for example, is seen as greenish-blue and a green one as pink.

FIG. 1.

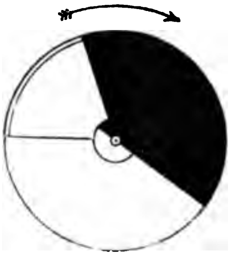
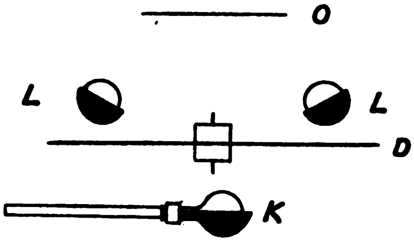


FIG. 2.



The tints thus produced are referred to in the paper as "pale" ones. I have since found that their intensity may in most cases be greatly increased if the object is illuminated more strongly than the disc. The best arrangement for the purpose is indicated in plan in fig. 2, where O is the coloured object, *e.g.*, a design painted on a card, L, L are two incandescent electric lamps of fifty candle-power, and K is a third lamp of thirty-two candle-power, supported horizontally a little above the axis of the disc: all three lamps are fitted with metal hoods to screen the light from the observer's eyes. The distance of the lamp K from the disc may be varied until the best results are obtained. When only a single lamp is used for illuminating both the object and the disc (as in the original arrangement), the light portion of the disc should be covered with paper of a pale neutral tint (not bluish), reflecting about half as much light as ordinary white paper; for experiments in bright diffused daylight, the paper may advantageously be of a pale yellowish-grey or buff tint. The dark part of the disc should be covered with good black velvet, and the open sector should extend to about 70°, instead of only 45°, as recommended in the former paper.

A number of observations made from time to time with the apparatus as thus modified have shown that the "pulsative" after-images, as they will be called, differ in several important respects from the "ordinary" negative after-images seen upon a white or grey background after the gaze has been fixed for some seconds upon a coloured object. The colours of the pulsative after-images produced by certain hues of red and of green may appear far more intense or saturated than those of the ordinary negative after-images excited by the same

[redacted]

primary colours under similar conditions of illumination; in particular, the greenish-blue into which bright red appears to be transformed is singularly strong and luminous. This is a matter for some surprise, since it might naturally be expected that the intermittent impressions of the exciting colour, even though not consciously perceived, would be compounded with and tend to enfeeble the complementary hue of the after-image. On the other hand, when the exciting colour is blue or yellow, it is found difficult to obtain a satisfactory pulsative after-image. The complement of blue is an orange-yellow, which is also the hue of the ordinary after-image. But the pulsative image excited by blue, especially if the colour is at all bright, is in most cases an impure pink or salmon of feeble intensity. By using dull greyish-blue pigments I have succeeded in obtaining a very fair yellow, which is further improved if a little lamp-black is added to the paint. But in such cases the formation of yellow is no doubt chiefly attributable to the inferior luminosity of the pigment, for a perfectly neutral-grey wash of lamp-black will itself give a yellow image, an effect which is probably due merely to intermittent illumination of feeble intensity. When a yellow pigment is the exciting colour, the hue of the pulsative image is not the complementary blue-violet but a pale purple, only just perceptibly bluer than the subjective purple excited by green. A pulsative image which is really blue has never been obtained from any pigment whatever, the nearest approach being the greenish-blue excited by orange, or the bluish-purple which follows yellow. It has been found equally impossible to obtain either a true red or a true green in the pulsative image. All greens, ranging from yellow-green to green-blue, are transformed into some form of purple, including rose and pink. Purple produces in the pulsative image almost the same kind of blue-green as red, quite different from the pale grass-green colour characterising the ordinary after-image of a purple object.

The effects observed with the apparatus described above may be shortly summarised in the statement that the pulsative image of a colour in which red predominates is blue-green, that of dull blue is yellow, and that of any other colour (including bright blue) is purple or purplish-grey. In the experiments to be described in the present paper, spectrum colours were used instead of pigments, being blended into uniform mixtures by means of a simple form of Sir W. Abney's well known "colour-patch" apparatus.*

II. *Methods of Experiment.*

Method I.—The arrangement for generating pulsative after-images when the blended spectrum colours are projected upon a screen is shown

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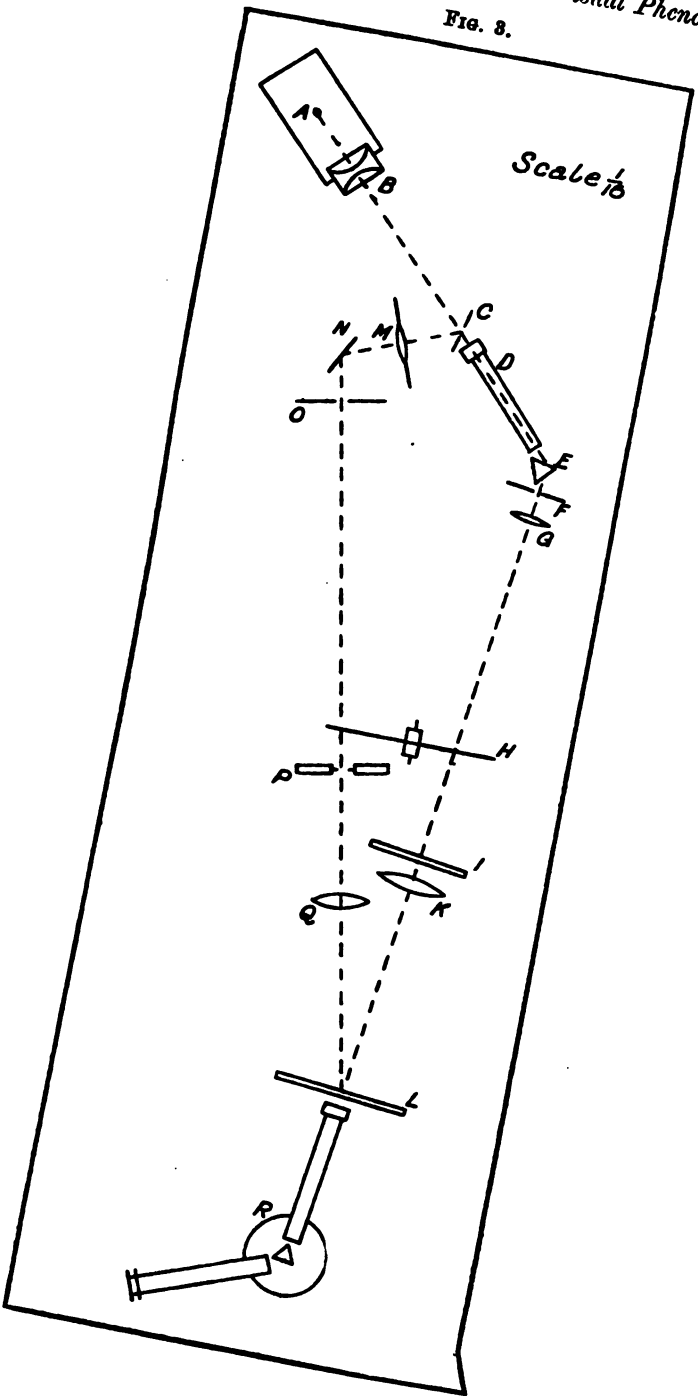
* 'Phil. Trans.,' 1886, Part II, p. 423.

FIG. 8.



in fig. 3, on a scale of one-sixteenth. By means of the condenser B, the image of the positive crater of the electric arc A is projected upon the slit of the collimator D. The emergent parallel rays are refracted by the prism E, and thence pass successively through a circular aperture in the diaphragm F, through the achromatic lens G, and through an opening in the rotating disc H (which renders the light intermittent) until they reach the slit-screen I, upon the face of which the spectrum is focussed by the lens G. The screen contains three adjustable vertical slits, the position of which can be varied; one, two, or three selected portions of the spectrum may be allowed to pass through the slits to the large lens K, which is arranged to project a sharp image of the circular aperture in the diaphragm F upon the white screen L. This image constitutes the "colour-patch"; it is illuminated by a uniform mixture of the spectrum-rays transmitted by the slit-screen.

In front of the collimator-slit D is placed a mirror C, from the back of which a strip of the silver, 20 mm. long and 4 mm. wide, has been removed. So much of the unabsorbed light from the electric arc as does not pass through the clear glass to the collimator-slit is reflected, as shown by the dotted line, through the lens M to the mirror N; thence it is again reflected through an aperture in the diaphragm O (where an image of the condenser B is formed by the lens M); it then passes (intermittently) through an opening near the circumference of the rotating disc H to the wooden screen P, upon which an elliptical image, about 12 cm. by 4·5 cm., of the positive crater is formed. The image is crossed by a dark vertical band, corresponding to the space of clear glass in the mirror C. An opening in the screen P is furnished with an iris-diaphragm, the aperture of which can be varied from 2 mm. to 30 mm. The mirror N is so placed that a portion of the image of the crater on one side or the other of the dark band may cover the iris-diaphragm. A lens Q focusses an image of the aperture in the iris-diaphragm upon the screen L, the disc of white light thus formed being concentric with the colour-patch.

The following are details of the apparatus: The collimator-slit is adjustable by a screw having a divided head; the achromatic lens at the other end has a clear aperture of 2·86 cm. ($1\frac{1}{8}$ inch) and a focal length of 25·4 cm. (10 inches). The extra dense flint-glass prism E has a refracting angle of 60°, and its faces are 5·1 cm. (2 inches) square. The diameter of the circular aperture in the diaphragm F is 2·3 cm. ($\frac{9}{10}$ inch). The focal length of the achromatic lens G is 76 cm. (30 inches), and its diameter 5·1 cm. (2 inches).

The zinc disc, H, as seen from the lantern, is represented in fig. 4. Its diameter is 34 cm.; the opening near the centre extends to 45° and that near the circumference to 135°; both could be varied by movable zinc sectors, but the angles specified were found to be generally the most effective. The disc is driven by an electric motor in

circuit with a variable resistance, the latter being adjusted so that the speed of rotation may be a little higher than is required for the experiment; a short-circuit key within reach of the observer's hand enables him to vary the speed at will or to keep it sensibly constant. A wire attached at right angles to the axis of the disc taps a strip of card at every revolution, producing a succession of audible clicks, which can, when desired, be compared with the taps of a metronome beating seconds. The most usual speed is from five to six turns per second. The disc apparatus is supported at such a height from the table that when the disc is turning in the direction of the arrow the spectrum projected upon the screen I (fig. 3) is eclipsed at the moment when the iris-diaphragm in the screen P is beginning to be exposed to the white light. During about one-half of a revolution both the diaphragm and the slits are shielded by the disc. The width of the spectrum projected upon the slit-screen I (fig. 3) is 2·9 cm., and its visible length in a dimly lighted room about 7 cm.; the measured distance between λ 6870 (Fraunhofer line B) and λ 4115 (iron line between *g* and H) was approximately 6·1 cm.

FIG. 4.

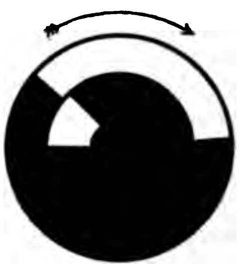
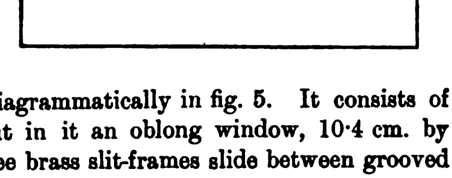


FIG. 5.



The slit-screen is shown diagrammatically in fig. 5. It consists of a mahogany board, having cut in it an oblong window, 10·4 cm. by 2·7 cm., over which the three brass slit-frames slide between grooved guides above and below. Each slit-frame is 1·8 cm. wide, and has an aperture of 2·5 cm. by 0·6 cm. The slit-jaws (not shown in the diagram) are attached to the front surfaces of the brass frames, and are adjustable in the parallel-ruler fashion, one of every pair being fixed to its frame; the slits can be opened to 0·55 cm. The two outermost slit-frames are attached by screws to sliding shutters, which serve to cover such portions of the window right and left of the slit-frames as would otherwise be open to the light. The spaces between the middle slit-frame and the two outer ones are closed by opaque black ribbons (shaded in the diagram), constituting miniature spring-roller blinds. The axes of the spring rollers are so placed (perpendicularly behind one edge of a slit-frame) that even when the slit-frames are in contact with one another, and the slits are opened to their widest extent, no obstruction to the passage of the light through the slits is presented by the rollers. Each slit-frame can be moved independently to any desired position, and clamped with a set-screw. On the other side of the slit-screen a second pair of guides is fixed, each having three parallel saw-cut grooves in it. These guides carry rectangular pieces of sheet zinc of various widths, which may be used to shield temporarily one or more of the slits when it is desirable that its adjustment shall not be disturbed. In some experiments it is necessary to use larger portions of the spectrum than can be transmitted by the slits; the slit-frames are then removed from the screen, and the spectrum dealt with solely by means of the zinc plates. Pieces of zinc sliding in different pairs of grooves may be made to overlap one another, thus providing screens or openings of almost any desired width with very little trouble.

The diameter of the lens generally used at K, fig. 3, is 10·2 cm. (4 inches), and its focal length 30·5 cm. (12 inches), the diameter of the circular colour-patch projected upon the screen being then only about 1·5 cm. This size was, however, amply sufficient for most purposes, and with a larger image the necessary luminosity could not always be obtained. Sometimes a lens having a focal length of 40·6 cm. (16 inches) was used at K, the diameter of the patch then being 2 cm.

The focal length of the lens M is 12·7 cm. (5 inches); it is surrounded by a broad diaphragm to screen off stray light. O is a device known to photographers as a "rotating diaphragm"; it has eight apertures ranging from 0·21 cm. to 1·42 cm. in diameter, any one of which can be placed in the path of the beam of light. Its object is to vary the luminosity of the white-light disc projected upon the screen L. The lens Q has a diameter of 6·5 cm. and a focal length of 16·5 cm. (6½ inches).

Wave-lengths of the Colour-patch Light.—No attempt was made to standardise the spectrum projected upon the slit-screen, the wave-lengths of the light illuminating the colour-patch being determined, when necessary, by means of the spectroscope R, fig. 3. The opaque white screen L being removed, a screen of ground-glass is put in its place, and the slit of the spectroscope is brought near the bright image on the glass. The purpose served by the ground-glass is to diffuse the light, so that any element of the light transmitted by the slit-screen may be at once examined without the need of turning the spectroscope in its direction. The spectroscope has a six-inch circle with a vernier reading to minutes; the prism is of extra dense Jena glass, the refractive index for D being 1·693. To ascertain the constitution of a colour-patch, the deviations corresponding to the two extremes of the one or more coloured bands seen in the spectroscope are determined,

and the related wave-lengths are derived from a large-scale curve. When it is desired to form a colour-patch consisting of a mixture of light of given limiting wave-lengths, the slits in the slit-screen are moved and adjusted until the limits of the bright bands seen in the spectroscope coincide with the vertical cross-wire when the telescope is set at the proper predetermined angles.

Illumination and Luminosity.—It should be remarked that the colour of an object, self-luminous or illuminated, is not completely specified by a mere statement of the wave-lengths of the light which it emits or reflects. This fact is of course well known, but it is doubtful whether sufficient importance is always attached to it; it has many times been strikingly brought to my notice in the course of the experiments under consideration. A complete account of the colour-conditions should include a determination of the luminosity expressed in terms of some standard unit; unfortunately, however, this cannot easily be given. In order to furnish data for approximately estimating the luminosity of the projected colour-patch when illuminated by selected spectral rays, a rough photometric measurement was made of the illumination of the white colour-patch produced by the whole recombined spectrum, a "focus" electric lamp of 25·5 standard candle-power being employed for the comparison. It was found that when the width of the collimator-slit was 0·5 mm. (the width usually employed), the illumination was equal to that due to 8800 standard candles at a distance of 1 metre, or, as it may be called, to 8800 "candle-metres." Taking the luminosity-sensation due to this illumination as the unit or standard of reference, the relative luminosity of a patch lighted by rays taken from any parts of the spectrum can be deduced from Abney's luminosity-curve for the normal electric-light spectrum.* For example, a purple colour-patch was formed by combining the red between λ 6380 and λ 6600 with the blue-violet between λ 4250 and λ 4370. The area enclosed by the curve and the ordinates meeting the horizontal axis at 6380 and 6600 was found to be 0·0361 of the whole, and the corresponding area for the blue-violet 0·0027. The luminosity of the purple patch relatively to that of a piece of white cardboard illuminated by 8800 candles at 1 metre was therefore 0·0361 + 0·0027 = 0·0388. The variation from time to time of the intensity of the source of light, though no doubt considerable, is for the present purpose unimportant.

Approximate values for the illumination of the white disc due to light reflected by the mirror C, fig. 3, and passing through the apertures in the diaphragm O, are given in the following table.

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* 'Phil. Trans.,' A, vol. 193 (1899), p. 282.

Table I.

Aperture No.	Diameter. mm.	Candle-metres.
1	14·2	5600
2	11·4	3600
3	8·6	2050
4	5 4	800
5	4 0	440
6	3 2	280
7	2 4	160
8	2 1	120

Method II.—It is shown in fig. 6 how the colour-patch may be viewed directly by means of a Huyghens' eyepiece. A diaphragm having an aperture of 1 cm. is fixed in front of the prism (F, fig. 3) and is seen in the eyepiece when properly placed as a sharply defined bright disc illuminated by the coloured rays passing the slit-screen I. The apparent diameter of the disc is about one-fourth of that of the field of view. Its coloration is sensibly uniform, but the method cannot be used to combine widely separated portions of the spectrum, and only a single slit was generally opened. The white light, which in the production of the pulsative after-image alternates with the coloured light, passes through the iris-diaphragm P, and the lens Q to the silvered mirror S; thence it is reflected to the unsilvered mirror T of thin plate glass, which directs some of the light upon the eyepiece V. For most observations pieces of ground-glass were placed behind the iris-diaphragm P and before the collimator-slit in order to subdue the light.

Method III.—The apparatus is arranged as in fig. 3, but for the white cardboard screen there is substituted a piece of ground-glass covered with opaque paper, in which is cut a circular opening 1 cm. in diameter, the colour-patch and the concentric white-light disc being projected upon the opening. At a distance of 9 or 10 cm. behind the glass is placed a Huyghens' eyepiece, its position being such that the field of view is just filled with the coloured light. By the aid of this device observations can be made much more satisfactorily than when the image upon the ground-glass is viewed merely by the unassisted eye. Rays from any part of the spectrum can be combined; but the absence of a surrounding white ground with which to compare the colour of the pulsative after-image is often found to be inconvenient. For some of the experiments a screen of thick brown paper attached to the rocking arm of a metronome was arranged to eclipse the spectrum rays periodically, without obstructing the white light; thus the pulsative image and the white light were seen in the eyepiece *lternately*, each for a period of a little more than one second, and it became easier to judge of the colour of the image. The iris-diaphragm was covered with ground-glass.

Method IV.—This is not a colour-patch method, but an ordinary spectroscopic one, the unmixed spectrum as dispersed by the prism being viewed through a tubeless telescope. The eyepiece V (fig. 7) occupies the place of the slit-screen behind the disc H; white light is reflected into the eyepiece by the silvered mirror S and the clear plate-glass T, as in Method II. A sheet of ground-glass takes the place of the iris-diaphragm, which is removed. The arrangement is in all essential respects similar to that adopted by Mr. Burch,* except that the reflected white light is derived from the electric arc instead of from the sky, its intensity being capable of wide variation. About one-third of the whole length of the spectrum can be seen at once; the eyepiece is so directed that the spectrum may occupy only the lower half of the field, while the white light, when admitted, fills the whole of it.

FIG. 6.

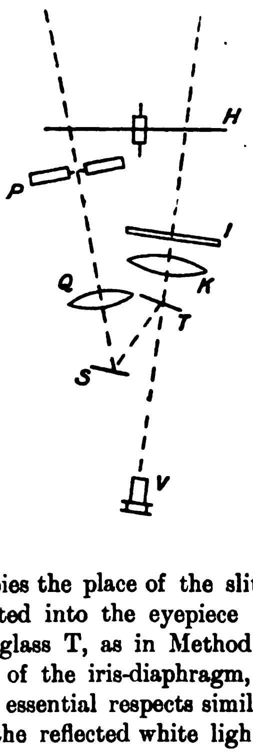
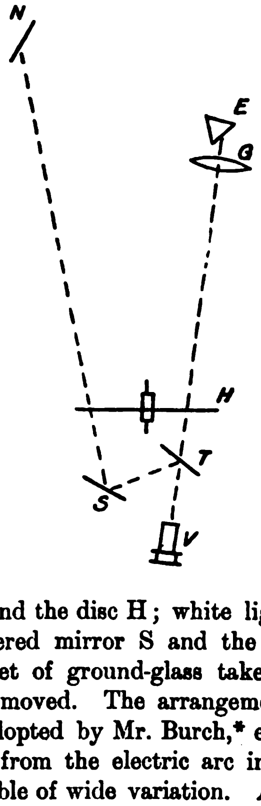


FIG. 7.



Ordinary Negative After-images.—The apparatus, whether arranged for the projection of a colour-patch upon a screen or for observation with an eyepiece, is exceedingly well adapted for the study of ordinary negative after-images. The zinc disc H is set so that a coloured image is formed upon a black ground; after this has been gazed at for 10 or 20 seconds, it is obliterated by turning the disc through a

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* 'Roy. Soc. Proc.,' vol. 66, p. 215.

small angle, a white patch of any desired luminosity appearing in its place. The hues of the negative images seen upon the white patch are often very different from those of the pulsative images formed when the disc is rotating continuously.

III. *Pulsative Images due to Various Colours.*

Red.—A red colour-patch formed on the screen by a combination of rays extending from the extreme limit of the spectrum to λ 6450 gives no pulsative after-image at all, the white-light disc, whatever may be its intensity, appearing white throughout. If the slit is further opened to admit rays up to λ 6320 a faint blue-green image is seen upon the white-light disc, provided that the latter is not too strongly illuminated; with apertures greater than No. 5 of the diaphragm O, fig. 3, the blue-green image disappears. The absence of a pulsative image after a low red is, no doubt, in great measure due to the superior persistence of this hue, for the ordinary after-image is quite distinct.

In general the pulsative images of red, or of red and orange mixed, are of a blue-green tint, exceeding in brightness and apparent saturation those due to any other exciting colours. Perhaps the strongest effect was observed when the colour-patch was illuminated by rays from about λ 6100 to λ 6550, aperture No. 4 of the rotating diaphragm being used for the white-light disc. No pulsative image of the red can, however, be formed unless the luminosity of the patch is fairly great.

With the eyepiece methods a feeble pulsative image was excited by red in the neighbourhood of the B line. Its hue appeared bluish with a slight tinge of green. In other respects the results for red were similar to those obtained by Method I.

Orange.—A colour-patch was formed by mixing rays from λ 5800 to λ 6150. Its ordinary after-image was bright sky-blue. The pulsative image upon the screen appeared a rather dull blue-green with aperture No. 2 of the rotating diaphragm and green-blue with apertures 3 and 4. The eyepiece method showed the colour as blue-green, paler than that excited by red.

Yellow.—The ordinary after-image of a patch of yellow, λ 5700 to λ 5890, was blue-violet. The tint of the pulsative image on the screen was a pale nearly neutral grey, pinkish when the illumination was weak, bluish when it was strong. A slightly more orange yellow, λ 5700 to λ 5980, gave an image of nearly the same character but a little stronger. When the eyepiece methods II and III were employed with yellow, the pulsative images were exceedingly feeble, and generally appeared to contain a trace of pink. The image due to a greenish-yellow, λ 5590 to λ 5740, was more decidedly pink or pale purple. Similar effects were obtained when the exciting yellow was produced by mixing red and green rays. An orange-yellow, made by combining the spectrum rays from the extreme red to λ 5340 in the green, had a slate-coloured or nearly neutral pulsative image; the addition of a very little more green turned the image pink.

Green.—A colour-patch sufficiently illuminated by green rays taken from any part of the spectrum between greenish-yellow and greenish-blue inclusive (about λ 5750 to λ 5050) produced a pink or dilute purple pulsative image; the purple was strongest when the exciting colour was a full green, but it never reached an intensity equal to that of the blue-green excited by red when the conditions were most favourable. On the other hand, there can be no question that a purple pulsative image after green is much more easily produced than a blue-green one after red, a fact which tends to indicate that, at least after a short period of repose, the colour-sense organs become fatigued more quickly by green light than by red. It seems to be generally believed that the red sensation is more readily exhausted than the green.* Rood,† however, attributes the "well-known intolerance of all full greens to the fact that green light exhausts the nervous power of the eye sooner than light of any other colour," this exhaustion being "proved by the observation that the after-pictures . . . are more vivid with green than with the other colours." The results of my own observations lead me to think that while after a prolonged gaze at brightly illuminated colours, blue-green after red is more conspicuous than purple after green, the opposite may be the case when the exposure has been brief or the illumination feeble. In the case of the pulsative image, however, account must be taken not only of fatigue, but also of persistence and of the latent period during which the first impact of light upon the eye fails to produce any recognisable sensation.

Blue.—Though the ordinary after-image of blue is orange, the pulsative image upon the screen was generally seen as some form of impure purple, variously described as dull pink, salmon, or flesh colour. The same was often the case when the eyepiece methods were employed. Among the blues tested were a mixture of λ 4700 to λ 4950, and one of λ 4550 to λ 4760, besides many others of which the limiting wave-lengths were not determined. By Method II a good orange-yellow image could always be produced from the last-named blue, provided that the illumination was sufficiently strong and the various luminosities carefully adjusted.

Blue-violet and Violet.—The ordinary after-image is yellow. The screen method showed scarcely any image at all for light of wave-lengths less than about λ 4500. With the eyepiece methods the image

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* Foster, 'Text-book of Physiology,' 6th edition, p. 1382.

† 'Modern Chromatics,' 2nd edition, p. 295.

usually appeared as a pale bluish-pink, which could be closely matched by blue-violet diluted with much white. The persistence of violet impressions is very great, and it is not unlikely that the bluish-pink image was due merely to the intermingled action of the violet and white-light rays (as in a Maxwell's disc), and was not a true pulsative after-image. In the circumstances mentioned in the last paragraph, when blue light gave an orange pulsative image, blue-violet also gave a yellow one, the persistence of blue-violet being less with strong than with weak illumination.

Purple.—A bright purple was made by combining red, λ 6180 to λ 6810, with blue-violet, λ 4330 to λ 4420. The ordinary after-image of the red alone was blue-green, and that of the purple grass-green. The pulsative image of the purple formed on the screen was, however, blue-green, and when the slit admitting the blue-violet light was alternately covered and uncovered, no change in the colour of the image could be detected.

IV. *Pulsative After-image of White.*

Recombined Spectrum.—If the slit-frames and their appurtenances are removed from the slit-screen I, fig. 3, the whole spectrum is recombined by the lens K, and forms upon the screen L a white "colour-patch," the illumination of which can be varied in a known manner by changing the width of the collimator-slit. The illumination of the "white-light disc" (which, during an experiment, alternates with the white "colour-patch") can also be adjusted to certain known intensities. A large number of experiments, which need not be described in detail, were made with various illuminations of the white colour-patch and of the white-light disc. The colour of the pulsative images of the white patch, which is not in general neutral like that of the ordinary after-image, was found to depend not only upon the absolute values of the two illuminations but also upon their ratios. Broadly speaking, it may be stated that with feeble illumination the patch appeared yellow (probably only an effect of weak intermittent light), with very strong illumination it was a neutral grey, and with all such intensities of illumination as are ordinarily employed it appeared a more or less decided purple.

In my former paper reference was made to the purple tint assumed by a white card when seen through the original black and white disc, and a distinguished physiologist, who saw the effect, expressed the opinion that the colour might be due to the "visual purple." In the light of the observations described in the present paper, it seemed possible that the phenomenon might be explained by the hypothesis that the purple was really an after-image of the green component hich, according to the Young-Helmholtz theory, is contained in the white light. All the various components set up fatigue after a moment's action, but green more than the others; if, therefore, the green stimulus were diminished to an extent corresponding to the excess of fatigue which it produced, the tint of the pulsative image might be expected to become neutral, like that of the ordinary negative after-image. Different parts of the green portion of the spectrum were accordingly cut out by interposing strips of black card of various widths, and it was found that when the green rays from λ 5030 to λ 5470 were intercepted, the tint of the pulsative image was absolutely neutral.

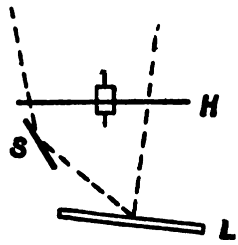
White compounded from Red and Blue-green.—Such a white always gave a pink pulsative image—a fact which confirms the inference derived from previously described observations that the blue-green sensation is, after an interval of repose, more readily fatigued than the red sensation.

White compounded from Yellow and Blue.—A white colour-patch was formed by combining a blue of λ 4530 to λ 4710 with a yellow of λ 5650 to λ 5860. The colour of the pulsative image was rather doubtful, but an artist (who did not know what to expect) unhesitatingly pronounced it to be yellow. Since the Young-Helmholtz theory supposes that yellow excites the green sensation, this result was unexpected. It is also opposed to the usually received opinion that the sensation of yellow is more readily exhausted than that of blue.[*]

V. *Pulsative Images of Complete Spectrum.*

The spectrum was projected upon a screen covered with white cardboard, which was put in the place of the slit-screen, as shown in fig. 8.

FIG. 8.



The beam of intermittent white light was reflected upon the screen by means of a mirror and formed an oblong bright patch upon the site of the spectrum. The upper part of the mirror was covered by a screen, so arranged that the site of the spectrum was longitudinally divided into two equal parts, the lower of which was exposed to intermittent

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[*] Foster, *loc. cit.*

white light, while the upper was not. Thus the spectrum and its pulsative image could be seen together, the one above the other. At first sight the pulsative image appeared to contain only two colours—blue-green corresponding to the spectral red and orange, and purple-pink corresponding to the green. Closer inspection revealed a pale grey band between the blue-green and the purple, and a feeble tint of lavender corresponding to the blue of the spectrum. Nothing at all could be seen beneath the violet and the extreme red. The boundaries of the several colours of the pulsative image were found to be roughly as follows:—Blue-green, λ 6800 to λ 6000; grey, λ 6000 to λ 5800; purple, λ 5800 to λ 5000; lavender, λ 5000 to λ 4300.

Observations were also made of the changes undergone by the red and green of the projected spectrum when the illumination was varied by altering the width of the collimator-slit. With a width of 0·06 mm. neither of the spectrum colours was at all affected; they appeared simply as intermittent red and green. With 0·125 mm. the green had become transformed into a purple, intermixed with which a little green could sometimes be glimpsed; this latter completely disappeared when the slit was made 0·2 mm. wide, the apparent colour being with this and all greater widths of slit a steady purple. At the same stage (0·2 mm.) red was still seen as red, though a flicker of blue-green could be detected upon it. At 0·45 mm. red appeared as blue-green with a red flicker, which ceased to be perceptible, except along the extreme edge, when the width of the slit was increased to 0·5 mm. With a slit of 0·94 mm. wide the last trace of red had vanished. Thus the more ready exhaustion of the green sensation is again evidenced.

VI. *Colour Changes with Reversed Cycle.*

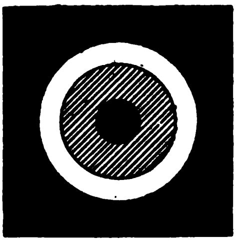
If the cycle is reversed by making the zinc disc turn in the opposite direction, most of the spectrum colours undergo remarkable changes. Red becomes rose-purple; orange a diluted crimson; yellow is made much paler, as if veiled by a white haze; green appears as blue-green, and blue-green as blue. Blue and violet are very slightly affected. Very similar effects are observed when the disc described in Section I is turned in the reverse direction. They naturally suggest that white light excites a blue or blue-violet sensation, the persistence of which exceeds that of any other fundamental sensation.

VII. *External and Border Phenomena.*

Some very remarkable and interesting phenomena are exhibited in the region of the visual field immediately adjacent to that upon which a "pulsative after-image" is being produced. It is a matter for surprise that one should be able to perceive after-images without detecting any indication whatever of the colours to which they are due, but it is perhaps even more surprising to find that parts of the retina upon which the intermittent white light does *not* fall may also be absolutely blind to the exciting colour.

The effect in question is conveniently demonstrated by the arrangement illustrated in fig. 9. A piece of clear glass, upon which is gummed a small circle of black paper or tinfoil, is fixed behind the iris-diaphragm P, fig. 3, and thus a round black spot, 0·6 cm. in diameter, is formed at the centre of the white-light disc projected upon the screen L. In fig. 9 the outer circle represents the white-light disc, the shaded circle the colour-patch, and the inner one the black spot upon the white-light disc. Suppose the colour-patch to be green. When the apparatus is worked, the shaded circle becomes purple; the site of the black spot, being illuminated five or six times in a second by green light, might be expected to appear green; but if viewed from a distance of 30 cm. or more it remains perfectly black throughout; under normal conditions no trace of a flicker of green light can be seen upon it. The apparent width of the blind region adjoining the site of the pulsative image, therefore, exceeds half a degree.

FIG. 9.



This induced blindness is most conspicuous when the light is green, and hardly less so when it is yellow; it does not occur at all with extreme red nor with violet light, which illuminate the site of the black spot quite strongly; but its absence is certainly not entirely due to the inferior luminosity of those hues. With a very narrow slit green can indeed be seen in the central part of the spot by an observer stationed quite near the screen; but if he is at a distance of 1·5 metre, the green light may be weakened by gradually closing the slit until the pulsative image completely disappears, yet no green is ever seen upon the spot.

The following are the results noted in one experiment, when a slit was moved across the spectrum from end to end. Red was seen upon the spot, at first nearly continuously, then intermittently, until the slit reached about λ 6220, when, unless the illumination was made very

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feeble, the spot became uniformly black, remaining so until about λ 5000, at which point a blue flicker began to appear; at λ 4700 the spot had become steadily blue. Blue-violet and violet seemed to illuminate the spot much more steadily than red. It was noticed that as soon as the black spot became distinctly coloured the pulsative image almost disappeared; the weakness of the pulsative images excited by light corresponding to the two ends of the spectrum may therefore probably be accounted for by supposing that the negative after-images become blended either with the primary images, or with positive after-images, or perhaps with both, producing the effect of white.

It was found possible to observe these phenomena not only when the zinc disc was spinning continuously, but even with a single properly timed cycle of (1) darkness; (2) colour-patch; (3) white light; (4) darkness. When the spectrum light was green, there appeared for a moment a bright white disc with a perfectly black central spot, which was surrounded by a well-defined purple annulus (as in fig. 9), the whole being free from any visible trace of green.

When a purple pulsative image excited by green rays was viewed in the eyepiece by Method II, it was seen to be surrounded by a purple corona, which extended considerably beyond the well-defined boundary of the aperture in the diaphragm (F, fig. 3). Sometimes, indeed, when the illumination was strong, the purple of the corona appeared to be fuller or more saturated than that of the image itself. Moreover, a purple haze of greater or less intensity always extended over the whole field of the eyepiece. These phenomena are, of course, to be explained by the "induced" blindness to green light which was demonstrated by the black spot.

Certain border effects of an entirely different character were also observed. If the rays illuminating the circular patch seen in the eyepiece were taken from the red, orange, or yellow regions of the spectrum, the image appeared to be surrounded by a narrow red, or rather crimson, border. Measurements of the composition of different colour-patches which showed this effect include a red of λ 6420 to λ 6600, a reddish-orange of λ 6200 to λ 6280, an orange-yellow of λ 5890 to λ 5990, and a yellow of λ 5740 to λ 5860; in the last case, the border was less conspicuous, but still recognisable with certainty. With a greenish-yellow patch containing rays from λ 5650 to λ 5750 no trace of the crimson border could be detected. It turned out that these crimson borders could be seen when the intermittent white light was screened off, though they were less easily visible against the dark background than against the bright one. They evidently belong to a class of phenomena discussed in a former paper,* in which it was

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* 'Roy. Soc. Proc.,' vol. 60, p. 368, "On Subjective Colour-phenomena attending *Sudden Changes* of Illumination."

shown that when a bright image is suddenly formed upon the retina after a period of darkness, the image generally appears for a moment to be surrounded by a narrow red border. The paper referred to contains an account of an experiment* demonstrating that when the bright object producing the image was looked at through variously coloured glasses, the red border did not appear unless the glass used, when tested spectroscopically, transmitted red light, and it was suggested that the phenomenon was due to sympathetic excitation of the "red nerve fibres" lying immediately outside the portion of the retina exposed to the direct action of the light. The orange and yellow glasses employed in the experiment referred to of course transmitted red light; it is interesting to find that the pure orange and yellow rays of the spectrum, of wave-length not necessarily exceeding about λ 5800, are competent to give rise to the same red borders.

These effects can be exhibited equally well by Methods I and II, the observations being rendered much easier by the aid of a device described in the former paper. A darning needle, blackened with camphor smoke, is cemented vertically across the opening in the diaphragm F, fig. 3, dividing the bright disc which is projected upon the screen or seen in the eyepiece into two equal parts. Each half disc then has its red border, and, if the intervening space is sufficiently narrow, the red borders along the two contiguous vertical edges meet, or possibly even overlap, with the result that the focussed image of the needle should appear to be red. This was the case when the slit was placed in any part of the spectrum between the extreme red and the greenish-yellow. With the slit in the greenish-yellow itself the image of the needle appeared to be almost colourless, but as the full green was approached the colour became a rather dark shade of blue-green, and remained so until the slit reached about λ 4500, near the beginning of the blue-violet, when the needle again became colourless. In a colour-patch formed of the pure blue rays from λ 4600 to λ 4725 the contrasted blue-green hue assumed by the image of the needle was strikingly conspicuous. The border-colour in question cannot easily be observed unless the intensity of the illumination is within certain limits; for, as in the case of the red borders which were discussed in a former paper,† the blue-green hue becomes transformed into its complementary if the light is very strong, and the needle appears reddish. For the green part of the spectrum it is especially necessary that the illumination should be very carefully adjusted; indeed, the phenomenon would probably never have been noticed at all with green light if its remarkable appearance when the light was pure blue had not first attracted attention. For the more refrangible part of the spectrum it is desirable to place in front of the collimator-slit a piece of blue glass

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* Experiment IV, *loc. cit.*, p. 372.

† 'Roy. Soc. Proc.,' 1897, vol. 61, p. 268.

[redacted]

which will obstruct the red rays; possible sources of error due to the reflection of red light by the prism are thus avoided. The origin of these blue-green borders is, no doubt, analogous to that of the red borders, but the matter requires more careful and thorough investigation than it has yet received.

Though the image of the needle was colourless when the patch was illuminated by the greenish-yellow rays of the spectrum, it appeared red when the same hue was formed by combining red and green rays. Red borders were also observed with a purple composed of red and blue rays, with a white composed of red, green, and violet rays, and with another white formed by recombining the whole of the spectrum; this last observation was, of course, practically a mere repetition in a slightly different form of the one which formed the chief subject of my previous paper.

No coloured border of the same class has yet been observed when the colour-patch was illuminated by the violet rays of the spectrum, Method II being the one employed. The edge of the yellow pulsative image was fringed with a pale violet rim, which, however, was wholly inside the geometrical boundary of the image and not external to it, as were the red and the blue-green borders. Red was very carefully looked for around the violet, but not found. The so-called "simultaneous contrast" effect was, however, very remarkable, the whole field of the eyepiece appearing of a strong yellow tint; often it was quite as strong as the colour of the image itself, which could only be distinguished from the background by the narrow violet ring surrounding it. An equally remarkable effect was produced when the stimulating light was blue, the "contrast-colour" being, like that of the image, orange.

VIII. *Discussion of the Observations.*

Nature of the Pulsative Image.—The phenomenon which, for brevity, has been termed the "pulsative after-image," may be defined as the negative after-image of a coloured object which is seen against a white ground after a very brief stimulation—1/60 to 1/30 of a second—following a period of repose. A strange peculiarity incidental to the formation of these after-images is, that under suitable conditions of illumination, the true colour of the light to which the phenomenon is due altogether fails to evoke its appropriate sensation and is not perceived at all, the only colour seen being that of the after-image. The difficulty experienced in attempts to find a really definite explanation of this fact, and illustrate it by curves of sensation, is in some degree diminished by the singular observations upon the "black spot." The black spot is, of course, merely a device for exhibiting a certain border effect in a convenient manner. A small disc of green light is flashed upon a white screen for about a fortieth of a second, and is immediately replaced by a concentric annulus of white light. During this process no green is seen at all; there appears only a purple annulus surrounding an area which is perfectly black. The white light clearly has the effect of restraining the visual sense-organs adjacent to those upon which it falls from responding to the green stimulus. It would seem to follow *a fortiori* that the sense-organs directly acted upon by the white light must be similarly incapacitated from evoking any green sensation. It is not the fact that the green sensation is produced for a moment and then swamped by a more powerful white one so completely as to escape notice; it actually never comes into existence. Nevertheless, the effects of fatigue by green are exhibited, and the physically white annulus is seen as purple.

It may be well to state that when once the necessary apparatus has been set up and the various luminosities adjusted to the order of those specified, the "black spot" observation is an exceedingly easy one. No skilled observer is required for it; it can be made at once by any one whose vision is normal, and the phenomenon can at any time be exhibited with certainty.

No explanation of it can, I think, be afforded by the Young-Helmholtz theory of colour-vision in its current form; an independent white sensation must be postulated, as by the theory of Hering. And the observations point to the conclusion, even if they do not of themselves sufficiently prove it, that the latent period for a colour-sensation is very much greater than that for white. For green, under the conditions of my experiment, the latent period must be at least 1/40 second, while for white it can hardly exceed 1/500 second, though the luminosity of the two may be nearly equal. The latent period for red is probably not very different from that for green under similar circumstances, that for blue being considerably greater;* but it is not quite certain whether the red and blue flickers seen upon the black spot are produced before or after the illumination by white light. I am inclined to think that the latter is the case, the negative after-image being followed during the period of darkness by a positive one. In all cases the duration of the latent period probably depends partly, through certainly not wholly, upon the intensity of the illumination.†

If in a darkened room a ray of green light is admitted to the eye for a period of 1/40 second, one sees a flash of green; but assuming

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* Some preliminary observations by a method of which I hope to submit an account at a future date indicated that, under the conditions of the experiments, the latent period was for red 0·031 sec., for green 0·028 sec., and for blue 0·040 sec.

† According to Exner, "If the intensities of the illumination of an object increase in geometrical progression, the times necessary for the perception of the same decrease in arithmetical progression," 'Wien. Akad. Sitzber.,' vol. 58, Abtheil II, p. 624, 1868.

that the suppositions which have been put forward are correct, the visible flash is not contemporaneous with the physical illumination. One does not begin to experience the green sensation until after the green ray which excited it has been shut off. What is actually perceived is, in fact, a positive after-image, the duration of which may be considerably longer than that of the stimulus. But if a sufficiently luminous white surface is presented to the eye immediately upon the expiration of the brief period of stimulation by green light, the after-image formed will not be positive but negative, and the only colour perceived will be purple. The fatigue to which the negative image is due must have been set up during the latent period when no image at all was actually perceived. It is noteworthy that if the white background is eclipsed by black before the expiration of the period during which the positive after-image normally continues, the purple negative after-image is seen to be followed by a green positive one, which appears as a bright object upon the dark ground.

One other point requires notice. According to Hering's theory, rays of every wave-length excite not only the sensation of a colour but also that of white. Supposing therefore that the colour-sensation lags behind the white-sensation, we should expect that when the zinc disc is turned, the black spot, even if no colour showed upon it, would appear more or less grey. This, however, is not the fact, at least to any perceptible extent; on the contrary, the spot appears more intensely black when it is illuminated by intermittent green light than it does when the green light is screened off. In the latter case (when no light whatever falls upon it) the spot seems to be veiled by a faint haze, the origin of which I have traced to a phenomenon attending sudden changes of illumination described in a former paper.* The "black spot" phenomena are therefore not fully in accord with either of the leading theories of colour-vision.

Red and Green Borders.—The narrow red and blue-green borders which appear to surround colour-patch images formed from different parts of the spectrum obviously point to the excitation of fundamental red and blue-green colour sensations, the effects of the excitation being sympathetically extended beyond the geometrical boundaries of the images projected upon the retina. Red borders are exhibited by colour-patches formed from any mixture of spectral rays which contains a considerable proportion of red; they also appear around patches illuminated by the simple orange and yellow rays of the spectrum (though with the latter they are feeble) and around white patches. With mixtures of spectral rays from which red, orange, and yellow rays are excluded, they are never seen. A blue-green border, on the other hand, appears only when the green or the blue of the spectrum enters into the combination, the addition of blue-

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* See 'Roy. Soc. Proc.,' vol. 60, p. 370, experiment I (2).

violet and violet having no sensible effect, while an admixture of red, orange, or yellow causes the border to become red. The intensity of the red borders is much greater than that of the blue-green, and if the two could occur together, the blue-green would no doubt be overpowered. According to Hering's theory the red and blue-green fundamental sensations, being antagonistic, cannot both be excited at the same time, and it is to be remarked that those spectral rays which are less refrangible than the greenish-yellow produce red borders, while those of refrangibility intermediate between greenish-yellow and blue-violet produce blue-green borders, which is nearly what the Hering theory would require. According to the most recent exponents of the Young-Helmholtz theory, green spectral rays excite the fundamental red sensation to about the same extent as orange-red rays; yet no red border is formed by the green, though that formed by the orange-red is very strong. If the presence of these borders may be taken as affording evidence of the excitation of fundamental colour-sensations, the evidence so far is in favour of Hering's views. But on the other hand the fact that the red borders can be caused by all kinds of white light seems to show that white excites the fundamental red sensation, while there is some evidence in Sections IV and VI that it excites green and blue or violet colour-sensations as well. No indication as to what one or more colour-sensations in addition to red and blue-green are fundamental ones has yet been afforded by the class of border phenomena under discussion.

Simultaneous Contrast.—When a purple pulsative image of a very bright green patch is formed upon a white ground by the eyepiece method, the whole physically white field appears to be strongly purple, a fact which shows conclusively that the phenomenon of simultaneous contrast may in certain cases be absolutely independent of mental judgment. It cannot be that the ground appears purple simply from contrast with green, for no green whatever is consciously perceived; the cause must necessarily be a physiological one. Similar remarks apply to the orange and yellow fields which accompany the pulsative images of blue and violet patches. It is curious that with a red patch the colour of the field is but very slightly affected.

But while these observations show that in certain cases the so-called contrast effects must have a physiological origin, it is beyond question that this is not invariably so. Some of Helmholtz's well-known experiments leave no room for doubt that mental judgment is sometimes the sole cause of contrast phenomena.

Colours of the Pulsative Image.—The chief results of the colour experiments are collected in Table II. One of the most noticeable features is the superior intensity of the pulsative after-images of red and green; another is the intrusiveness of some form of purple. Purple after green is, as before mentioned, more easily obtainable than

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any other colour, and if the appearance of purple in the pulsative image may be regarded as a test for the presence of green in the luminous object, then it appears from Nos. 4, 8, and 9 that green is a constituent of yellow, of blue, and of white.

TABLE II.

Ref. No.	Spectrum colours.	Complementary colours.	Pulsative colours.	Remarks on pulsative image.
1	Extreme red	Green-blue ..	Green-blue	The image could only be seen by direct vision. None was formed on the screen.
2	Red	Blue-green....	Blue-green	The most intense of all pulsative colours.
3	Orange......	Blue	Pale blue-green	Green-blue with strongest illumination and direct vision.
4	Yellow......	Blue-violet ..	Nearly neutral	Pinkish with ordinary illumination, bluish with strong. Always inconspicuous.
5	Green-yellow	Violet	Pink, or pale purple	Mixed red and green light gave images similar to those of Nos. 4 and 5.
6	Green	Purple	Purple	Inferior only to No. 1 in intensity. Easier to produce than any other.
7	Blue-green ..	Red	Purple	Nearly the same as No. 6.
8	Blue........	Orange-yellow	(1.) Dull pink (2.) Orange	(1.) For ordinary illumination and on screen. (2.) For intense illumination with direct vision.
9	Blue-violet and violet	Yellow	(1.) Bluish-pink (2.) Yellow	Remark as for No. 8. Violet gave no visible image upon screen.
10	Purple......	Green	Blue-green	Same as No. 2. The addition of blue to red made no perceptible difference.
11	White	Neutral grey..	(1.) Purple or purplish-grey (2.) Neutral	(1.) With all ordinary illumination, for recombined spectrum and for combinations of red and green and of yellow and blue. (2.) With strong direct sunlight.
12	Spectrum....	—	—	Blue-green and purple very conspicuous; all other colours comparatively feeble.

The weakness of the pulsative image of yellow is remarkable, and cannot be readily explained. If a yellow colour-patch is formed by *combining* red and green rays, and the image is then put slightly out of focus by moving the screen 3 or 4 cm. nearer to the lens, there appear two patches, one red the other green, which overlap one another, the part common to both being yellow. In the pulsative image the red and green become respectively blue-green and purple, while the overlapping portion is almost colourless. Possibly both the pulsative colours are less blue than they should be, with the result that their combination produces white or grey.

The difficulty of forming a satisfactory pulsative image from blue and violet is no doubt to be accounted for by the superior persistence of those colours. With stronger luminosity than can be obtained by the method of projection or by the use of pigments this difficulty is diminished, for then the greater part of the luminous impression vanishes more quickly.

Though the work of which an account is given in the present paper has occupied a large amount of time, it is obvious that the subject is far from being exhausted. Several doubtful points remain to be cleared up and apparent discrepancies reconciled, while of a number of remarkable phenomena which presented themselves no mention at all has been made. With more refined apparatus than that at present at my disposal, similar methods of experiment might be expected to yield important contributions to the theory of colour-vision.

"The Solar Activity 1833–1900." By **William J. S. Lockyer**, M.A., Ph.D., F.R.A.S., Assistant Director, Solar Physics Observatory, Kensington. Communicated by Sir **Norman Lockyer**, K.C.B., F.R.S. Received April 29,—Read May 23, 1901.

Introduction.

A close examination of the curves representing the varying amount of spotted area on the Sun's surface, shows that no two successive cycles are alike either in form or area. The individuality of the cycles seems, on further inspection, to be repeated after a certain period of time, and this peculiarity, coupled with a like variation in the curves representing the variations of the magnetic elements, and with suspected cycles of change in various terrestrial phenomena, suggested a new investigation of the whole subject.

The object of this communication is to place before the Royal Society the first results which an examination of the various records has furnished.

Dr. Rudolf Wolf,* of Zürich, from a study of the sunspot observations made up to the end of 1875, drew attention to the facts, to use

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* 'Mem. R. Astron. Soc.,' vol. 43, p. 200.

his own words, that "la fréquence des taches solaires persiste à changer périodiquement depuis leur découverte en 1610; que la longueur moyenne de la période est de $11\frac{1}{9}$ ans, et que cette même période satisfait aux changements de la variation magnétique, et même de la fréquence des aurores boréales."

Dr. Wolf was careful to point out that it was only the *mean length* of the solar period that covered a period of $11\frac{1}{9}$ years, and that the real length of any one period might differ from this value by as much as two years. The form in which he stated this result* was

$$T = 11{\cdot}111 \pm 2{,}030 \text{ (als Schwankung) } \pm 0{,}307 \text{ (als Unsicherheit)};$$

where T represented the length of the period, ± 2,030 the variation from the mean value, and ± 0,307 the probable error of the determination.

His attention was also drawn to the fact that the times of maxima did not occur a constant number of years after a preceding minimum, and he was led to determine the *mean* time of occurrence of the maximum after the preceding minimum and of the minimum after the preceding maximum, giving the *mean* intervals as 4·5 and 6·5 years respectively.

Further, he at first concluded that the total spotted area for each period was nearly constant, but, as he later remarks,† this view could not be held, as these quantities not only varied but indicated "eine bestimmte Gesetz-mässigkeit." The length of the period of this variation he gave as about 178 years, which covered practically sixteen ordinary sunspot periods. ("11,1111 × 16 = 177,7777.")

Somewhat later Dr. Wolf was led to suggest a shorter period of 55·5 years, which comprises about five ordinary eleven-year periods.

In a recent paper‡ Professor Simon Newcomb has published the results of his investigation of the irregularities in the successive sunspot periods, using as a basis Dr. Wolf's numbers up to the end of 1872, and the spot areas as derived from the Greenwich reduction of the solar photographs taken daily at Greenwich, Dehra Dun, and Mauritius.

The final conclusion at which he arrives is summed up in the following paragraph :—

"Underlying the periodic variations of spot-activity there is a uniform cycle unchanging from time to time and determining the general mean of the activity."

Professor Newcomb mentions, however, no length of period for this cycle, but speaking of its origin he remarks, "whether the cause of this cycle is to be sought in something external to the Sun or within

* 'Astron. Mittheil.,' Wolf, 187 ; p. 40.

† 'Astron. Mittheil.,' 1876, p. 47 *et seq.*

‡ 'The Astro-Physical Journal,' vol. 13, No. 1, 1901, p. 1.

it; whether, in fact, it is in the nature of a cycle of variations within the Sun, we have, at present, no way of deciding."

In the investigations on periods of solar activity most workers have relied simply on Wolf's numbers, which are given by him back to the year 1749. Any one acquainted with these knows that from the time *systematic* observations of the Sun's surface were commenced by Hofrath Schwabe (1833), these numbers agree very closely with the actual facts; but before that date, the numbers are based, not on facts alone (which were not very numerous), but on a system of "meaning,"[*] suggested by the results of the observations from 1833 to 1876.

Although then Dr. Wolf was able to present us with a curve dealing with the spotted area from 1749, it was decided for the present communication to limit the discussion to those relative numbers which are based on the actual systematic observations since 1833. This necessarily restricted the investigation to a comparatively short number of years, namely, sixty-six (1833–1899), but it was thought that any variations detected, if greater than any which might be justifiably considered errors of observation, would be based on sound facts, and not on uncertain data.

The important magnetic results obtained from a discussion of the Greenwich Observations by Mr. William Ellis,[†] placed at my disposal a most valuable check on any variation that might be obtained from the sunspot curves, Mr. Ellis having shown that the curves for the magnetic elements are in almost exact accord with those of the sunspots obtained by Dr. Wolf. In this connection Mr. Ellis writes[‡]:

"Considering that the irregularities in the length of the sunspot period so entirely synchronise with similar irregularities in the magnetic period, and also that the elevation or depression of the maximum points of the sunspot curve is accompanied by similar elevations and depressions in the two magnetic curves, it would seem, in the face of such evidence, that the supposition that such agreement is probably only accidental coincidence can scarcely be maintained, and there would appear to be no escape from the conclusion that such close correspondence, both in period and activity, indicates a more or less direct relation between the two phenomena, or otherwise the existence of some common cause producing both. The sharp rise from minimum epoch to maximum epoch, and the more gradual fall from maximum epoch to minimum epoch, may be pointed out as characteristic of all three curves."

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[*] For Wolf's method of "meaning" see 'Astronomische Mittheilungen,' von Rudolf Wolf, Zürich, 1876, p. 39 *et seq.*

[†] 'Roy. Soc. Proc.,' vol. 63, p. 64.

[‡] *Ibid.*, p. 70.

The Sunspot and Magnetic Epochs employed.

As this paper deals mainly with the times of minima and maxima of both the sunspot and magnetic curves, it was necessary to utilise the results obtained from curves which had been "smoothed," as the original curves are of a subsidiary oscillatory character, especially at maximum.

The sunspot curves just referred to are reproduced in fig. 1. They are so arranged in order of date that each individual curve can be examined separately. The times of succeeding *minima* are arranged vertically under each other, so that any variation as regards acceleration or retardation of the following maxima, and any inequality in the length of the period minimum to minimum can be seen at a glance.

Up to the sunspot maximum of 1870·6 Dr. Wolf has published* the dates of these epochs, and these are utilised here. The more recent epochs have been brought together by Mr. Ellis,† and these complete the data available up to the last epoch, namely, the maximum of 1894·0.

Each of these epochs is indicated in fig. 1 by a short arrow with the corresponding dates. The magnetic epochs here used are those published by Mr. Ellis in the paper just mentioned, and obtained from curves smoothed similarly to those of the sunspot curves. Unfortunately the observations he discussed only commenced in the beginning of 1841, so that comparisons cannot be made previously to this date.

The smoothed curves obtained by Mr. Ellis are not here reproduced, but they will be found in his valuable paper‡ published in 1880.

The Sunspot Curves. Minimum to Maximum.

In the following table are brought together the dates of the epochs of maxima and minima:—

Sunspot epochs (Wolf).		Maximum *minus* minimum years.
Minimum.	Maximum.	
(1) 1833·9	1837·2	3·3
(2) 1843·5	1848·1	4·6
(3) 1856·0	1860·1	4·1
(4) 1867·2	1870·6	3·4
(5) 1879·0	1884·0	5·0
(6) 1890·2	1894·0	3·8
		Mean 4·03

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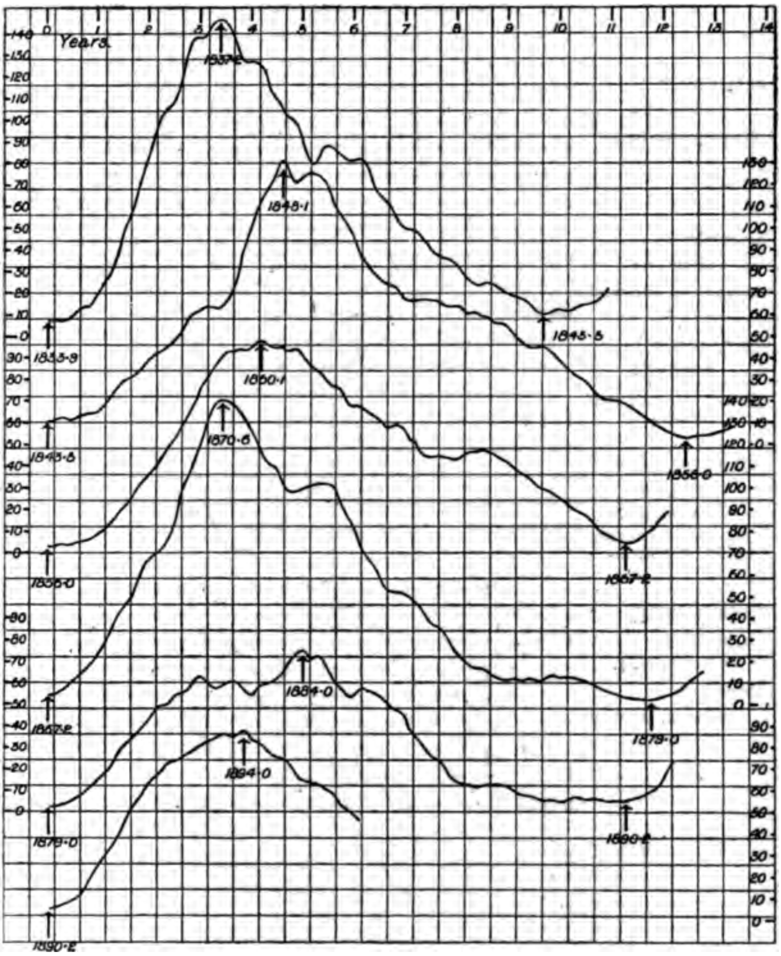
* 'Mem. R. Astron. Soc.,' vol. 43, p. 202.

† 'Roy. Soc. Proc.,' vol. 63, p. 67.

‡ 'Phil. Trans.,' 1880, Part II, Plate 22.

If these figures in the last column be utilised as ordinates and the time element as abscissæ, the curve in fig. 2 (curve B) is produced. The peculiarity of this curve is that we have a very rapid rise to a maximum in 1843, and slow fall to the minimum in 1867. This is followed by a similar rapid rise to the next maximum in 1879 and a gradual fall as far as observations at present indicate.

FIG. 1.

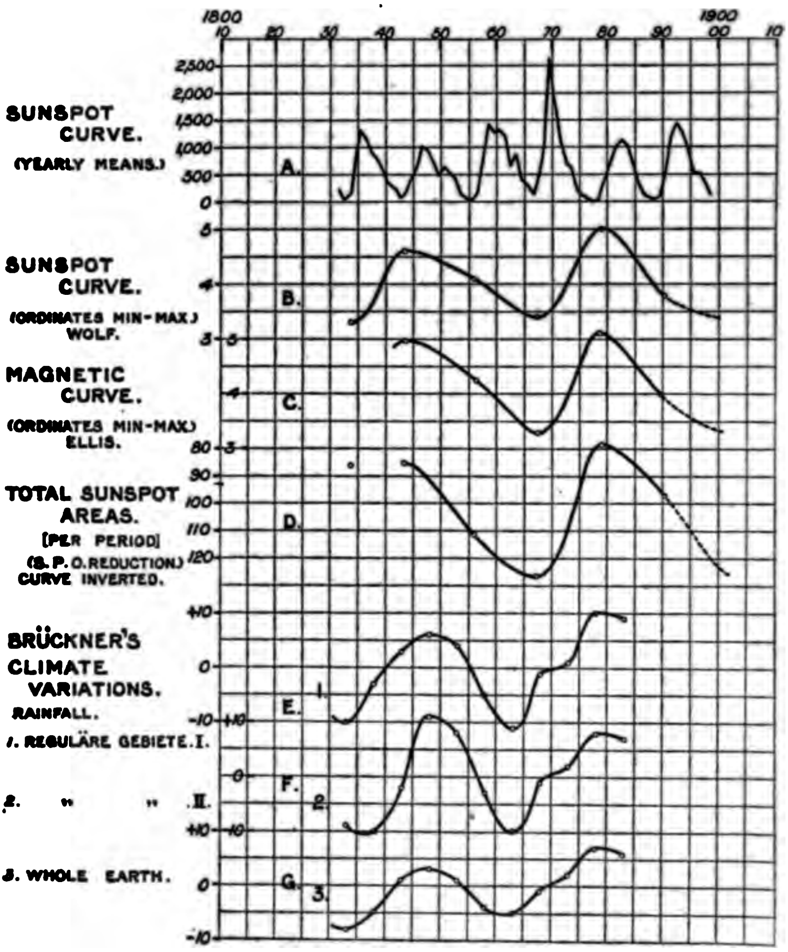


The curve thus indicates that there is some law at work which introduces a secular variation by retarding the sunspot maxima in relation to the preceding minima.

[redacted]

The period of this retardation can be deduced by taking the interval between the times of maxima or minima of this secular variation curve. By considering the minima, *i.e.*, from 1833·9 to 1867·2, we have a period of 33·3 years, and if we take the maxima at 1843·5 and 1879·0 we obtain 35·5 years. The mean of these two values gives a period of 34·4 years.

Fig. 2.



The Magnetic Curves. Minimum to Maximum.

Mr. Ellis's values for the dates of the magnetic epochs were investigated in exactly the same way as the sunspot epochs were examined.

It may be again mentioned that as the observations he reduced only begin in the year 1841, no comparison can be made with the epochs of 1833·9 and 1837·2.

Forming the table of maximum *minus* minimum as before and adding in the last column the values of maximum *minus* minimum of the sunspot curves from the previous table for the sake of comparison, we have as follows:—

Magnetic epochs (Ellis).		Maximum *minus* minimum.	
Minimum.	Maximum.	Magnetic.	Sunspots.
(1) —	—	—	3·3
(2) 1843·60	1848·55	4·95	4·6
(3) 1856·15	1860·40	4·25	4·1
(4) 1867·55	1870·85	3·30	3·4
(5) 1878·85	1883·90	5·05	5·0
(6) 1889·75	1893·75	4·00	3·8

The nearly complete parallelism of the numbers in the last two columns indicates their strict accord with each other.

The curve showing this magnetic variation is given in fig. 2 (curve C), and it is practically a counterpart of curve B.

The value for the length of the period, as gathered from the interval between the two maxima of this curve at 1843·60 and 1878·85, is 35·25 years, which does not differ very much from the value deduced from the maxima of the corresponding sunspot curve, namely, 35·5 years.

Sunspot and Magnetic Curves Combined. Minimum to Maximum.

By combining the values of the intervals (minimum to maximum) from both the sunspot and magnetic curves, their mean values can be determined as shown in the last column of the following table, the general mean for the whole period being added below:—

From minimum occurring about	Mean of sunspot and magnetic intervals in years.
(1) 1833	3·3
(2) 1843	4·77
(3) 1856	4·17
(4) 1867	3·35
(5) 1879	5·25
(6) 1890	3·90
	Mean .. 4·12

Since these numbers cover more than a complete cycle, they may be combined so that mean values for the intervals minimum—maximum may be obtained for those epochs when the intervals have their largest, intermediate, and smallest values. Thus in the years 1843 and 1879 the maxima followed the minima in 4·77 and 5·25 years respectively, the mean interval thus being 4·91 years. For the intermediate stage (combining (3) and (6)) a value of 4·03 years is found, while for the minimum interval combining (1) and (4) this value 3·32 years.

The actual epoch of maximum relative to the preceding minimum oscillates about the mean value, its greatest amplitude being in the mean 0·8 *year.*

The Total Sunspot Areas. Minimum to Minimum.

The great divergence in the amount of spotted area during consecutive eleven-year cycles suggested that perhaps this periodical retardation of the maxima with respect to the each preceding minimum might be accompanied by variations following the same law. It was observed that when a maximum occurred comparatively soon after a minimum, the tendency of the whole spotted area for that sunspot period was to be increased.

I have been permitted for this inquiry to utilise the values which have quite recently been obtained at the Solar Physics Observatory from a new reduction of the curve representing the solar spotted area, and these values, representing the total spotted area in millionths of the Sun's visible hemisphere from minimum to minimum, are given in the last column of the following table :—

Sunspot period from		Total spotted area.
From minimum	to minimum.	
1833·9	1843·5	86 003
1843·5	1856·0	85 201
1856·0	1867·2	111 514
1867·2	1879·0	126 188
1879·0	1890·2	78 353
1890·2	1901· +	96 734+

The figures in the last column show a similar but inverted sequence to those in the previous tables. Thus from minimum 1867·2 to the following maximum 1870·6 we have a short interval of time; the spotted area for that period is greatest. If the above values in the last column be graphically shown, and the curve inverted, we have a *remarkable* similarity (fig. 2, Curve D) to the two curves B and C previously described. Special attention is called to the slow fall from 1843 to the minimum at 1867·2, and the rapid rise to 1879·0.

It may be remarked that the value for the total spotted area for the period 1833·9 to 1843·5, the earliest value in point of time dealt with, is not quite in harmony with the other values. It is probable that although at this period the time of maximum and minimum could be accurately determined, the values may be too small owing to the fact that Schwabe's observations were not made at that period quite on a uniform plan. Mr. Warren de la Rue and Professor Balfour Stewart[*] on this point wrote :—

"By the commencement of 1832 Schwabe had matured his system to such an extent as to give, no doubt with considerable precision, the shape and area of each group; although it was not until the commencement of 1840 that he finally fixed upon the system of delineation, which he henceforth pursued up to the time when he discontinued his observations."

The above suggestion seems to be borne out by the reduction of sunspot photographs secured at the Wilna Observatory, where it was found that the maximum of 1870 was of about the same order as that of 1836. The Report of the Wilna Observatory for the year 1871 refers to this point in the following terms[†] :—

"The curve traced from our observations about the last maximum period of spots (1870) is one and a-half times as high as that of the three most recent periods, *i.e.*, the total sum of the areas of the spots about the maximum period of 1870 was one and a-half times larger than during the last thirty-six years. This marked difference obliged us to enter upon a double verification of our calculations, but we did not discover any appreciable errors."

With reference to the value given in the last line of the last column of the table, although this is probably very near the truth, it is yet impossible to state the date of the present minimum (1901·2 probably). All the areas recorded since the minimum of 1890 and up to the beginning of 1900 have been employed; this value is, however, only slightly below the real one, so that a + sign has been printed against it.

If, therefore, these two facts be kept in mind, it will be seen that the inverted total sunspot-area curve can be considered practically an exact counterpart of the other two curves.

The Total Area of the Magnetic Curves. From Minimum to Minimum.

The remarkable similarity between the magnetic and sunspot curves, especially in the later years when such observations are naturally more

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[*] 'Report of the Committee on Solar Physics, 1882.' Appendix B, p. 77.

[†] *Ibid.*, Appendix D, p. 154.

[redacted]

accurate, made it unnecessary to discuss the variation (as shown in the case of the sunspot areas) regarding the total areas of the curves from minimum to minimum. This variation seems to be more pronounced in the curve representing the horizontal force than in that representing declination.

Length of the Period of Variation thus determined.

In summing up the values obtained for the length of the secular period of variation under discussion, we form the following table:—

	Maximum to maximum. Years.	Minimum to minimum. Years.
Sunspot curve	35·5	33·3
Magnetic ,,	35·25	—
Total spotted area for period	35·5	—
Means	35·41	33·3
Combined mean	34·89	

The observations thus lead to the conclusion that *underlying the ordinary sunspot period of about eleven years there is another cycle of greater length, namely, about thirty-five years.*

This cycle not only alters the time of occurrence of the maxima in relation to the preceding minima, but causes changes in the total spotted area of the sun from one eleven-year period to another.

The Variation in the Length of the Interval Minimum to Minimum.

Having found a definite variation in the length of the interval minimum to maximum, the curves show a further variation when the interval—minimum to minimum—was considered. An attempt was therefore made to see if any law could be traced, but the inquiry only led to a negative result.

The following table contains the values for the periods—minimum to minimum—and the differences from the mean, for both the sunspot and magnetic curves individually and combined. It will be seen that the alternation of signs in the columns showing the sunspot differences is not corroborated by the magnetic differences, but when the combined values are used this oscillation for consecutive periods is still *in evidence*:—

Minimum beginning in the year	Sunspots.		Magnetics.		Combination.	
	Minimum to minimum.	Differences from mean.	Minimum to minimum.	Differences from mean.	Minimum to minimum.	Differences from mean.
	Years.	Years.	Years.	Years.	Years.	Years.
1833 1843	9·6	−1·7	..	..	9·6	−1·7
1843 1856	12·5	+1·2	12·55	+1·0	12·52	+1·32
1856 1867	11·2	−0·1	11·40	−0·14	11·30	+0·10
1867 1879	11·8	+0·5	11·30	−0·24	11·55	+0·35
1879 1890	11·2	−0·1	10·90	−0·64	11·05	−0·15
Means..	11·3	—	11·54	—	11·20	—

Although there is a suspected variation in the length of both the magnetic and sunspot periods (reckoning from minimum to minimum), which increases and decreases in *alternate* eleven-year periods from a mean value, the observations do not extend over a sufficient interval of time to allow a more definite conclusion to be drawn.

Relation of the Sunspot Curve to the Light Curve of η Aquilæ.

It is generally conceded that the spots on the surface of the Sun are the result of greater activity in the circulation in the solar atmosphere, and therefore indicate greater heat and, therefore, light. This being so, the curve representing the spotted area may be regarded as a light curve of the Sun.

The Sun may thus be considered a variable star (1) the light of which (reckoning from minimum to minimum) is variable, with a mean value of about 11·1 years; (2) the epoch of maximum does not occur a constant number of years after the preceding minimum, but varies regularly, the cycle of variations covering about 35 years.

It is interesting therefore to inquire whether there be any other known star or stars which exhibit variations similar in kind to those given above.

In the year 1896 I undertook the investigation of all the observations, whether published or not, of the variable star η Aquilæ * which had been made between the years 1840 to 1894, numbering in all 12,000.

For the present inquiry the light curve of this star is of great interest, as its chief peculiarities are similar to those I have indicated in connection with the sunspot curve.

Not only are the more rapid rise to maximum and slow fall to

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* 'Resultate aus den Beobachtungen des veränderlichen Sternes η Aquilæ,' Inaugural-Dissertation, Universit. Göttingen, 1897 (Dulau and Co., London).

minimum distinct features of the curve, but the periods (reckoning from minimum) vary slightly in length in the course of many *mean* periods. More important still, the time of occurrence of the maximum in relation to the preceding minimum varies to a comparatively *large* extent in the course of *few* mean periods. The facts arranged in tabular form sum up the information with regard both to the sunspot curve and that of η Aquilæ.

To facilitate the comparison, the different intervals of time converted into fractions and multiples of the sunspot (Q) and η Aquilæ (P) periods are given in separate columns.

		Light curve of			
		Sun.		η Aquilæ.	
Minimum to minimum.		Years.			
	Mean value.......	11·20	= Q	$7^d\ 4^h\ 14^m\ 4$	= P
	Period of variation	Unknown	?	—	2400 P
	Maximum variation from mean......	± > 1·4	± > 0·12 Q	$\pm 3^h$	0·017 P
Minimum to maximum.	Mean value.......	4·12 (about)	0·37 Q	$2^d\ 5$	0·31 P
	Period of variation	34·8 „	3·10 Q	—	400 P
	Maximum variation from mean......	±0·8 „	±0·07 Q	$\pm 5^h$	±0·03 P

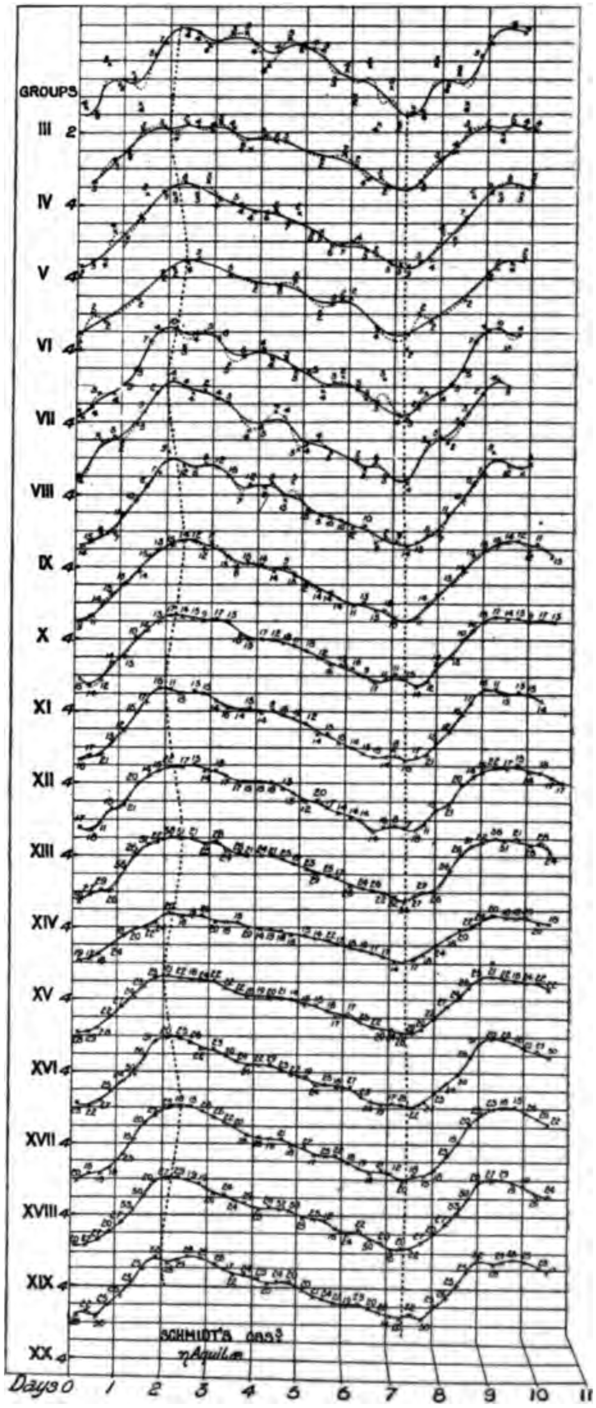
Fig. 3 is a reproduction of a set of light curves of the star η Aquilæ, in which the dotted line and the two vertical wavy and oblique dotted lines passing through the points of maxima and minima indicate the variations of the times of maxima and minima.

The curve for each group is the result of a combination of the observations made over a period equal in length to 100 mean periods (mean period = $172^h{\cdot}2344$) of the star. This whole set of curves is the result of a discussion which I made of all the observations of η Aquilæ made by one observer, Herr Julius Schmidt.

Other Cycles of about Thirty-five Years.

Having found that, in addition to the well-known eleven-year period of sunspot frequency, there is another cycle which extends over about thirty-five years, and which is indicated clearly, as has been shown, both by the changes in the times of the occurrence of the epochs of maxima and in the variations in area included in consecutive eleven-year periods of both sunspot and magnetic curves, it is only natural to suppose that this long-period variation is the effect of a cycle of disturbances in the Sun's atmosphere itself.

FIG. 3.


GROUPS
III 2
IV 4
V 4
VI 4
VII 4
VIII 4
IX 4
X 4
XI 4
XII 4
XIII 4
XIV 4
XV 4
XVI 4
XVII 4
XVIII 4
XIX 4
XX 4
SCHMIDT'S OBS?
η Aquilæ
Days 0
1
2
3
4
5
6
7
8
9
10
11

Such a cycle, if of sufficient intensity, should cause a variation from the normal circulation of the Earth's atmosphere, and should be indicated in all meteorological and like phenomena.

It is not intended to go into any detail as regards such terrestrial variations, but it may be noted that much important work has been done on the investigation of changes in climates by Professor Eduard Brückner,[*] who expended immense labour during many years in the promotion of the inquiry. Professor Brückner did not restrict his discussion to observations made over a small area or for a short interval of time, but utilised those made in nearly every part of the civilised world, and extending as far back in point of time as possible. Further, he did not restrict himself to the discussion of the observations of one or two meteorological phenomena, but examined critically all likely sources from which such changes as he expected could be detected. Thus he sought variations in the observations of the height of the waters in inland seas, lakes, and rivers; in the observations of rainfall, pressure, and temperature; in the movements of glaciers; in the frequency of cold winters; growth of vines, &c.

The result of the whole of the investigation led him to the conclusion that there is a *periodical variation in the climates over the whole earth, the mean length of this period being* 34·8 ± 0·7 *years*.

It may be of interest to remark, that so convinced was Professor Brückner of the undoubted climate variations that he deduced, and so certain was he that such variations could only be caused by an external influence, that he investigated Wolf's sunspot numbers to see whether such a cycle was indicated.

Misled by the long period of variation of sunspots of fifty-five years as suggested by Wolf, he was led to conclude that his climate variation was independent of the frequency of sunspots. He sums up his conclusion in the following words[†]:—

"Die Klimaschwankungen vollziehen sich unabhängig von den Schwankungen der Sonnenflecken-Häufigkeit; eine 55-jährige Periode der Witterung, wie sie der letzteren entsprechen würde, ist in unseren Zusammenstellungen nicht zu erkennen."

Nevertheless, he was led to make the bold suggestion, that such a variation as he sought must really exist in the Sun, but might possibly be independent of sunspots. He finally concluded that the climate variations are the first symptom of a long period variation in the Sun, which probably will be discovered later.

In the light of the present communication Professor Brückner's conclusions are of great interest, because not only does the length of

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[*] 'Geographische Abhandlungen Wien,' Band 4, Heft 2, p. 155, 1890. "Klima-Schwankungen seit 1700 nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit."

[†] 'Klimaschwankungen,' Brückner, p. 242.

the period, but the critical epochs of his cycle, completely harmonise with those found in the present discussion of the sunspot and magnetic curves.

To illustrate more fully this connection, and to take only one case, namely, rainfall, the three rainfall curves* are reproduced in fig. 2 (curves E, F, G).

E and F represent the secular variations for what Professor Brückner calls "Reguläre Gebiete I und II,"† while curve E is the mean for the whole set of observations he has employed, and represents the secular variation of rainfall over the whole earth as far as can be determined.

The comparison of these curves with those representing the sunspot and magnetic results given above them, shows that when the epoch of maximum spotted area (curve B) follows late after the preceding epoch of minimum (1843, 1878), or when the spotted area from minimum to minimum is least (curve D), the long-period rainfall curve is at its maximum or we have a wet cycle.

When on the other hand the maximum (curve B) follows soon after the preceding minimum (1867), and the spotted area for this cycle is at a maximum (curve D), the rainfall curve is at a minimum or a dry cycle is in progress.

It may also be observed that in a detailed investigation of the movements of glaciers, Professor Ed. Richter finds a cycle of thirty-five years. In his 'History of the Variations of Alpine Glaciers,'‡ he sums up his results as follows:—"Die Gletschervorstösse wiederholen sich in Perioden, deren Länge zwischen 20 und 45 Jahren schwankt, und im Mittel der drei letzten Jahrhunderte genau 35 Jahre betrug."

Further he pointed out that the variations agreed generally with Brückner's climate variations, the glacier movement being accelerated during the wet and cool periods.

Another very interesting investigation to which reference must be made is that which we owe to Mr. Charles Egeson, who published his researches§ in solar and terrestrial meteorology just a few months before the appearence of Professor Brückner's volume. Mr. Egeson not only finds a secular period of about thirty-three to thirty-four years in the occurrence of rainfall, thunderstorms, and westerly winds in the month of April for Sydney, but the epochs of maxima of the two latter harmonise well with the epochs of the thirty-five yearly period deduced in the present paper for sunspots.

Thus he finds that the yearly numbers of days of thunderstorm

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* Brückner, *ibid.*, p. 171.

† Brückner, *ibid.*, p. 170.

‡ 'Zeit. d. Deuts.-Oesterr. Alpen-Vereins,' 1891, Band 12.

§ Egeson's 'Weather System of Sunspot Causality.' Sydney, 1889.

[redacted]

attain their maxima values in 1839 and 1873, and those of the westerly winds in April in 1837 and 1869. As the secular variations of the sunspots have their maxima in 1837·2 and 1870·8, the agreement is in close accord.

There seems little doubt that, during the interval of time covered by the present investigation, the meteorological phenomena, number of auroræ, and magnetic storms, show secular variations of a period of about thirty-five years, the epochs of which harmonise with those of the secular variation of sunspots.

As we are now approaching another maximum of sunspots which should correspond with that of 1870·8, it will be interesting to observe whether all the solar, meteorological, and magnetic phenomena of that period will be repeated.

Conclusion.

1. There is an *alternate* increase and decrease in the length of a sunspot period reckoning from minimum to minimum.

2. The epoch of maximum varies *regularly* with respect to the preceding minimum.

The amplitude of this variation about the mean position is about ± 0·8 year.

The cycle of this variation is about thirty-five years.

3. The total spotted area included between any two consecutive minima varies regularly.

The cycle of this variation is about thirty-five years.

4. There is no indication of the fifty-five-year period as suggested by Dr. Wolf.

5. The climate variations indicated by Professor Brückner are generally in accordance with the thirty-five-year period.

6. The frequency of auroræ and magnetic storms since 1833 show indications of a secular period of thirty-five years.

"On the Variation in Gradation of a Developed Photographic Image when impressed by Monochromatic Light of Different Wave-lengths." By Sir William de W. Abney, K.C.B., D.C.L., D.Sc., F.R.S. Received March 26,—Read May 2, 1901.

Introductory.

When a series of small spaces on a photographic plate are exposed to a constant light for geometrically increasing times, or for a constant time to geometrically increasing intensity of illumination, the spaces *so exposed* will on development show deposits of silver of different

opacities. These opacities may be measured and noted as "transparencies," "opacities," or "densities," the last being the $-\log$ transparencies and the opacity $\frac{1}{\text{transparency}}$. (These definitions of opacity and density are those given by Hurter and Driffield, and are generally understood as such in photographic literature.) Where varying time exposures are given, it is convenient to start with some unit of time, such as 10 seconds for the exposure of the first small space on a plate, to double this exposure for the next small space, and so on. When the measurements of transparency or density are made, and the curve has to be plotted, the scale for the abscissa is conveniently the number of the exposure—that is, the time of exposure in powers of two. The ordinates are then set up as transparency of deposit, total transparency being 100, or as densities which give the absolute light cut off in terms of common logarithms. The curve joining these different ordinates is in both cases approximately a straight line for some distance, and, at each end, tends to become parallel to the scale of abscissæ, and this straight portion is taken as representing the gradation of the plate. If the same plate be thus exposed to different monochromatic lights, and the images developed together and the density measured, it is easily seen from the plotted curves if the "gradation" of the plate is the same in each case, since, if they are, the straight portions of each curve should be parallel.

[It may be noted that the less steep the gradation of a plate, the greater will be the extremes of lights and shades in an object or view that will be shown in a print, as the blackest tone obtainable on it reflects about 3 per cent. of light. For this reason in sun-lighted views, a plate showing a flat gradation should be employed, whilst in those illuminated by a cloudy sky, a plate giving a steep gradation should be used.]

When obtaining the three negatives for three-colour printing where the object is photographed through an orange, a bluish green, and a blue screen, if there is much change in gradation caused by the difference in the colour of the light reaching the plate, the true rendering of an object in its natural colours becomes an operation of extreme difficulty. It was with a view to ascertain if some of the difficulties which have been encountered in this process were due to difference in gradation caused by the different coloured screens, that this research was commenced some three years ago. Nearly two years ago, in an article in 'Photography,' I indicated that a variation in gradation due to difference in the monochromatic light in which the exposure was made did exist, and some six months ago Mr. Chapman Jones, in a paper communicated to the Royal Photographic Society, independently announced the same result from experiments made principally with orthochromatic plates with light passing through various coloured

media, and he generalised from his experiments, that the smaller the wave-length, the less steep was the gradation, the ultra-violet rays giving the least steep, and the red the most steep gradation. My experiments, which had at that time been partially completed, did not bear out this generalisation to the full when pure silver salts were used; and my subsequent measurements with them show that the least steep gradation is that given by the monochromatic light to which the simple silver salt experimented with is most sensitive, and that the gradation becomes steeper as the wave-lengths of light employed depart in either direction in the spectrum from this point, the steepest gradation being given by the extreme red. The case of orthochromatic plates in which is a complex mixture of silver salt and dye, is necessarily less simple, involving considerations of the localities in the spectrum to which the dye or dyes, together with that of the silver salt, are most sensitive. For this reason the simple salts have been experimented with in preference to the more complex organic compounds.

Methods of Experimenting.

As pointed out in the opening paragraph, there are two ways of experimenting, one where the illumination is constant, the times of exposure being altered, and the other in which the time of exposure is constant, and the illumination is altered. This last is the condition under which an image in the camera is photographed. It might appear that both methods should give identical quantitative results, but it was more than probable that they would not do so, from the experiments that I had previously carried out with these two methods with ordinary white light.

The first set of experiments were with *fixed time of exposure* and varying intensity of light. To obtain the varying intensity, a photographic plate was exposed to white light, the parts exposed being limited to an area having the form of a triangle with the top cut off at the apex, the two sides being radial to the centre of the plate. The enclosed angle was about 20°, so that by turning the plate round its centre, twelve different spaces would be exposed. After the plate had been developed with ortol or ferrous oxalate, fixed, washed, and dried, the intervals between the exposed parts were blocked out. The opacities were then ready for measurement. Fig. 1 is a reproduction of the "star" graduated opacities.

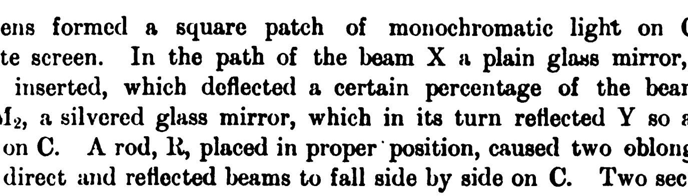
Measurement of Star Opacity with different Colours.

It became necessary to see whether the deposit obstructed light equally for each ray of the spectrum, and the following arrangement was adopted. The colour patch apparatus which I have

FIG. 1.

described in previous papers on Colour Photometry in the 'Philosophical Transactions,' was brought into use. A ray of the spectrum was allowed to issue through S, fig. 2, and after passing through

FIG. 2.



a lens formed a square patch of monochromatic light on C, a white screen. In the path of the beam X a plain glass mirror, M_1, was inserted, which deflected a certain percentage of the beam Y to M_2, a silvered glass mirror, which in its turn reflected Y so as to fall on C. A rod, R, placed in proper position, caused two oblongs of the direct and reflected beams to fall side by side on C. Two sectors, A and B, were placed in the paths of X and Y respectively. The apertures of A could be opened or closed at pleasure whilst the disc was rotating. A red ray of the spectrum first came through S, and the aperture in A required to equalise the two adjacent patches of light was noted. Other rays of the spectrum were similarly dealt with, when it was found that the aperture in A remained unaltered, showing that within the limits of error of observation the percentage of reflec-

tion from M_1 remained the same for all rays. The star-shaped opacities were then introduced into the beam X at D, and when necessary, B was rotated with known and fixed apertures, and the patches of light again made equally bright by means of A. It was found that the apertures of A varied as the different spectrum colours passed through the deposits, forming the graduated star. Using the same scale for the spectrum as used in my former papers (B is 61·3. Li 59·7, C 58·1, D 56, E 39·8, F 30·05, Li 22·8, G 11·2), the absorptions were calculated for the whole spectrum. It was found that the coefficient of absorption (obstruction) of white light and of the ray 26·8, coincided, and taking this as unity (for a purpose which will be seen presently) the coefficients of the other rays are as follows:—

Table I.

Scale number.	Absorption.
59 to 49·8	0·87
47·5	0·90
42·9	0·92
38·3	0·93
83·7	0·95
29·1	0·97
26·8	1·00
22·2	1·02
17·6	1·02
8·4	1·08

The transparencies of the different parts of the star to lamplight were measured and calculated out in powers of −2, the light transmitted through the part on which no deposit appeared being taken as zero. The following are the transparencies as calculated:—

Table II.

Opacity.	Transparency in powers of −2.
No. 1	0
„ 2	0·38
„ 3	0·75
„ 4	1·05
„ 5	1·73
„ 6	2·36
„ 7	3·5
„ 8	4·16
„ 9	5·2
„ 10	5·9
„ 11	6·9
„ 12	8·9

In percentages the transmission of white light through No. 1 and No. 12 is therefore 100 and 0·477 respectively, which allows a sufficiently wide range of intensity to be investigated. The above numbers represent then the absorption of white light, and also that of the blue light coming through a slit placed at 26·8 of the scale of the spectrum. To obtain the scale in powers of -2 for the other rays they must be multiplied by the factors given in Table I.

The star can now be used for the purpose for which it was prepared.

Experiments with Fixed Time of Exposure.

With the colour-patch apparatus a patch of red light was thrown on the star backed by a sensitive plate, which could be revolved round their central point in a special dark slide, and exposure was made to the patch with the plates rotating for the time it was judged necessary to cause an impression of each intensity of light. The rotation was deemed necessary in case the light coming through the thick part of the prism was more absorbed than that coming through the thin part. The plate was then removed from the slide, and a scale of gradation impressed on a part which had been covered up during the previous exposure. The source of light used for this scale was an amyl-acetate lamp placed at 4 feet from the plate, and the time was doubled for each successive exposure. On development there was an image of the star, each space in different densities, and alongside a graduated scale of densities with which the star densities could be compared. Other plates were exposed to other rays of the spectrum, those selected being at the scale numbers recorded in Table I. As each separate image of the star could be compared with the scale of gradation given by the amyl-acetate lamp they could be compared with one another.

Spectrum Sensitiveness of Bromo-iodide of Silver.

The first sensitive salt of silver with which experiments were made was the bromide of silver, to which a small quantity of iodide of silver had been added. A spectrum of the electric arc light was impressed on the gelatine plates prepared with this salt, and the sensitiveness to the various rays ascertained by the plan given in a previous paper.* (To facilitate a comparison of the results given in this paper with the curve of sensitiveness the latter is drawn on the prismatic scale as given above.)

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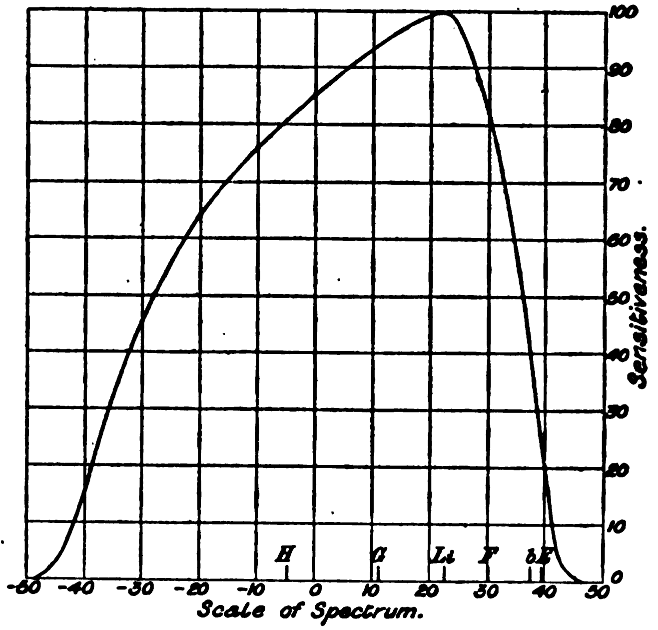
* "The effect of the Spectrum on the Haloid Salts of Silver," Abney and Edwards, 'Roy. Soc. Proc.,' vol. 47. Read December 12, 1889.

Fig. 3.



The following table applies to the curve, fig. 3.

Table III.

Scale No.	Sensitiveness.	Scale No.	Sensitiveness.
42	5	12	95
44	21	8	92
38	35	4	89
36	50	0	85·5
34	63	− 4	82
32	74	− 8	77·5
30	82	−12	73·5
28	89	−16	69
26	96	−20	64
24	99	−28	50
22	100	−36	29
20	99	−42	13
16	97	−48	0

The measurement of the densities on the plates was made by means of an arrangement by which the comparison light was transmitted through a graduated black annulus, whose thickness increased arithmetically with the number of degrees from the zero point. This ve the density measured on a scale of logarithms on a base due to its coefficient of absorption (obstruction). The mode of measurement has been described in other papers by myself and need not be repeated. As the "star" opacities and the graduated opacity scale on each plate were measured with the same annulus, it was unnecessary to reduce the measurements to densities which are usually taken in terms of common logarithms, or to transparencies in percentages of the initial light.

Example of Experiments.

It will facilitate matters if one example of measures be given in detail, and the mode in which they are applied. The spectrum colour used was at the scale No. 56·7. The star with the plate in contact with it was placed in the dark slide, and so arranged that the square patch of monochromatic red light would cover the whole of the former. The only light which would penetrate to the plate was through the star opacities. The star and plate were made to revolve round their centre in the slide by means of a spindle projecting outside, on which was a pulley that could be geared to an electromotor. Exposure was given for 65 minutes. No light was in the room except the red light. To make certain that the red light which fell on the prisms, and which illuminated them to a certain small extent, had no effect on the plate, the slit S, fig. 2, was covered with red glass, which only allowed the red of the spectrum to pass. The plate after the first exposure was completed; was removed and placed in a special slide, which allowed varying time exposures to be made on small square areas of the plate alongside that part which had been already impressed. The exposures were made to an amyl-acetate lamp at 4 feet distance, and were of 1, 2, 4, 8, &c., units of time duration. The plate was developed with ortol developer, fixed, washed, and dried. It was then placed in the measuring apparatus, and the scale densities of the amyl-acetate lamp exposures and the star opacities measured. On looking at Table I it will be seen that the coefficient of absorption, as there shown, is 0·87. The numbers in Table II were therefore multiplied by 0·87 to give the scale for abscissa in powers of 2. The following measures were obtained (Tables IV and V).

These results were plotted (fig. 4), and straight parts of both curves were compared. It will be seen that in the star opacities the curve cuts the abscissa 1 with an ordinate of 174, and this same ordinate is found on the scale curve at 2·65 in the abscissa. Again, the first has an ordinate of 63 at the abscissa 4, but the scale has abscissa 6·65 for the same ordinate. This shows that the exposures of the star would have had to be prolonged in both cases to have acquired the same density as the scale, but very unequally. We can find the unequal times necessary by subtracting the two abscissæ from one another at each point, and expressing the inequality by a fraction.

[redacted]

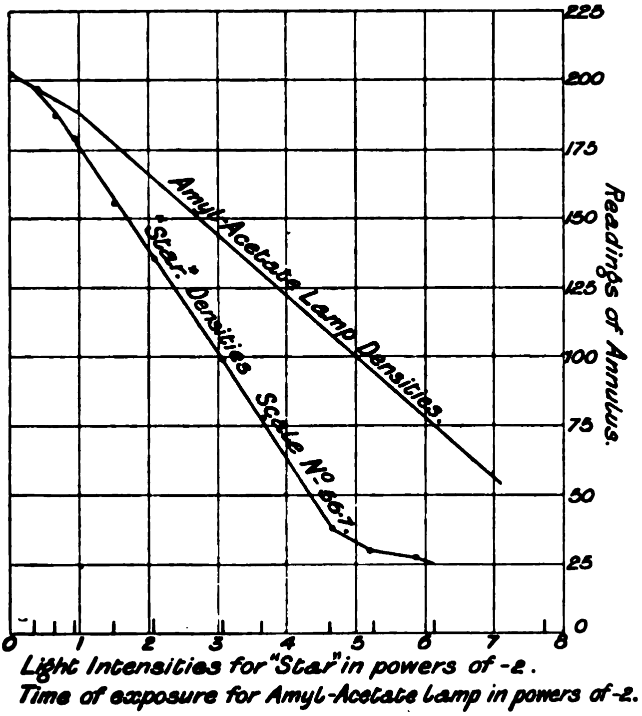
Table IV.

Amyl-acetate scale.	
Exposure in powers of 2.	Reading of Annulus.
1	202
2	189
3	168
4	145
5	122
6	98
7	77
8	55
Bare glass	21

Table V.

"Star" opacities.	
Intensity in powers of −2.	Reading of annulus.
0	202
0·33	197
0·65	187
0·93	178
1·50	156
2·05	136
3·05	97
3·62	77
4·61	39
5·22	30
6·13	26
7·74	—
Bare glass	21

Fig. 4.



Thus :—

Abscissa.

Star. Scale.
1 = 2·65 (ordinate 155)
4 = 7·60 (ordinate 42)
— ——
3 = 4·95
or 1 = 1·65

That is to say, the gradation of the plate when subjected to the red light is much steeper than when subjected to the light of the amyl acetate, and that to produce the same slope the ratio of the times of exposure to red light would have to be shortened in the ratio of 1 : 1·70; that is, if the exposure was doubled for the red light on each small space; then to make the slope the same for the amyl-acetate light the successive exposures given with it would have to be 3·3 times. It must be recollected that the first exposures required to give any deposit on a plate would be widely different, being far larger for the red light.

Results of Measures made.

To avoid any white light with which the prisms were illuminated reaching the plate through the slits, the following absorbing media were placed in front of the slit at the places indicated. The times of exposure are also shown.

Scale No.	Exposure.	Absorbing medium in front of slit.
56·7	65 min.	Stained red glass.
54·4	20 ,,	,, ,,
52·1	5 ,,	,, ,,
50·6	5 ,,	Orange.
47·5	3 ,,	Lemon yellow.
42·9	2 ,,	Chrome green.
38·3	2 ,,	Peacock green.
33·7	10 secs.	,, ,,
29·1	8½ ,,	Blue dye.
26·8	12 ,,	,,
22·2	5 ,,	Cobalt glass and blue dye.
17·6	5 ,,	,, ,, ,,
8·4	4 ,,	Methyl violet.

The following tables give the measured curves, and from them the gradations are found, as in the above example, the exposures given being as follows :—

Table VI.

Wave-lengths.																						
λ6395		6188	6004	5802	5689		5422		5187		4990		4816		4735		4584		5450		4207	
Scale Numbers.																						
56·7		54·4	52·1	50·6	47·5		42·9		38·3		33·7		29·1		26·8		22·2		17·6		8·4	
Intensity.	Density.	Density.	Density.	Density.	Light intensity.	Density.	Light intensity.	Density.	Light intensity.	Density.	Light intensity.	Density.	Light intensity.	Density.	Light intensity.	Density.	Light intensity.	Density.	Light intensity.	Density.	Light intensity.	Density.
0	202	158	191	176	0	214	0	165	0	202	0	142	0	165	0	180	0	180	0	175	0	197
0·33	197	148	177	165	0·34	201	0·35	152	0·35	196	0·35	235	0·37	159	0·38	176	0·39	176	0·39	172	0·40	195
0·65	187	135	165	155	0·68	189	0·64	141	0·66	184	0·68	127	0·73	151	0·75	168	0·76	166	0·76	166	0·79	190
0·93	178	124	153	145	0·94	180	0·97	128	0·98	176	1·00	120	1·04	145	1·05	165	1·06	157	1·06	163	1·11	184
1·50	156	103	131	126	1·56	156	1·53	106	1·61	157	1·64	103	1·70	131	1·73	155	1·77	148	1·77	152	1·84	167
2·05	136	81	108	97	2·12	136	2·17	84	2·19	140	2·25	89	2·32	117	2·35	142	2·40	134	2·40	137	2·62	148
3·05	97	55	67	65	3·15	99	3·2	58	3·25	110	3·32	70	3·44	95	3·5	119	3·57	112	3·57	109	3·7	128
3·62	77	40	48	46	3·74	75	3·85	46	3·87	91	3·95	55	4·07	81	4·16	103	4·23	99	4·23	96	4·4	107
4·61	39	28	31	229	4·77	49	4·9	30	4·95	64	5·05	42	5·2	61·5	5·3	78	5·4	75	5·4	70	5·6	77
5·22	30	24	26	25	5·4	35	5·5	28	5·66	45	5·7	36	5·9	55	6·0	70	6·1	60	6·1	55	6·35	62
6·13	26	—	—	—	6·3	28	6·5	—	6·66	39	6·7	31	6·95	44	7·05	55	7·15	48	7·15	42	7·45	56
7·74	—	—	—	—	8·01	—	8·2	—	8·4	25	8·5	—	8·75	—	8·9	39	9·1	28	9·1	29	9·4	35
Bare	21	21	21	21	—	22	—	22	—	21	—	21	—	21	—	21	—	21	—	21	—	21

Table VII.—Scales of Gradation taken with the Amyl-acetate Lamp.

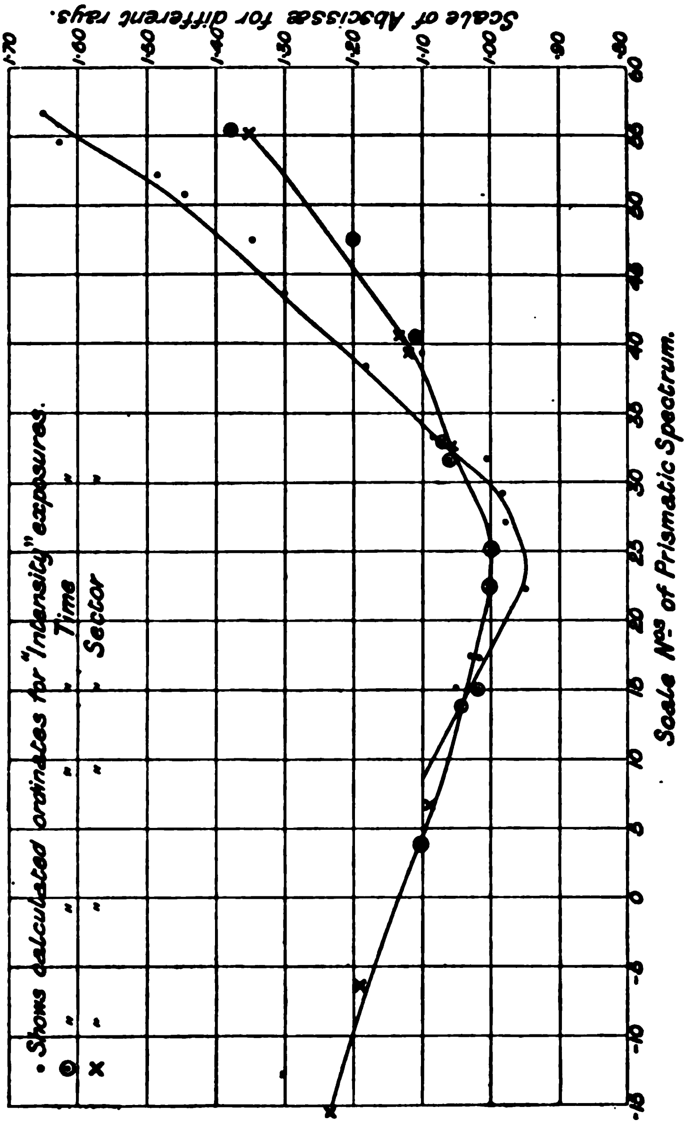
Time of exposure in powers of −2.	Densities.												
	(λ6395) 56·7	(λ6188) 54·4	(λ6004) 52·1	(λ5292) 50·6	(λ5689) 47·5	(λ5422) 42·9	(λ5187) 38·3	(λ4990) 33·7	(λ4816) 29·1	(λ4735) 26·8	(λ4584) 22·2	(λ4450) 17·6	(λ4207) 8·4
0	202	187	225	208	235	227	187	180	175	170	172	170	175
1	189	167	213	184	220	202	162	162	153	158	151	158	155
2	168	145	187	160	187	172	139	142	131	137	130	137	135
3	145	120	160	139	165	143	114	122	110	116	109	115	114
4	122	96	133	113	135	114	90	102	88	94	88	93	95
5	98	72	105	88	106	85	66	83	72	73	67	72	74
6	77	54	75	65	76	68	50	62	56	56	49	51	55
7	55	40	54	50	50	53	40	55	46	44	35	41	44
Bare glass....	21	21	21	21	22	22	21	21	21	21	21	21	21

Table VIII.

Scale No.	56·7	54·4	52·1	50·6	47·5	42·9	38·3	33·7	29·1	26·8	22·2	17·6	8·4
Gradation compared with amyl-acetate light.	1·65	1·63	1·48	1·45	1·35	1·3	1·18	1·08	0·98	0·98	0·95	1·05	1·10

Fig. 5 gives the results as shown in bottom line of the table. It will be seen that the slopes of the gradation of the different parts of the spectrum are least when near the maximum photographic effect (compare fig. 5 with fig. 2) and greatest in the red.

FIG. 5.



Experiments with Fixed Intensities of Rays.

Before commenting on this curve it will be better to describe the next set of experiments in which the light is constant, and there is a change in time.

The arrangements made were as follows:—Four slits in a card were made of such convenient width as (found by trial) allowed four different rays of the spectrum to emerge, and in front of the slits were cemented strips of a spectacle lens, which each gave an image of the prism surface of small size, but alongside one another. To prevent the white light which illuminated the prisms causing any error in the exposure, in front of each slit was placed a strip of glass of a colour approximately corresponding to the colour coming through it. Exposures were made to the four colours in the same plate and for the same length of time, the exposure being admitted or shut off at the slit of the spectroscope, and when completed the plate was given a graduated scale with the amyl-acetate lamp as before. The development of the plate was then carried out and the densities measured as usual.

The curve of the amyl-acetate light was plotted first, and the places which corresponded to the density of the "blue" light scale was marked on it. It was necessary to do this, for although the electric arc light was steady, yet it did not remain absolutely the same in intensity throughout the whole of the exposures. The places so fixed on the scale made by the amyl-acetate lamp by the blue exposures gave the points in the abscissa to which to refer the ordinates of the three other colour curves. These were duly set up and the curves drawn. Fig. 6 shows Table IX drawn diagrammatically. It was again found that the gradation given by the colours less refrangible than the Scale No. 24 were steeper than that of this No., as were also those of the colours more refrangible.

The slits were then moved into new positions and the same process gone through. (See Tables IX, X, and XI.) When these gradation factors are plotted on their appropriate scale numbers we get a curve convex to the base, with the lowest part lying about Scale No 24, confirming the results obtained by the previous place. (See fig. 5.) There can be but little doubt from both of these results that the place of minimum gradation given by rays is close to the wave-length to which the salt of silver under consideration is most sensitive.

[redacted]

Fig. 6.

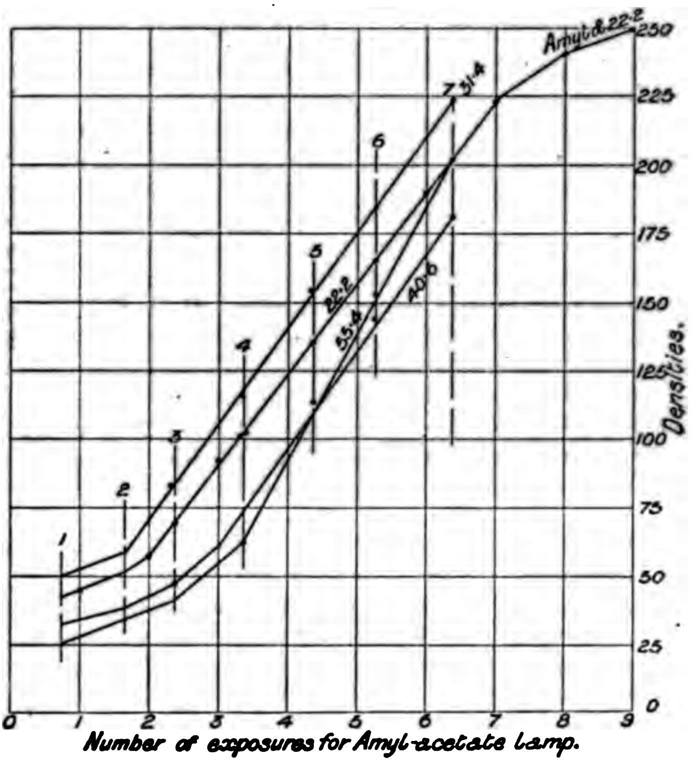


Table IX.

Amyl-acetate.		Scale numbers.							
E	D	55·4 (λ 6277)		40·6 (λ 5300)		31·4 (λ 4901)		22·2 (λ 4584)	
		E	D	E	D	E	D	E	D
1	47	1	26	1	33	1	51	1	42
2	60	2	35	2	43	2	61	2	53
3	93	3	42	3	47	3	85	3	70
4	126	4	63	4	73	4	118	4	101
5	159	5	114	5	110	5	155	5	135
6	192	6	151	6	144	6	187	6	165
7	225	7	202	7	186	7	225	7	202
8	242								
9	250								

Table X.

Amyl-acetate.		Scale numbers.							
E	D	39·3 (λ 5326)		25 (λ 4675)		15 (λ 4877)		6·6 (λ 4162)	
		E	D	E	D	E	D	E	D
1	55	1	43	1	43	1	55	1	53
2	70	2	47	2	47	2	60	2	59
3	94	3	74	3	87	3	101	3	108
4	128	4	82	4	92	4	108	4	115
5	162	5	127	5	133	5	152	5	161
6	198	6	143	6	147	6	164	6	177
7	228	7	167	7	169	7	186	7	201
8	240	8	190	8	190	8	208	8	223
9	250								

Table XI.

Amyl-acetate.		Scale numbers.							
E	D	47·4 (λ 5683)		32·7 (λ 4952)		22·8 (λ 4602)		14·5 (λ 4364)	
		E	D	E	D	E	D	E	D
1	75	1	66	1	45	1	77	1	105
2	99	2	108	2	61	2	113	2	142
3	123	3	134	3	83	3	134	3	163
4	147	4	165	4	110	4	164	4	191
5	171	5	193	5	135	5	182	5	214
6	195	6	202	6	143	6	190	6	223
7	217								

In the above tables, E is exposure and D is measured opacity in degrees of the annulus.

Table XII.

From Table IX.		From Table X.		From Table XI.	
Scale number.	Gradation factor.	Scale number.	Gradation factor.	Scale number.	Gradation factor.
55·4	1·38	39·3	1·10	47·4	1·20
40·6	1·11	25	1·00	32·9	1·07
31·4	1·06	15	1·02	22·8	1·00
22·2	1·00	6·6	1·10	14·5	1·04

The "Gradation factor" is the alteration required in the abscissa when expressed in powers of 2, the scale No. 22·2 having abscissa of unit length.

Table XIII.—Exposures to Amyl-acetate.

No.	Time in seconds.
1	1
2	2
3	4
4	8
5	16
6	32
7	64
8	128
9	256

Table XIV.—Exposures for Monochromatic Rays.

No.	Time in minutes and seconds.
1	5″
2	10″
3	20″
4	40″
5	1′ 20″
6	2′ 40″
7	5′ 20″
8	10′ 40″

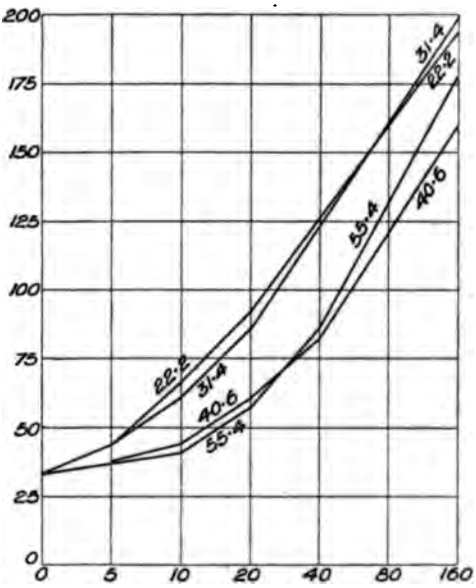
Experiments with Fixed Intensities of Rays, and Times of Exposure varied by means of a Rotating Disc.

Still one more plan, however, remained to be tried, viz., with a fixed intensity of light, but an alteration in the time of exposure by rotating a disc with gradually increasing apertures before the plate. The disc so pierced is shown in fig. 7. It will be seen that there are two apertures, one near the centre and another at the extreme outside of the radius, which include 40° only. There are thus three apertures of 40°, and if the patch of light is uniform the readings of the three should be the same. All the plate was covered by a mask except a portion ½-inch wide which extended its whole length, so that successive portions might be exposed to rays of different wave-lengths at first. The exposed strip of plate was placed in a horizontal direction, *i.e.*, a direction at right angles to the edges of the prisms, *nd it* was then found that the three readings of the 40° apertur

were not the same. To ascertain the cause of this an exposure was made through the slit without any disc intervening, and on development it was found that the reduction of silver was greatest in that part which was illuminated by the light coming through the edge of the prism, and least where it passed through the bases of the prism,

FIG. 7.

FIG. 8.



Apertures of Sectors in degrees.

showing that the glass of the prisms absorbed a certain proportion of the different rays as they passed through. It appeared probable that if the length of the ½-inch-wide slit were placed vertically in the patch of light (*i.e.*, parallel to the edges of the prism) no difference in absorption would be found. Such proved to be the case; the exposure through the slit and the patch of light without the intervening sectors gave a uniformly dense deposit, and when the sectors were replaced the densities given by the three 40° exposures were the same. On each plate exposures were given to four different colours, the total exposure varying in each case according to the colour; a single exposure was also given to some colour without the sector, and an exposure to an amyl-acetate lamp was also given. The following tables give the results obtained, and fig. 8 the results shown diagrammatically of Table XV, and the combined results are shown in fig. 5.

Table XV.—Densities.

Aperture of sectors.	Scale number.			
	55·4 (λ 6277)	40·6 (λ 5300)	31·4 λ 4901	22·2 λ 4584
°				
5	35	37	45	45
10	42	44	60	65
20	57	60	85	90
40	82	80	122	125
80	130	119	160	160
160	178	159	197	195

Table XVI.—Densities.

Aperture of sectors.	Scale number.			
	39·3 (λ 5320)	25 (λ 4675)	15 (λ 4377)	6·6 (λ 4162)
°				
5	53	75	75	53
10	67	98	100	60
20	89	121	125	82
40	115	144	150	107
80	140	167	174	133
160	166	190	198	157

Table XVII.—Densities.

Aperture of sectors.	Scale number.			
	17·6 (λ 4450)	3·3 (λ 4100)	−6·7 (λ 4130)	−15·8 (λ 3940)
5°	60	78	85	93
10	75	95	102	119
20	97	118	127	145
40	118	142	153	171
80	140	165	171	185
160	152	185	187	192

Table XVIII.—Densities.

Aperture of sectors.	Scale number.		
	32·7 (λ 4952)	22·8 (λ 4602)	14·5 (λ 4364)
5°	35	77	45
10	41	101	57
20	58	124	75
40	72	146	99
80	90	169	122
160	114	192	147
320	138	202	171

Table XIX.

Scale number.	Gradation factor.	Scale number.	Gradation factor.	Scale number.	Gradation factor.
55·4	1·35	25·0	1·00	−6·7	1·19
40·6	1·13	15·0	1·05	−15·8	1·23
31·4	1·05	6·6	1·09	32·7	1·05
22·2	1·0	17·6	1·025	22·8	1·00
39·3	1·12	3·3	1·10	14·5	1·04

It will be seen that these gradation factors are very closely the same as those obtained by the other plan of altering the time exposures, the intensity of the light acting remaining the same. The curve in these results has been pushed further into the ultra-violet than in the other experiments.

Causes of Difference of Results in the Experiments.

We next have to consider the cause of the difference between the results obtained when the intensity of the light was altered, the time being fixed, and these last two sets of results. I must refer to a paper which appeared in the 'Proceedings' of the Royal Society in 1893, entitled "On a Failure of the Law in Photography," &c., more particularly to the Addendum of July 4th, when it was shown that though the product of time of exposure and intensity of light remained constant, yet when the intensity was diminished the photographic action might also be less, and that when the intensity became very small, the diminution was very marked. These observations were further developed in subsequent communications to the Royal Photographic Society, in the same year, and it was shown that when the intensity of the same light remained constant during a set of exposures, the time being altered, the gradation of the plate remained the same though the curves occupied very variable positions in relation to the scale of abscissæ. Thus if with a light of a unit intensity exposures were given to different parts of a plate for, say, 1, 2, 4, 8, &c., seconds, and the light was reduced for another set of exposures on the same plate to 1/100 unit, and in order to make time × intensity constant in both cases the exposures were prolonged to 100, 200, 400, 800, &c., seconds, on plotting the densities of the deposit in the manner described above, the two curves would be strictly parallel though by no means coincident.

In the last two sets of experiments as the relative times of exposure are kept the same, though the intensity is small, the gradation of the different rays would be the same, however much the intensity was increased. On the other hand, where the intensity of the light is small (and when we say intensity, we mean the photographic intensity), the gradation would be steeper than would be the case if the intensity of the light were large. The photographic intensity of the light used for the red ray is less than 1/500 of the blue: hence on this account alone the "gradation factor" is larger than in the last two sets of experiments. This accounts for the difference between the gradation factors obtained by the two methods, from the red to the blue, and also for the approximate coincidence from the blue to the extreme violet when the photographic intensities of the light used are nearly the same. We see, then, that the gradation factors as found by the last two methods are those which really represent the difference due to the alteration in wave-lengths of the monochromatic light, and that the factors found by the first method are compounded between this alteration and that due to diminished photographic intensity.

As before remarked, the results of the first method of experimenting are those which apply to camera images, for they are formed by different intensities of light, and the exposure is the same for any . If, then, a plain surface were covered with a graduated scale

of greys, and a photograph taken of it through red glass, which practically cuts off all spectral rays except the red, and also through blue glass, the gradation of greys in the negative would be much more pronounced in the case of the red image than that of the blue, and we come to the conclusion that for three-colour photographic printing from a "red," a "green," and a "blue" negative this difference should be a source of difficulty, and this is certainly the case.

What scientific explanation there is of this difference in true gradation factor is hard to say. It almost appears that in the case of the blue waves acting on the atoms of the molecule of sensitive salt, whilst the amplitude is increased the rate of oscillation is slightly altered, gradually making the periodic motion of the waves of light out of tune with the motions of the atoms; whilst with the red rays, which are vastly out of synchronism with the atomic swings, the atoms got more nearly synchronous with them, and thus produce more photographic action. In my work on 'The Action of Light in Photography,' I have given a possible explanation of the difference in effect caused by a feeble intensity and a great intensity of light, and it may be that the same kind of explanation might hold good in this newly found phase of the action of light. It appears that these photographic phenomena are worthy of attention from the point of view of molecular physics.

It may be thought that these results might be peculiar to the salt of silver experimented with. A further series of experiments were conducted with the chloride of silver in gelatine. The maximum sensitiveness of these plates was found to be near H in the solar spectrum. The gradation was found to be least at this point, and increased when rays on each side of this point were employed to act on the film. In the blue near the F line, where the sensitiveness of the plate was very small, the gradation was excessively steep, as it also was in the extreme ultra-violet.

Wave-lengths for Prismatic Scale.

The following table shows the wave-lengths of the scale Nos. :—

Scale No.	λ.	Scale No.	λ.
60	673	28	478
58	652	24	464
56	633	20	452
54	615	16	440
52	600	12	430
50	585	8	420
48	572	4	410
44	548	0	400
40	527	−10	381
36	508	−20	364
32	492		

"A Comparative Crystallographical Study of the Double Selenates of the Series $R_2M(SeO_4)_2,6H_2O$—Salts in which M is Magnesium." By A. E. Tutton, B.Sc., F.R.S. Received April 29, —Read May 23, 1901.

(Abstract.)

This memoir on the magnesium group of double selenates, in which R is represented by potassium, rubidium, and cæsium, is analogous to that which was presented to the Society in March 1900 concerning the zinc group.

The conclusions derived from the study of the morphological and physical properties of the crystals of the three salts are generally similar to those arrived at from the study of the zinc group. There is observed a uniform progression with regard to every property in accordance with the order of progression of the atomic weights of the three alkali metals present. That is to say, the constants of the rubidium salt are generally intermediate between those of the potassium and cæsium salts.

The magnesium group has, however, proved particularly interesting, inasmuch as the progressive diminution of double refraction, according to the rule which has now been established for this series of double sulphates and selenates, leads in the case of cæsium magnesium selenate to such close approximation of the three refractive indices that the crystals of this salt exhibit exceptional optical phenomena. This includes dispersion of the optic axes in crossed axial planes at the ordinary temperature, the uniaxial figure being produced for wave-length 466 in the blue; and the formation of the uniaxial figure for every wave-length of light in turn as the temperature is raised, the attainment of uniaxiality for red lithium light occurring at the temperature of 94°. As the life-history of the salt terminates at 100°, owing to the presence of water of crystallisation, this substance exhibits the property of simulating uniaxial properties at some temperature within its own life-range for every wave-length of light, while still retaining the general characters of monoclinic symmetry, including slight dispersion of the median lines. In this respect it resembles to a truly remarkable extent the analogous sulphate, which the author has shown to possess like peculiarities, but it is even more striking than the sulphate, as the dispersion is much larger. It is interesting to observe that these optical properties of cæsium magnesium selenate could have been predicted, given the constants of the potassium salt and the rules of progression established for the double sulphate and for the zinc group of double selenates. For the double selenates resemble the double sulphates so closely that in general it may be said that their properties are precisely parallel, the constants and curves being merely moved on to a slight extent by the replacement of sulphur by selenium without disturbing their relationships.

"On the Presence of a Glycolytic Enzyme in Muscle." By Sir T. Lauder Brunton, M.D., F.R.S., and Herbert Rhodes, M.B.

Received May 7,—Read May 23, 1901.

It was found by Claude Bernard as well as by Ludwig and Generich that the blood which issued from a contracting muscle contained less sugar than the arterial blood which entered it. This destruction of sugar during its passage through the muscle might no doubt be partially due to the action of the blood itself upon the sugar, but it is natural to think that it may be due to the action of some glycolytic ferment contained in the muscle itself. An attempt to isolate such a ferment or enzyme was made by one of us (Brunton) in 1873. The attempt was only partially successful. The method employed was that of von Wittich. Some fresh muscle was comminuted, thoroughly mixed with glycerine and allowed to stand for many days. The glycerine extract was then filtered off. When some of this extract was mixed with a solution of glucose and allowed to stand for some hours at the temperature of the body, a distinct diminution was observed in the amount of glucose, while a control specimen of the glucose treated in the same way with a similar quantity of pure glycerine showed no diminution. The presence of a glycolytic substance was thus clearly shown.

An attempt was made to isolate out a glycolytic enzyme from the glycerine extract by diluting the glycerine and mixing it with alcohol. A scanty white precipitate was obtained, but the precipitate exhibited little if any glycolytic power. Numerous experiments having failed to isolate the ferment, they were not published, and the result was only briefly noticed in a foot-note to a paper on Diabetes in the 'British Medical Journal' of February 21st, 1874. At that time, one of us (Brunton) administered raw meat to diabetic patients in the hope of supplying sufficient glycolytic ferment to enable the sugar to be better utilised in the body, and also tried the administration of glycerine extract of muscle. The success attending these attempts was not, however, sufficient to encourage the persistent use of this means of treatment, and the attempt to isolate a glycolytic ferment was abandoned for a good many years.

The success of Buchner in separating an alcoholic ferment from yeast by means of great pressure gave promise of possible success in separating a glycolytic ferment from muscle by similar means, and by the kindness of Messrs. Allen and Hanbury, who allowed us the use of their hydraulic press, with a pressure of five tons to the square inch, we were enabled to resume the research. The following was the method adopted: The bone and superfluous fat were removed from the muscular part of a newly killed sheep. The muscle was then minced in a sterilised sausage machine and pounded in a mortar with silver sand. The silver sand was previously cleaned by means of hydrochloric acid and washing with water until all the hydrochloric acid had been removed. The mass was then put into a canvas bag and placed under the hydraulic press. The juice was received into clean, stoppered bottles, the portion which was yielded on different pressures being received into different bottles. The quantity of juice obtained from a leg of mutton was as follows:—

1750 grammes of flesh yielded approximately—

At 0·1 ton pressure per sq. inch	...	450 c.c. of juice.
„ 1·2 tons „ „	...	350 c.c. „
„ 2·5 tons „ „	...	125 c.c. „

The method of experiment was as follows:—5 c.c. of the muscle juice were placed in a flask and boiled for one minute, 5 c.c. in another flask remained unboiled. To each flask 50 c.c. of a 1 per cent. diabetic sugar solution and 5 c.c. of a 1 per cent. solution of lactic acid, with a fragment (about 0·25 gramme) of thymol were added. Both vessels were incubated at 37° C. for 24 or 48 hours. After the incubation was finished the sugar was estimated in both flasks by titration with Fehling's solution, after precipitation of the albumin by boiling and neutralisation if required. Six experiments were done with concordant results, and we have only given the result of one as being typical.

Sugar as estimated by reduction of Fehling fluid—

1st sample	A (boiled juice)	48 hrs.' incubation	0·57	per cent. dextrose
2nd „	B (unboiled juice)	„ „	0·2	„ „

The destruction of sugar in the flask containing unboiled sugar seemed to be almost certainly due to some glycolytic enzyme, as the contents of the flask remained quite clear at the time of experiment. Later on, however, the contents of the unboiled flask became turbid, and after four days a definite growth of fungi was obtained. We next attempted to render the muscle juice sterile by a Pasteur-Chamberland filter. The sugar solution was sterilised by boiling, and all the flasks and other vessels used in these experiments by heating in an autoclave. The muscle juice after filtration was completely sterile, as was shown by the fact that it was kept in a bottle plugged with sterilised wool for many weeks without any bacterial growth exhibiting itself. The glycolytic power of this sterilised muscle juice was tested in the following manner: 5 c.c. of the sterilised juice was placed in each of two flasks. In one of them the juice was boiled so as to destroy any glycolytic ferment it might contain. Into each flask we then placed 30 c.c. of a 2 per cent. sterile solution of diabetic sugar. They were incubated for forty-eight hours. The amount of sugar in each flask was then ascertained by titration with Fehling's solution in the same way as before, and the result obtained was 1·5 per cent. of diabetic sugar in the flask containing boiled meat juice, and only 0·75 per cent. in the flask containing unboiled juice. A very distinct glycolytic action is thus shown by this experiment, which was repeated three times with identical results.

A number of experiments were now made to isolate an enzyme by dialysis through membranes consisting of sausage skin or parchment. In the first series a distinct glycolytic action was observed, but this was probably due to bacterial action, as the media became turbid, and in a subsequent series made with aseptic precautions no glycolytic power was observed in the dialysate, although a flocculent precipitate resulted on the addition of absolute alcohol.

An attempt was made in another series of experiments to isolate the glycolytic ferment of muscle itself by precipitation. These were not successful. Fresh juice was mixed with four times its volume of absolute alcohol, the precipitate was collected, dried and pulverised. It was then extracted with glycerine, but this extract had little or no glycolytic power. It gave a white flocculent precipitate with absolute alcohol, which was soluble in saline solution, but which was quite without any glycolytic action whatever. The action of muscle juice was also tested on neutral diabetic urine and on a neutral solution of commercial dextrose. The results were as follows:—

Flask C contained 2 c.c. boiled muscle juice and 10 c.c. neutral diabetic urine.
„ D „ 2 c.c. unboiled muscle juice and 10 c.c. neutral diabetic urine.

After 50 hours' incubation at 37° C.
C contained 1·25 per cent. of dextrose.
D „ 0·75 „ „ „

Flask E contained 2 c.c. boiled muscle juice, 10 c.c. neutral diabetic urine and 1 c.c. of a 1 per cent. solution of lactic acid.
„ F „ 2 c.c. unboiled juice, urine, and lactic acid as E.

Again after incubation
E contained 2·5 per cent. dextrose.
F „ 0·5 „ „

Flask G contained 2 c.c. boiled muscle juice, 10 c.c. neutral solution of 0·5 per cent. commercial dextrose.

Flask H contained 2 c.c. unboiled muscle juice, the rest as G after incubation.
„ G „ 0·37 per cent. dextrose.
„ H gave no reduction with Fehling's solution.

The experiments that we have described prove, we think, that muscle certainly contains a glycolytic enzyme, though it is of such a delicate nature that we have not been able to isolate it without destroying its power.

June 6, 1901.

Annual Meeting for the Election of Fellows.

Sir WILLIAM HUGGINS, K.C.B., D.C.L., President, in the Chair.

The Statutes relating to the Election of Fellows having been read, Sir George King and Professor Herbert McLeod were, with the consent of the Society, nominated Scrutators, to assist the Secretaries in the examination of the balloting lists.

The votes of the Fellows present were collected, and the following Candidates were declared duly elected into the Society:—

Alcock, Alfred William, M.B.
Dyson, Frank Watson, M.A.
Evans, Arthur John, M.A.
Gregory, John Walter, D.Sc.
Jackson, Henry Bradwardine, Capt. R.N.
Macdonald, Hector Munro, M.A.
Mansergh, James, M.Inst.C.E.
Martin, Charles James, M.B.
Ross, Ronald, Major (I.M.S., retired).
Schlich, William, C.I.E.
Smithells, Arthur, B.Sc.
Thomas, Michael R. Oldfield, F.Z.S.
Watson, William, B.Sc.
Whetham, William C. Dampier, M.A.
Woodward, Arthur Smith, F.G.S.

Thanks were given to the Scrutators.

June 6, 1901.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read :—

I. "On the Electric Response of Inorganic Substances. Preliminary Notice." By Professor J. C. **Bose**. Communicated by Sir M. **Foster**, Sec. R.S.

II. "On Skin Currents. Part I.—The Frog's Skin." By Dr. A. D. **Waller**, F.R.S.

III. "Vibrations of Rifle Barrels." By A. **Mallock**. Communicated by **Lord Rayleigh**, F.R.S.

IV. "The Measurement of Magnetic Hysteresis." By G. F. C. **Searle** and T. G. **Bedford**. Communicated by Professor J. J. **Thomson**, F.R.S.

V. "A Conjugating 'Yeast.'" By B. T. P. **Barker**. Communicated by Professor **Marshall Ward**, F.R.S.

VI. "Thermal Adjustment and Respiratory Exchange in Monotremes and Marsupials: a Study in the Development of Homo-thermism." By Professor C. J. **Martin**. Communicated by E. H. **Starling**, F.R.S.

VII. "On the Elastic Equilibrium of Circular Cylinders under certain Practical Systems of Load." By L. N. G. **Filon**. Communicated by Professor **Ewing**, F.R.S.

VIII. "The Measurement of Ionic Velocities in Aqueous Solution, and the Existence of Complex Ions." By B. D. **Steele**. Communicated by Professor **Ramsay**, F.R.S.

"Vibrations of Rifle Barrels."* By A. Mallock. Communicated by Lord Rayleigh, F.R.S. Received May 2,—Read June 6, 1901.

It has long been known that a shot fired from a rifle does not in general start from the muzzle in the direction occupied by the axis of the barrel at the first moment of ignition of the charge.

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* The greater part of the notes from which this paper is drawn were made in 1898, but since that time the interesting experiments of Messrs. Cranz and Koch, of Stuttgart, on the same subject have been published, and I have looked through my notes again and put them in their present form, as it may be of some interest to compare results obtained in such different ways.

The late W. E. Metford was, I believe, the first to point out the origin of this deviation, showing by experiment that it was due to the unsymmetrical position which the mass of the stock held as regards the barrel; and, further, that if the initial direction of the shot passed below the apparent direction of aim when the rifle was held in the ordinary position, the initial direction would be high if the rifle were aimed upside down, and to the right or left if the plane of the stock were horizontal and the stock itself to the left or right of the barrel.

He showed, in fact, that the initial direction of a shot lay on a cone, whose axis was the axis of the barrel at the instant before the ignition of the powder, and in a plane containing the axis of the barrel and the centre of gravity of the rifle, and he rightly attributed the deviation of the shot to the bending couple acting on the barrel, due to the direction of the force causing the recoil not passing through the centre of gravity of the rifle.

The object of this paper is to examine this problem of "flip" or "jump," as it is called, from a mathematical point of view, and to show what effect may be expected from given variations either in the length of the barrel, the nature of its attachment to the stock, or the nature of the explosive employed.

The investigation is not merely a matter of curiosity, but has an important bearing on the accuracy of rifle shooting, and until some method is introduced, not of avoiding "jump," but of suitably regulating its variation with the variation of explosive force, I think no great advance will be made on the precision already attained in modern rifles.

This precision is already considerable, and, roughly speaking, any good modern rifle will shoot with a probable deviation of considerably less than 2′ from the intended path. When the results indicated in the course of this paper are considered, it seems wonderful that such accuracy should be possible, and it speaks well for the quality and uniformity of the ammunition that such good shooting should be common.

The problem of "jump" may be stated mathematically thus:—"An elastic tube, to which a mass is unsymmetrically attached, is subjected for a given time to a couple of arbitrary magnitude. Determine the subsequent motion." To solve this problem we must consider the tube and its attached mass as forming a single system, and examine what are the natural modes of vibration of this system, and what their natural periods. The arbitrary couple must be expressed in an harmonic series as a function of time, and the forced vibration which each term of this series will evoke in the system calculated.

To represent the initial conditions (namely, that at the moment before the explosion the barrel is at rest and unrestrained), such free vibrations of the system must be supposed to exist as, in combination with the forced vibration, will satisfy these conditions. The subsequent motion will then be determined by taking the sum of the forced and free vibrations as long as the arbitrary couple acts, and when this has ceased to act, the sum of the free vibrations only.

If the system could be represented by a uniform rod, the solution might at once be expressed in symbols, since the theory of the transverse vibrations of rods and tubes is well known. When we come, however, to a "system" like a rifle, although in many respects its behaviour may be compared with that of a uniform elastic rod of "equivalent length," the ratio between the periods of the vibrations of its various modes are altered, and recourse must be had to experiment to determine both the natural periods and the position of the nodes.

As far, however, as the rifle can be considered as being represented by an equivalent rod, it must be looked upon as being free at both ends at the moment of firing, because the motion communicated to the rifle is so small at the time the shot leaves the muzzle, that the constraint which hands and shoulders can impose on it is negligible compared to the acceleration forces called into play by the explosion.

This being so, the slowest vibration of which the system is capable is that with two nodes. The next in order of rapidity will have three nodes, and so on, as shown in the figures 1, 2, 3.

FIG. 1.—Mode I.

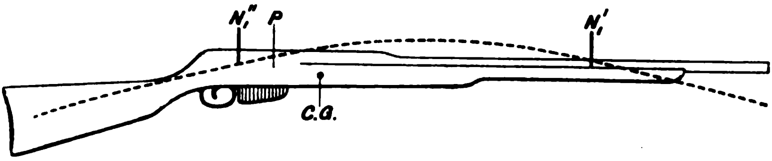


FIG. 2.—Mode II.

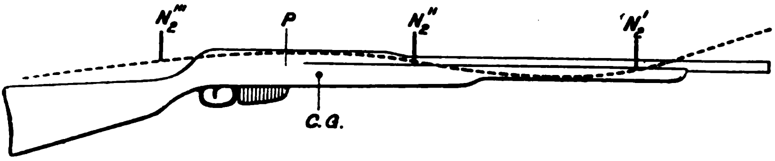
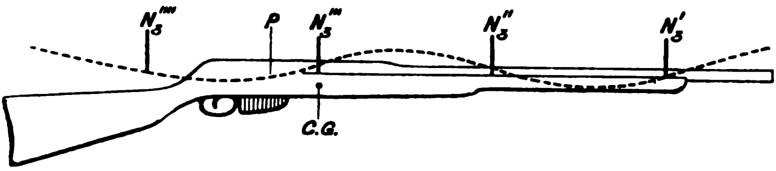


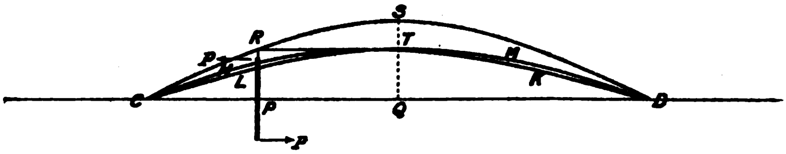
FIG. 3.—Mode III.



The figure assumed by the muzzle end of the barrel will be nearly exactly the same in each mode as the figure assumed in the corresponding mode by an uniform rod whose length is such as to make the distance of the node from its free end equal to the distance from the node to the muzzle of the rifle.

The couple which acts on the barrel during the explosion is measured by the rate at which the shot is accelerated, the distance of the axis of the barrel from the centre of gravity of the rifle. The effect of a given couple in causing a particular mode of vibration in the barrel depends on its point of application with reference to the nodes of the system as well as on its magnitude.

FIG. 4.



$QS = y_{QQ}$. $PR = y_{PQ} = QT = y_{QP}$.

CHTKD is the curve into which CD is bent by F acting at P.

CLTMD is that part of the deformation which belongs to the mode of vibration which has nodes at C and D.

If in fig. 4, C and D are two adjacent nodes belonging to some particular mode of vibration, it is evident that a couple applied midway between C and D would not cause any displacement of the system in this mode.

If a is the distance between the nodes C D and a couple pd at point P distant x from c, there will be

(1) A downward force at C $= pd/2x$ with an equal upward force at P, and

(2) An upward force at D $= \dfrac{pd}{2(a-x)}$ with an equal downward force at P.

On the whole, therefore, there is at P an upward force acting $= \dfrac{pd}{2}\left(\dfrac{1}{x} - \dfrac{1}{a-x}\right)$, or $\quad F = \dfrac{pd}{2}\left(\dfrac{a-2x}{x(a-x)}\right)$.

Suppose $y_{QQ} = cF$ to be the displacement which the force F would cause if acting at the point Q, midway between C and D. It is known that if a force F acting at Q causes a displacement y_{PQ} at P, the same force acting at P will cause a displacement y_{PQ} at Q, that is $y_{PQ} = y_{QP}$.*

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* This theorem is due to Lord Rayleigh.

Approximately, the equation to the curve between the nodes C and D for the mode of vibration which has these nodes may be taken as a simple harmonic function of x

or $$y = \zeta_{QQ} \sin 2\pi \frac{x}{a};$$

hence the displacement at P due to F acting at Q, and the displacement at Q due to F acting at P, are each equal to

$$\text{CF} \sin 2\pi \frac{x}{a},$$

or $$y_{QP} = c\frac{pd}{2} \frac{a-2x}{x(a-x)} \sin 2\pi \frac{x}{a} \quad \text{..................} \quad (1).$$

In a rifle the point of application of the couple is settled by the nature of the connection between the stock and the barrel, and it is a matter of great difficulty to make certain how the strains are distributed. The actual maximum pressure in the barrel which is spoken of as "chamber pressure" is known for various small arms and various explosives with considerable accuracy; but the curve of pressure in terms of the travel of the shot along the barrel is much more difficult to ascertain. In this paper, therefore, I shall consider several types of such curves in order to show what effects are to be looked for as the pressure curve changes its character.

The condition fulfilled in each of the pressure curves considered is that each must give the same muzzle velocity to the shot by acting on it through the length of the barrel, and in the numerical results given the velocity and weight of the projectile are taken as 2000 feet per second and 215 grains respectively, with an effective length of barrel of 2·3 feet, these being nearly the velocity, weight, and length of barrel used in the Lee-Enfield rifle.

The simplest case of all (and the furthest removed from truth) is that of a uniform pressure acting on the base of the shot throughout the length of the barrel.

Here we have, if p_0 is the acceleration, v_m the muzzle velocity, $\mathfrak{T}$ the time taken by the shot in reaching the muzzle, and l the length of the barrel,

$$v_m = p_0 \mathfrak{T} \quad \text{..............................} \quad (2),$$

$$l = p_0 \frac{\mathfrak{T}^2}{2} \quad \text{..........................} \quad (3),$$

$$p_0 = \frac{v_m^2}{2l} \quad \text{..............................} \quad (4),$$

$$\mathfrak{T} = \frac{2l}{v_m} \quad \text{..............................} \quad (5).$$

Putting $v = 2000$ f.s., and $l = 2{\cdot}3$ ft.,

we have $p_0 = 860{,}000$ f.s.s., $\mathfrak{T} = 0{\cdot}0023$ secs.

An acceleration of 860,000 is about 27,000g, so that a uniform force of 27,000 times its own weight, or 835 lbs., would give the 215-grain shot its observed velocity in the actual length of the barrel.

With a uniform force, the pressure curve in terms of space is the same, of course, as if expressed in terms of time; but for any other case we must, for the purpose of this paper, express the pressure curve (which experiment would give in terms of the distance travelled by the shot in the barrel) in terms of time.

The pressure at time t being p, we have

$$p = \frac{dv}{dt}; \quad \text{also} \quad \frac{dv}{dt} = \frac{dv}{ds}\frac{ds}{dt} = v\frac{dv}{ds}, \quad \text{and} \quad p\,ds = v\,dv$$

$$\therefore \; v = \sqrt{(2\textstyle\int p\,ds)} \qquad \text{(6)};$$

and

$$t = \int \frac{ds}{\sqrt{(2\int p\,ds)}} \qquad \text{(7)}.$$

If we take the case of the pressure decreasing uniformly with the travel of the shot, it is easy to show by (5) and (6) (although the analogy with the force acting on a pendulum or spring at once suggests it), that the velocity and position of the shot are:—

$$s = l\left(1 - \cos t\sqrt{\frac{p_0}{l}}\right) \qquad \text{(8)},$$

$$v = \sqrt{p_0 l}\,\sin t\sqrt{\frac{p_0}{l}} \qquad \text{(9)},$$

$$p_0 = \frac{v_m{}^2}{l} \qquad \text{(10)},$$

$$\mathfrak{T} = \frac{\pi}{4}\frac{l}{v_m} \qquad \text{(11)}.$$

With the before-mentioned values for l, v, and w, $p_0 = 1{\cdot}174 \times 10^6$ f.s.s. and $\mathfrak{T} = 0{\cdot}00171$ second.

One more case by way of example will suffice. Let the pressure decrease uniformly with the time so that

$$p = p_0\left(1 - \frac{t}{\mathfrak{T}}\right) \qquad \text{(12)}.$$

From this we get

$$v = p_0 t - p_0\frac{t^2}{2\mathfrak{T}} \qquad \text{(13)},$$

$$s = p_0\frac{t^2}{2}\left(1 - \frac{t}{3\mathfrak{T}}\right) \qquad \text{(14)},$$

and the relation between p and s is

$$s = \frac{l}{2}\left(2 - 5\frac{p}{p_0} + 4\frac{p^2}{p_0^2} - \frac{p^3}{p_0^3}\right) \ldots\ldots\ldots\ldots \quad (15).$$

From (13) (14), using the above values for v_m and l,

$$p_0 = 2 \cdot 32 \times 10^6 \text{ f.s.s.} \qquad \mathfrak{T} = 0 \cdot 00173 \text{ sec.}$$

The three cases are illustrated in diagrams 5, 6, 7, in which the various curves show the pressure, velocity, and time elapsed since the beginning of the motion during the passage of the shot through the barrel.

Diagrams 8, 9, 10 show the pressure in terms of time, and it is these curves which have to be represented by a harmonic series.

In order to avoid having a constant term at the beginning of the series, the fundamental t is taken equal to $2\mathfrak{T}$.

Then by the ordinary rules for finding the coefficient of a Fourier series, the succession of "battlements" which form the pressure curve in case 1 (uniform acceleration), we find

$$p = p_0\frac{4}{\pi}\left\{\sin 2\pi\frac{t}{t_1} + \frac{1}{3}\sin 3\left(2\pi\frac{t}{t_1}\right) + \frac{1}{5}\sin 5\,2\pi\frac{t}{t_1} + \&c.\right\} \quad (16).$$

In case 2, where the pressure curve is a succession of half-lengths of a simple harmonic curve, the general coefficient of the nth term is

$$p_0\frac{2}{\pi}\frac{4n}{4n^2 - 1},$$

and the series is

$$p = p_0\frac{2}{\pi}\left\{\frac{4}{3}\sin 2\pi\frac{t}{t_1} + \frac{8}{15}\sin 2\left(2\pi\frac{t}{t_1}\right) + \&c.\right\} \ldots\ldots \quad (17).$$

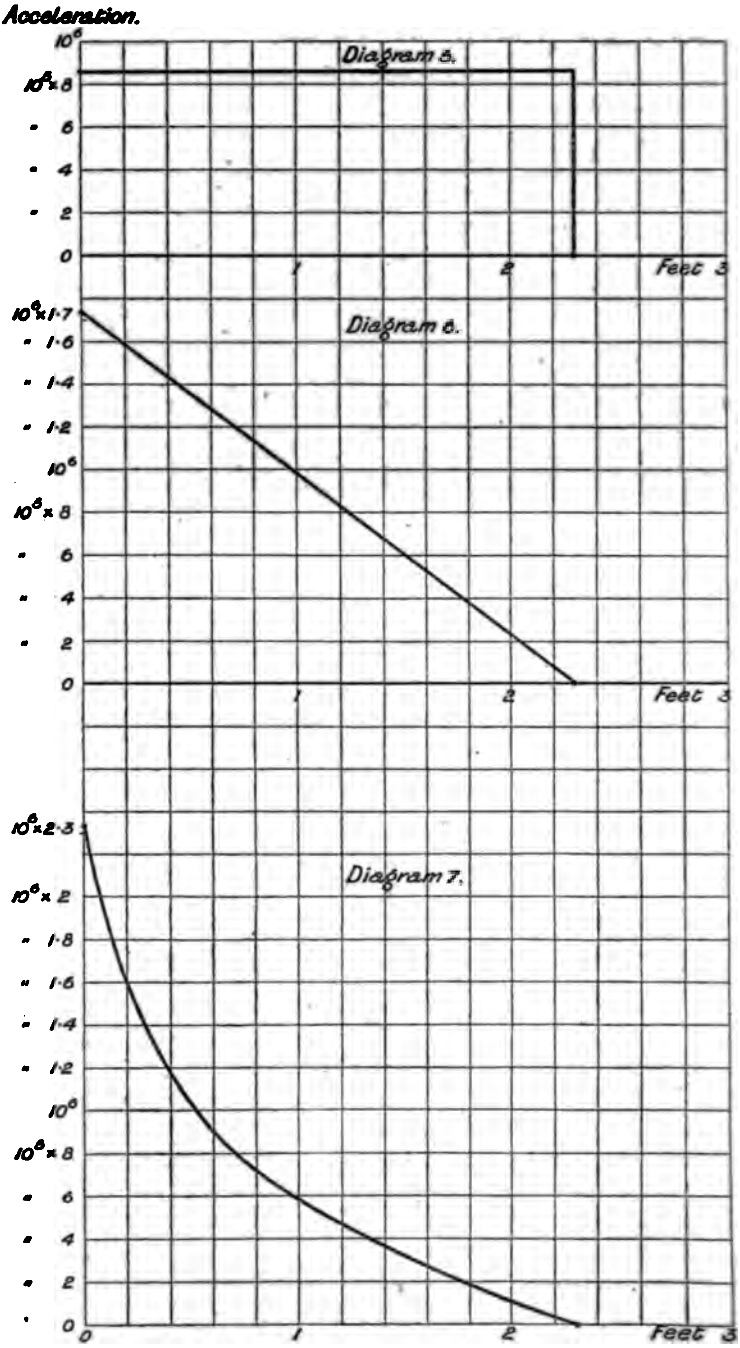
The series for case (3), where $p = p_0\left(1 - \frac{t}{\mathfrak{T}}\right)$, is

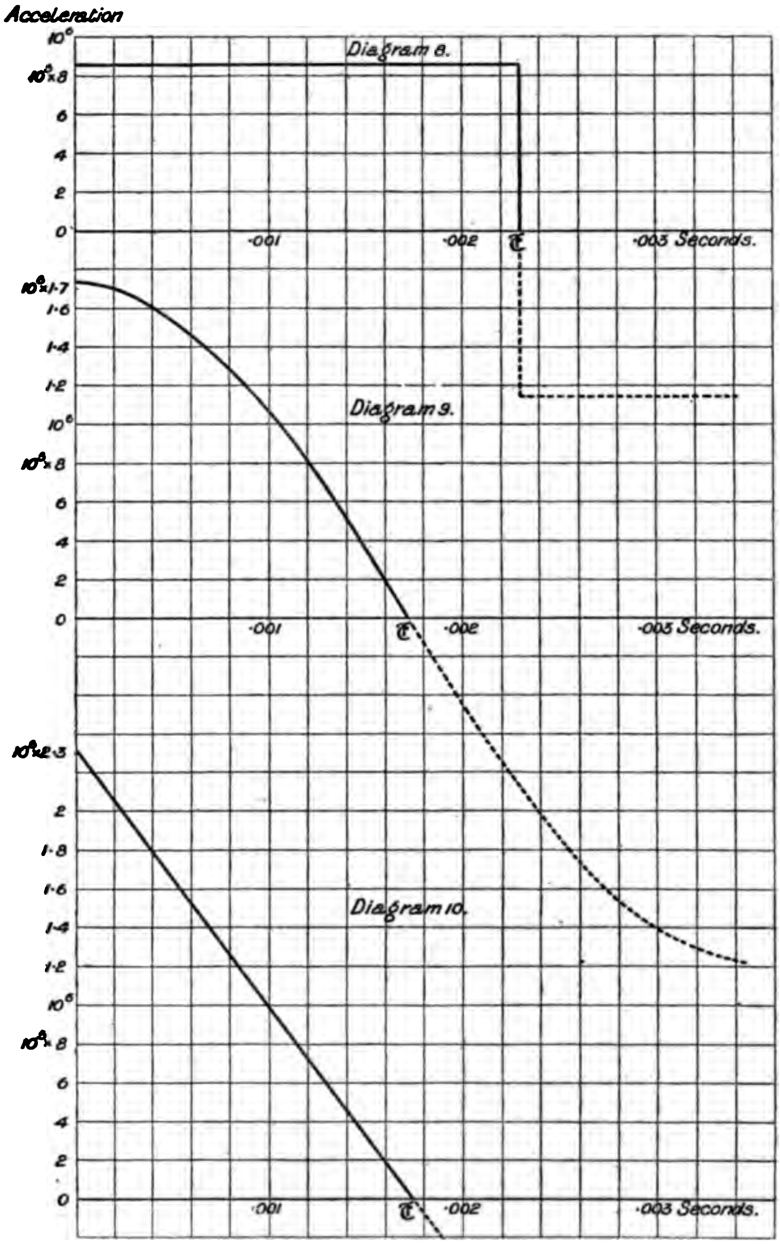
$$p = p_0\frac{2}{\pi}\left\{\sin 2\pi\frac{t}{t_1} + \frac{1}{2}\sin 2\left(2\pi\frac{t}{t_1}\right) + \frac{1}{3}\sin 3\left(2\pi\frac{t}{t_1}\right) + \&c.\right\} \quad (18).$$

The coefficients in series 17 and 18 soon become sensibly equal in the corresponding higher terms of each.

In the cases just considered, except the first, it is assumed that the pressure at the muzzle is zero, which of course is not true, but the existence of a terminal pressure can be readily represented by adding a series of the form of (16) of suitable magnitude. The effect of this is to increase the relative importance of the first and all the odd terms.

We must now examine the forced vibrations which each term of the series expressing the accelerating pressure would set up in the rifle,


Acceleration.
Diagram 5.
10^6
$10^6 \times 8$
" 6
" 4
" 2
0
1
2
Feet 3
Diagram 6.
$10^6 \times 1{\cdot}7$
" 1·6
" 1·4
" 1·2
10^6
$10^5 \times 8$
" 6
" 4
" 2
0
1
2
Feet 3
Diagram 7.
$10^6 \times 2{\cdot}3$
$10^6 \times 2$
" 1·8
" 1·6
" 1·4
" 1·2
10^6
$10^5 \times 8$
" 6
" 4
" 2
0
0
1
2
Feet 3



supposing that the harmonic couple it represents continued to act. If T_1, T_2 . . . T_m are the natural periods of the various modes in which the rifle can vibrate, and d the distance of the centre of gravity from the axis of the barrel, the forced oscillation which the nth term in the series will evoke in the mth mode of the rifle will be, when expressed as the angle through which some particular part of the system bends during the oscillation, is

$$\theta = \theta_m p d \mathrm{A}_n \frac{1}{1 - q^2_{nm}} \sin 2n\pi \frac{t}{t_1} \quad \ldots\ldots\ldots\ldots\ldots \quad (19).$$

In this expression θ_m is the angle at the place of observation which the unit couple would cause if acting to produce a displacement of the system in the mth mode (the values of θ_m can be found approximately by statical experiments on bending).

A_n is the numerical coefficient of the nth term of the harmonic series, and

$$q_{nm} = \frac{\mathrm{T}_m}{t_n} \text{ or } \frac{\mathrm{T}_m}{nt_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (20).$$

To represent the initial conditions, which are that the moment before the explosion the barrel is at rest and unstrained, it suffices to suppose the co-existence of free oscillations of the system, with phases and amplitudes such as to make the velocity and displacement zero when $t = 0$. If a and b are the amplitudes of the forced and free vibrations respectively, we have

$$a \sin 2\pi \frac{t}{t_1} + b \sin 2\pi \frac{t}{\mathrm{T}_n} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (21),$$

and

$$\frac{2\pi}{t_n} a \cos 2\pi \frac{t}{t_n} + \frac{2\pi}{\mathrm{T}_m} b \cos 2\pi \frac{t}{t_m} = 0 \quad \ldots\ldots\ldots\ldots \quad (22),$$

whence

$$q_{nm} = -\frac{b}{a} \quad \ldots\ldots\ldots\ldots\ldots\ \ldots\ldots\ldots\ldots \quad (23),$$

hence the free vibration, which at $t = 0$ leaves the system at rest, so far as the oscillation excited by the nth term in the mth mode is concerned, has q_{nm} times the amplitude of the corresponding forced vibration.*

It is convenient in the complete expression for displacement to refer to the natural periods of the system, which are constant, rather than to the periods contained in the pressure curve. So, substituting for t_n its value T_m/q_{nm}, we have for the angular displacement of the system at that time after the explosion (*i.e.*, for the sum of the forced and free vibrations at that time due to the term and mode under consideration)

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* For the purposes of this paper it is not necessary to consider the gradual extinction of the free vibrations, for the number of periods involved is so small, even for the highest component taken into account, that extinction will not mate-lly affect the amplitude.

$$\theta_{nm} = \theta_m p d \mathrm{A}_n \frac{1}{1 - q^2_{nm}} \left(q_{nm} \sin 2\, p \frac{t}{\mathrm{T}_m} - \sin q_{nm} 2\pi \frac{t}{\mathrm{T}_m} \right) \ldots \quad (24).$$

Diagram 11 shows the curves represented by the function

$\dfrac{q \sin \phi - \sin q\phi}{1 - q^2}$ from $\phi = 0$ to $\phi = 2\pi$ and $q = 0{\cdot}6$ to $q = 4$.

When $q = 1$ this expression takes the form of $\propto . 0$ which, evaluated in the usual way, gives

$$\frac{\phi \cos \phi - \sin \phi}{2}.$$

I will now apply the above results to examine the form of the Lee-Enfield rifle at the moment the shot leaves the barrel, assuming that the pressure developed during the explosion is that shown in fig. 10, taking into consideration the first three terms of the harmonic series for that curve and the first three modes of vibration of the rifle.

For this rifle it was found by experiment* that a couple of 1 foot-lb. acting at the nodes caused at the muzzle the following deflections :—

Mode I .... $\theta_1 = 1'{\cdot}13$
Mode II .... $\theta_2 = 0'{\cdot}765$
Mode III .... $\theta_3 = 0'{\cdot}565$

In the authorised 'Text-book for Military Small Arms' the initial pressure in the chamber of the Lee-Enfield is given as 15 tons per square-inch.

The area of the base of the shot is 0·0725 square-inch, so that the initial pressure on the shot is 1·09 tons or 2450 lbs. Since the weight of the shot itself is 215 grs., the force acting on it is $\frac{7000}{215} \times 2450$, nearly 80,000 times its own weight. Multiplying this by g, the acceleration which the shot would undergo in the absence of friction in the barrel is 2,560,000 feet per second per second.

In case 3 (14) the initial pressure was found to be 2,320,000 feet per second per second, so that, allowing for the force required to press the shot into the rifling and the friction in the barrel, it seems probable that the pressure curve of case 3 represents with some degree of approximation the actual acceleration which the shot experiences.

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* It would occupy too much space to describe these experiments in detail. They were made by loads suitably placed on the rifle, and the deflections caused by them were measured by optical means. The deflections so found were reduced to what they would have been had the action of the couples been concentrated at the nodes. In virtue of the approximate straightness of the free end of a vibrating rod, the angular deflection at the muzzle was taken as equal to the angular deflection at the nearest node. Hence the deflections above given are rather less than the true values.

[redacted]

The centre of gravity of the rifle is just an inch below the axis of the barrel, and, taking the accelerative pressure on the shot as 2250 lbs., the bending couple at the first instant is 187 ft.-lbs.

Also $$A_1 = \frac{2}{\pi}, \quad A_2 = \frac{2}{2\pi}, \quad A_3 = \frac{2}{3\pi}.$$

Thus

$$p_0dA_1 = 118 \text{ ft.-lbs.}, \quad p_0dA_2 = 59 \text{ ft.-lbs.}, \quad p_0dA_3 = 40 \text{ ft.-lbs.},$$

Table I.

$$\begin{array}{lll} \theta_1p_0dA_1 = 133' & \theta_2p_0dA_1 = 90'\cdot5 & \theta_3p_0dA_1 = 66'\cdot5 \\ \theta_1p_0dA_2 = 66'\cdot5 & \theta_2p_0dA_2 = 45' & \theta_3p_0dA_2 = 33'\cdot3 \\ \theta_1p_0dA_3 = 45' & \theta_2p_0dA_3 = 30' & \theta_3p_0dA_3 = 22'\cdot2 \end{array}$$

These are the angular displacements which the muzzle would undergo if in each case it experienced the full statical effect of couple corresponding to the first, second, and third term of the series representing the explosion curve acting so as to deform the system in the first, second, or third mode.

Owing, however, to the position of the point of application of the couples with reference to the nodes of the various modes (see I, and figs. 2 and 3), it appears that for the first mode the couple will cause 0·88 of its full effect, as for this mode the node N_1'' coincides nearly with the point of application of the couple. The nodes N_2' and N_2'' of the second mode fall at such a distance from P as to reduce the effect of the couples to about 0·35 of the above value. And the reduction is about 0·6 for displacements in the third mode.

The following table is an approximation to the actual values of—

Table II.

	m.		
n.	1.	2.	3.
1	117'	31'·5	39'
2	59'·5	15'·8	20'
3	39'·5	10'·5	13'·2

To determine the periods T_1, T_2, T_3, namely the natural periods of the rifle in the first, second, and third modes, experiments were made by tapping the barrel so as to excite the modes in question, and determining the notes emitted by comparison with tuning forks. The positions of the nodes were found by noting the position of the points of support which did not damp the vibrations in each mode examined.

The results were as follows:—

Table III.

	Frequency.	Period.	Distance of nearest node from muzzle.
	Per sec.	sec.	in.
Mode I	66	0·015	12·5
Mode II	172	0·00575	8·6
Mode III	395	0·00253	6·5

In case 3, again, the value found for $\mathfrak{T}$ was 0·00173 second, hence for the assumed ammunition $t_1 = 0{\cdot}00346$ second.

We can now construct a table of the value of q_{nm}.

Table IV.

Values of q_{nm} for $m = 1$ to $m = 3$, $n = 1$ to $n = 3$.

	T_1.	T_2.	T_3.
t_1	4·3	1·64	0·72
t_2	8·6	3·28	1·44
t_3	17·2	4·92	2·94

The abscissa on Diagram 11, which corresponds to the time $\mathfrak{T}$ will be

For Mode I .... $2\pi\dfrac{\mathfrak{T}}{T_1} = 42^\circ{\cdot}5.$

„ Mode II .... $2\pi\dfrac{\mathfrak{T}}{T_2} = 111^\circ$

„ Mode III .... $2\pi\dfrac{\mathfrak{T}}{T_3} = 250^\circ.$

If then Diagram 11 had curves for all values on it, we should, in order to determine the deflection (due to vibration evoked in the mth mode by the nth term of the harmonic series) of the muzzle as the shot leaves it, merely have to take the ordinate of the curve for which $q = q_{nm}$ at the abscissa $2\pi\dfrac{\mathfrak{T}}{T_m}$, and multiply this ordinate by $\theta_m p d A_n$ as given in Table I, but the diagram, to avoid confusion, has shown on it only curves relating to a few values of q.

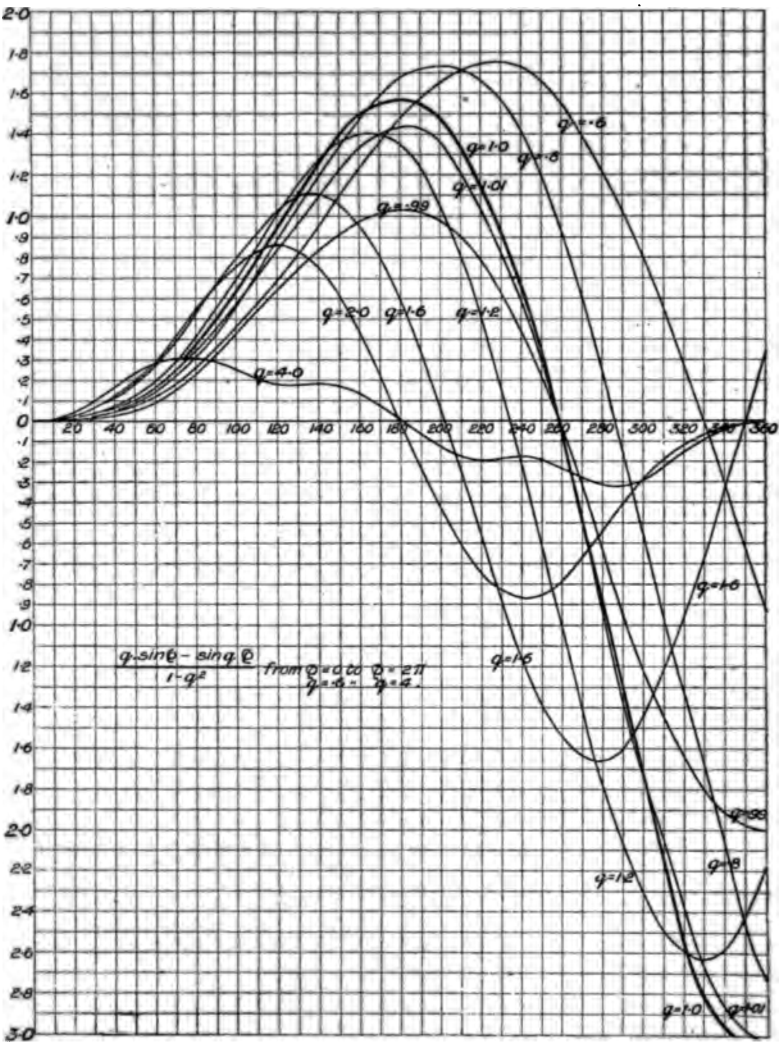
Using, however, the values of q_{nm} given in Table IV, and computing θ_{nm} for these values, by 24 it is found that

[redacted]

Table V.

θ_{11} = 19′·5 up.	θ_{12} = 28′·5 down.	θ_{13} = 60′ up.
θ_{21} = 4′·7 up.	θ_{22} = 4′·8 down.	θ_{23} = 25′ down.
θ_{31} = 1′·55 up.	θ_{32} = 2′·05 down.	θ_{33} = 4′·9 down.

DIAGRAM 11.



Hence, adding these results, we find for the total upward deflection of 85′·85, a downward deflection of 65′·25, or finally, a resultant of 20′·6, as the angle which the instantaneous axis makes in an upward direction with the unstrained axis of the barrel, at the moment of the shot leaving the muzzle.

The course of the shot differs from instantaneous axis of the barrel by an amount depending on the ratio of the transverse linear velocity of the muzzle (due to the vibration) to the muzzle velocity of the shot. The transverse velocity v' of the muzzle consequent on the nth term vibration in the mth mode, can be obtained by differentiating θ_{nm} with respect to t, and multiplying by R_m (the distance of the nearest node of the mth mode from the muzzle). We then find the ratio v'/v

$$= \frac{2\pi R_m \theta_m p l A_n q_{nm}}{V_m T_m (1 - q^2_{nm})} \left(\cos 2\pi \frac{\mathfrak{T}}{T_m} - \cos 2\pi q_{nm} \frac{\mathfrak{T}}{T_m}\right) \ldots\ldots \quad (25).*$$

Computing from this a table of corrections of angle corresponding to Table V representing the alterations of the values of the angles in Table V depending on the vertical linear speed of the barrel, we have approximately

Table VI.

	I.	II.	III.
1.	4′·6 up.	2′·5 down.	5′·0 up.
2.	0′·35	0′·0	0′·0
3.	0′·21	0′·8	0′·0

or on the whole 6′·9 of upward inclination must be added to the 20′·6 found from Table V, so that the flight of shot lies 27′ nearly above the direction of the unstrained axis.

The actual jump found by experiment for the Lee-Enfield rifle is, I believe, nearly about this amount, but from the uncertainty of the positions found for the nodes in the neighbourhood of the breech, and the small number of terms computed, as well as the doubtful approximation to the pressure curve, no great accuracy could be expected. The example is useful, however, and is introduced to show that the jump depends on the difference between comparatively large quantities, many of which are sure to be varying rapidly with q_{nm}.

The variations of q_{nm} may be caused either by the variation of T_m or t_n. For each individual rifle T_m of course is constant, depending as

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* It may be noticed that in (24) and (25) $\sin 2\pi q_{nm} \frac{\mathfrak{T}}{T_m}$ must $= 0$, and $\cos 2\pi q_{nm} \frac{\mathfrak{T}}{T_m} = \pm 1$.

[redacted]

it does only on the elasticity and mass of the weapon, but t_n and A_n depend on the rapidity and rate of the explosion.

Suppose that in place of assumed explosive a slower burning explosive were used, with a charge sufficient to give the same muzzle velocity. This would cause an increase in $\mathfrak{T}$ and t_n; that is, q_{nm} would be diminished, and, owing to the greater terminal pressure (see (15) *et seq.*) all the values of A_n for n odd would be increased in relative importance compared with those for n even. The result in the case of a small variation of this kind in the Lee-Enfield would be an increased upward jump.

A lower muzzle velocity would also correspond to an increase of $\mathfrak{T}$, and would give an increased upward jump in this rifle, and at some particular range it should be found that the variation of jump and variation of initial velocity compensate one another, and that for moderate variations of charge the sighting at this range does not require alteration.

The natural periods of the rifle may be altered either by adding mass, or shortening the barrel. In the first case $\mathfrak{T}$ will remain unaltered, and q_{nm} will increase; thus the tendency of a small mass added near the muzzle will be to make the rifle shoot low.

If the barrel is shortened both T_m and $\mathfrak{T}$ are diminished, but the alteration in T_m (which depends on the square of length of the equivalent rod) is much more important than the alteration in $\mathfrak{T}$; hence a small shortening of the barrel may be expected to cause a considerable diminution in q_{nm} and a corresponding increase in upward jump.

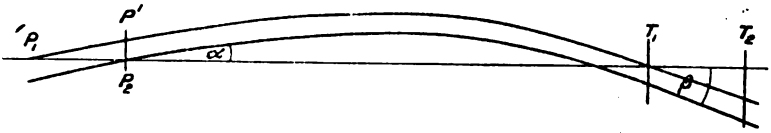
The most important factors in these changes (as regards the Lee-Enfield) are $q_{1\cdot 2}$ and $q_{1\cdot 3}$, that is the effect of the first term of the harmonic expansion of the explosion curve in exciting the 2nd and 3rd mode vibration of the rifle.

If ammunition could be made absolutely uniform in its action, "jump" would be of comparatively small importance, but the ± 40 feet per second by which the initial velocity of the service bullet varies may, by altering the factors on which "jump" depends, exaggerate with some classes of rifles, and diminish with others, the variation of the trajectory due to the effect of gravity and the altered initial velocity.

Suppose a rifle to be aimed and shot from P_1, fig. 12, so as to hit the centre of a target T_1 at range R, when the initial velocity is V. What will be the effect on the aim of a variation of the initial velocity?

Let α be the angle of elevation of the rifle and β the angle of descent of the bullet at T_1. Let P′ be the place in the trajectory of the shot (whose initial velocity is V) where the velocity has fallen to $V - v$. If a shot is fired from P_2 with the same sighting as was used at P_1 and with the initial velocity $V - v$, the trajectory of this shot will always be a constant distance P_1P_2 below the trajectory through P_1, and will therefore strike the target T_1 at this distance below the centre. If a second target, T_2, is placed at a distance P_1P_2 ($= a$) behind T_1 so that $P_1T_1 = P_2T_2 = R$, the second target will be struck

FIG. 12.



$\alpha\beta$ below the hit in the first target; hence since $P_1P_2 = a\alpha$, the error due to the variation of initial velocity is $a(\alpha + \beta)$. β may be found from the range tables of any rifle by the relation

$$\beta = R \,.\, da/dR.$$

Applying this to the Lee-Enfield, the following table shows the errors due to a variation of 40 feet per second in the initial velocity, on the assumption that the direction of the shot is not affected by "jump."

Table VII.

a = 54 feet = distance from muzzle at which the speed has fallen 40 feet per second.

Range in yards.	α.	β.	$a(\alpha + \beta)$. feet.	$= \frac{a}{R}(\alpha + \beta)$.
100	4′	48′	0·141	1′·6
500	31′	43′	1·17	2′·16
1000	88′	144′	3·8	4′·35
1500	177′	320′	7·8	6′·0
2000	305′	570′	13·8	7′·8
2500	477′	980′	23·0	10′·5

These errors are comparable with, but, especially at the longer ranges, greater than what the best shots are liable to in practice, so that with this particular rifle the compensating action of the variation of "jump" is a distinct advantage.*

For some time I was under the impression that the complete elimination of the effect of "jump" which could be effected by a recoiling barrel, such as has been used in some repeating rifles, would lead to

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* The fact that in this rifle variation of "jump" had a corrective effect was noticed by the late Sir Henry Halford.

improved accuracy in shooting; but in view of the above results it would appear that this is not the case.*

The present inquiry shows that in the design of a rifle it is most important to consider the relations between the explosion force and the natural periods of the rifle, considered as an elastic structure, and that probably the compensating effect above mentioned might be made of more use than it is at present.

For this purpose the explosion curves for various classes of ammunition and the variations to which they are liable should be accurately known, and the proportions and length of the barrel, as well as the attachment of the barrel to the stock, should be so arranged with regard to the nodes of the system as to make variation of "jump" with the variation of initial velocity most nearly balance, within certain ranges, the alteration in the trajectory which gravity would otherwise effect in virtue of the altered initial velocity.

To show the sort of advantage which may be obtained by this means, we may, for example, suppose the rifle to be so constructed that for some particular class of ammunition the variation of "jump" due to a ± 40 f.s. of initial velocity causes downward or upward variation of 6′ in the initial direction of the shot. Then by subtracting 6′ from E in Table VII, and multiplying by R, we get the following results:—

Table VIII.

Error due to ± 40 f.s. in initial velocity.

	Error	
	Without jump.	With jump.
100 yards	± 0·14 feet.	∓ 0·38 feet.
500 "	1·17 "	1·70 "
1000 "	3·8 "	1·26 "
1500 "	7·8 "	0·00 "
2000 "	13·8 "	± 3·15 "
2500 "	23·0 "	9·8 "

Such a correction, if it can be realised without an inconvenient construction of the mechanism, would be valuable for military purposes now that long-range fire is becoming of such great importance.

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* There is another form of "jump," however, in the Lee-Enfield rifle, whose absence is most desirable, as it introduces horizontal movements of the barrel. It depends, not on the acceleration of the shot, but on the statical pressure of the powder gas acting on an unsymmetrical breech-closing action, and the remedy, as well as the disadvantages, are so clear in this case as not to call for further remark.

" A Conjugating ' Yeast.' "

By B. T. P. **Barker**, B.A., Gonville and Caius College, Cambridge. Communicated by Professor **Marshall Ward**, F.R.S. Received May 4,—Read June 6, 1901.

(Abstract.)

At the outset, the idea of a true yeast (*Saccharomyces*) which conjugates may appear anomalous in the extreme, but it is not improbable that such an event has been observed before in such organisms, though the phenomena have been misinterpreted.

The yeast which is the subject of this communication was obtained from commercial ginger, pieces of this substance being placed in sterile saccharose-Mayer solution and kept at 25° C. until the organisms situated on the surface of the ginger had attained vigorous growth. These were separated by means of fractional plate-cultures of beer-wort gelatine.

The colonies of the yeast-form, as seen on beer-wort gelatine plate-cultures, appeared to the naked eye as small rounded white dots, about the size of a pin's head. Under the low power of the microscope colonies on the surface of the gelatine had regular edges, while submerged colonies had a woolly appearance, due to numerous radiating branches.

A pure culture was obtained from a colony developed from a single cell kept under observation in a hanging drop of beer-wort gelatine.

Streak cultures on beer-wort gelatine and beer-wort agar are of a milky-looking brownish-white colour, and have well-marked regular crenate edges. Streak cultures on potato and bread are milky-white when moist, and chalky-looking when dry; on pieces of moist ginger their colour is darker.

A yeast-ring is formed in old cultures on many liquid media, but no films are produced. In tubes of beer-wort, which have been actively fermenting, the ring makes its appearance in 10—14 days at 25° C. It is milky-white in colour, and looks like a layer of cream, deposited around the edges of the liquid. Such rings are also formed on dextrose-Mayer, lævulose-Mayer, saccharose-Mayer, and maltose-Mayer solutions, being particularly well developed on those liquids which have undergone an active fermentation.

The vegetation of the cultures described consists of typical ovoid and round yeast cells, and in the older cultures a few sausage-shaped and many irregular cells also, some of the latter containing spores.

Reproduction by budding in a typical yeast-like manner is the usual method of growth, taking place best at 25—30° C., the maximum and minimum limits being 37—38° C. and 10—13° C. respectively.

Reproduction by spores occurs under the usual conditions of spore-

[redacted]

formation for the Saccharomycetes. The gypsum-block method gives a plentiful supply, while spore-containing cells are frequently found in old cultures on nutrient media, whether solid or liquid. The spore-containing cells differ from those of most other Saccharomycetes in being compound cells, *i.e.*, they consist of two ordinary ovoid or round cells which have conjugated by means of a beak developed from each, the tips of the beaks fusing, the process thus resembling the well-known case of conjugation of many Algæ and Fungi. The compound cells are thus made up of two ordinary yeast-like cells joined together by a narrow neck, the length of which varies according to the circumstances under which spore formation has taken place.

Details of the process have been observed in hanging-drops of distilled water, in which have been placed a number of vigorously growing cells, the temperature being kept about 25° C. The cells, originally clear and homogeneous, in a few hours began to grow vacuolated, and numerous bright-looking granules made their appearance. In twelve or more hours after sowing, a beak-like tubular process was put forth by many of the cells. The beaks of two neighbouring cells grew towards each other until their tips were in contact. Fusion of the walls then took place at the point of contact, being followed by the fusion of the protoplasmic contents of the beaks, which were clearer and brighter than the rest of the protoplasm in the cells. In a few hours after fusion, the protoplasm began to contract in the cells, and small round masses were formed: these eventually developed into the spores.

The bright granules in the cells arranged themselves into groups in connection with the above masses and formed a network around them, the final differentiation of the spores being completed by the formation of a cell-wall around each mass. The size of the ripe spore is 4—5 μ; and the number in each compartment of the mature cell varies from one to four, the most common arrangement being two in each.

The spores germinate in a normal manner. After swelling they bud like ordinary yeast-cells. Fusion of spores in some cases seems to occur before germination. The optimum temperature for spore formation lies between 25° C. and 30° C., the first signs of spores appearing in 16—24 hours. At 34° C., 32—36 hours are required, and at 36—37° C., 2—3 days. Above 38° C. no spores are formed. At 13—15° C., 10—14 days are required, and below 13° C. practically no spores are produced.

When heated for 10 minutes in beer-wort the spores are generally killed at 60° C., but some withstand an exposure of 5 minutes to a temperature of 65° C.

In old cultures on nutrient media, and in spore cultures where the conditions were not of the most favourable character for the formation of spores, many cells of exceedingly irregular shape are found. These are apparently produced from the ordinary ovoid or round cells during efforts at spore-formation. Beaks are formed at different points of the cell, but no conjugation takes place ; or, if it does occur, no spore formation follows. Consequently cells of great irregularity in shape result, and such may be considered as cells which have made attempts at spore-formation, but have failed owing either to lack of energy or substance in themselves, or to unfavourable external conditions.

The behaviour of the nuclear contents during conjugation and spore-formation is suggestive. Stained preparations of cells in different stages of these processes show that the tips of the beaks are occupied by a deeply stained mass, which on conjugation fuses with a similar mass in the beak of the other cell which takes part in the process. The fused mass then divides into two, one portion withdrawing into each compartment of the compound cell; there division again takes place, in such a way as to provide the basis of each spore about to be formed. Previous to the latter division a deeply stained and prominent granular network becomes arranged around each mass, and this separates into groups when the final division occurs, the number of groups corresponding with the number of masses.

By this time each mass is rounded off into a spherical body—the young spore—and around each spore a group of granules is arranged and eventually a wall is formed. The spores then ripen. Lack of knowledge as to the exact nature of the yeast nucleus prevents a complete interpretation of the histological facts observed, but it seems certain that the deeply stained masses are nuclear in nature, and that consequently a kind of nuclear fusion takes place. If so the process must be looked upon as a simple sexual act, somewhat similar to that occurring in the process of spore-formation of *Schizo-saccharomyces octosporus.*

Alcoholic fermentation is produced in beer-wort by this yeast. It also ferments lævulose vigorously, and dextrose and saccharose slightly. Maltose, lactose, and dextrin are not fermented. A mixture of dextrose with maltose and dextrin is fermented more freely than dextrose alone. Long-continued cultivation in beer-wort seems to have increased its fermentative activity for that medium.

In conclusion, there seem to be three possible views regarding the nature of the fusion-process, viz.: (1) It is an abnormal or pathological phenomenon due to the conditions of culture; (2) it is a mere cell-fusion, such as frequently occurs between contiguous cells in fungi; or (3) it is a true sexual process, such as is now known to occur in many fungi.

The first view seems unlikely, since the result of the process is the production of normal healthy spores, and the conditions are exactly such as are generally efficacious in the production of spores in yeast of all kinds.

[redacted]

The second view receives a certain amount of support from the fact that such fusions are known in other yeasts, *e.g.*, *Saccharomyces Ludwigii* (Hans), but in these cases growth is active, and there does not seem to be any nuclear fusion.

Having regard to the behaviour of the nuclear contents and the subsequent formation of spores, the third view seems most likely. Looking upon the process then as a sexual act of the simplest kind, and in view of the fact that, while all its other characters accord with those of Saccharomyces, it differs from the latter in the manner of its spore-formation, it is proposed to place it in a new genus, *Zygosaccharomyces*, on the analogy of the genus Schizo-saccharomyces, suggested by Beyerinck for the fission-yeasts.

"The Measurement of Magnetic Hysteresis."

By G. F. C. SEARLE, M.A., and T. G. BEDFORD, M.A. Communicated by Professor J. J. THOMSON, F.R.S. Received May 2,—Read June 6, 1901.

(Abstract.)

§ 1. In 1895 one of the authors described* a method of measuring hysteresis by observation of the throw of a ballistic electro-dynamometer. The method in its most elementary form is very simple. An iron ring of section A and mean circumference l is uniformly wound with Nl turns of primary winding, and the primary current C passes also round the fixed coils of an electro-dynamometer. A secondary coil of n turns wound on the ring is connected in series with the suspended coil of the dynamometer and an earth inductor, the total resistance of the circuit being S.

The effects of self-induction in the secondary circuit being neglected, the secondary current c is

$$c = \frac{An}{S} \cdot \frac{dB}{dt}.$$

If the couple acting on the suspended coil due to the currents C, c be qCc, then at any instant

$$\text{Couple} = qCc = q\,\frac{An}{4\pi NS}\,H\,\frac{dB}{dt},$$

since $H = 4\pi NC$, when the magnetic force due to c is neglected.

If the instrument be used ballistically, the angular momentum acquired by the coil while C changes from C_0 to $-C_0$, is

$$K\omega = q\int Cc\,dt = q\,\frac{An}{4\pi NS}\int H\,dB.$$

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* G. F. C. Searle, "A Method of Measuring the Loss of Energy in Hysteresis," '*Camb. Phil. Soc., Proc.*,' vol. 9, Part I, 11th November, 1895.

Now let the earth inductor be inverted, and so produce a change of induction P, and let the primary current at the time be C′, then

$$K\omega' = qC'\int cdt = qC'P/S.$$

If θ_1, θ_2 be the two throws which occur when C changes from C_0 to $-C_0$ and from $-C_0$ to C_0, and if ϕ be the throw due to the earth inductor, then $\theta/\phi = \omega/\omega'$ and thus for a complete cycle,

$$W = \frac{1}{4\pi}\int HdB = \frac{C'PN}{An\phi}(\theta_1+\theta_2).$$

Thus the sum of the two throws θ_1 and θ_2 is a measure of the energy dissipated in hysteresis in a complete cycle. When the factor $C'PN/An\phi$ has been determined, measurements of hysteresis can be made as rapidly as measurements of induction with a ballistic galvanometer.

§ 2. In developing a more complete theory the authors employ the equations

$$E = RC + \frac{d}{dt}(NlAB + L'C + Mc),$$

$$0 = Sc + \frac{d}{dt}(nAB + MC + Lc).$$

With the aid of the principle of the conservation of energy, these equations lead to the result

$$\begin{aligned} W &= \frac{C'NP}{An\phi}(\theta_1+\theta_2) - \frac{16\pi^2N^2QA}{\sigma}\int\left(\frac{dB}{dH}\right)^2\frac{dC}{dt}dC \\ &\qquad - \frac{N}{SAn}\int\left(\frac{4\pi n^2A}{l}\frac{dB}{dH}+L\right)\left(4\pi nAN\frac{dB}{dH}+M\right)\frac{dC}{dt}dC \\ &= U - X - Y. \end{aligned}$$

Here σ is the specific resistance of the specimen, and Q a numerical constant depending upon the geometrical form of the section, having the value $1/8\pi$ or 0·03979 for a circle and 0·03512 for a square.

The term U is determined by the dynamometer throws. The term X is the energy dissipated in eddy currents in the specimen during the two semi-cycles, and Y is roughly the energy spent in heating the secondary circuit.

It is shown that Y, when appreciable, can be determined by making two observations for U with two different values for S. In the authors' experiments Y was nearly always negligible. When a suitable key is employed to reverse the current, X + Y can be determined by making two observations for U with two different resistances of the primary circuit, the E.M.F. being at the same time so altered as to produce the same maximum current C_0 in each case.

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This method of determining X + Y has lately been used successfully at the Cavendish Laboratory by Mr. R. L. Wills in the case of specimens of large section. In the authors' experiments X was generally negligible.

As the corrections X and Y depend upon dC/dt it is necessary that the primary current should change only gradually. By inserting a choking coil of great self-induction in the primary circuit, and by using a special key to cause the reversal of the current, this end is satisfactorily attained.

The authors have made many comparisons between the values of W found by their method and those calculated from the areas of cyclic B–H curves obtained by a ballistic galvanometer, and have found satisfactory agreement.

§ 3. By using a ballistic galvanometer in addition to the dynamometer, the two authors were able to make simultaneous observations of the range of the magnetic induction $\pm B_0$ and of the energy dissipated in each cycle. The range of the magnetic force $\pm H_0$ was also observed.

It was found that the cyclic B–H curve is not always divided into two parts of equal area by the line $H = 0$. The effect is well marked in the case of an iron wire freshly annealed, and sometimes does not disappear in spite of many reversals.

When the magnetic force is reversed many times both B_0 and W decrease. The effect is most apparent in soft iron freshly annealed, and subjected to a small magnetic force. Thus when the limits of H were $\pm 2{\cdot}5$, in the first cycle after the annealing, $B_0 = 2220$ and $W = 598$. In the forty-first cycle $B_0 = 1840$, $W = 433$.

§ 4. When an iron wire is stretched by a variable load, and is put through cycles with the limits $\pm H_0$, the first application of the tension results in an increase in both B_0 and W. As the tension increases, B_0 and W reach maxima and then decrease. The effect is more marked when H_0 is small than when it is large. Thus with a wire of section 0·00708 cm.^{2} a load of 16 kilos. raised B_0 from 1233 to 5870 and W from 494 to 3820, with $H_0 = 4{\cdot}524$.

A series of experiments was made upon the effects of torsion. When H_0 is kept constant, as the torsion increases there is a large decrease in both B_0 and W. Thus in the case of a soft iron wire when $H = 3{\cdot}0$, by torsion within the elastic limit B_0 was brought down from 2280 to 1070 and W from 907 to 276. Further, both B_0 and W exhibit hysteresis with respect to the torsion.

Experiments were also made in which the torsion was gradually increased till the wire broke. In other experiments the authors studied the influence of permanent torsional set upon the effects of cycles of torsion. They also examined the development of a cyclic state, for cycles of torsion, after initial permanent torsional set.

In all these experiments, the curves showing W in terms of the stress, bear a close resemblance to those showing B_0 in terms of the stress. To examine this point, curves were plotted showing how W varies with B_0, when H_0 is kept constant and B_0 is varied by varying the stress.

For both tension and torsion each curve for a given value of H_0 takes the form of a straight line having a hook at one end. The straight portions of the separate curves for different values of H_0 all pass, on prolongation, through a single point, generally on the line $B_0 = 0$. Thus the straight parts are represented by $W = mB_0 - b$. Plotting m against H_0 it is found that $m = aH_0^{\frac{1}{4}}$, and thus the formula becomes $W = aH_0^{\frac{1}{4}}B_0 - b$, where a and b are constants. It is found that this formula represents W closely when both H_0 and B_0 vary over a considerable range in the neighbourhood of the maximum permeability, the iron being now free from stress.

§ 5. An electric current flowing along an iron wire magnetises it circularly, and may be expected to diminish both B_0 and W for the given limits $\pm H_0$. Experiment showed that the expected effect occurs, a current of 1·123 ampere through an iron wire about 1 mm. in diameter diminishing W by 22·7 per cent.

§ 6. The numerical values of the quantity Q, which occurs, in § 2, in the expression for the heat produced by the eddy currents in the specimen, are calculated in Appendix I for rods of both circular and rectangular sections.

§ 7. In their experiments the authors have used straight iron wires about 50 cm. in length. They discuss the effect of the de-magnetising force due to the induced magnetism of the specimen, and show how to apply corrections to the value of W calculated from the formula $1/4\pi \cdot \int H'dB'$, where H′ is the magnetic force due to the current, and B′ is the magnetic induction at the centre of the wire; they also give numerical examples of these corrections. Appendix II contains an account of experiments made to find the de-magnetising force h under two sets of conditions. In the first case, h was determined when $H = H_0$, after many magnetic cycles with the limits $\pm H_0$. Using a freshly annealed wire, and increasing H_0 from 0 to 124 C.G.S., h was found to rise to a maximum, which occurred nearly when μ had its maximum value; the maximum was followed by a minimum of h, and the value of h for the largest values of H_0 was *less* than that which would obtain if the induction through the centre of the wire flowed in and out only by the *ends* of the wire. This small value of h implies the existence, between the centre and either end of the wire, of a "pole" of sign opposite to that of the pole at the end, a circumstance only to be accounted for by the effects of hysteresis. In the second case h was found for several points on the cyclic B–H curve, and curves are given showing h in relation to both H and B. In both curves h

exhibits very marked hysteresis with respect to H and B. Over a part of the cyclic h–B curve, the direction of h is *opposite* to that corresponding to the direction of the induction at the centre of the wire. The results obtained show that the method of "shearing" usually adopted to correct B–H curves for the effects of the de-magnetising force must be used with great caution.

The paper is illustrated by diagrams of apparatus and by curves showing the experimental results.

"Thermal Adjustment and Respiratory Exchange in Monotremes and Marsupials.—A Study in the Development of Homothermism." By C. J. Martin, M.B., D.Sc., Acting Professor of Physiology in the University of Melbourne. Communicated by E. H. Starling, F.R.S. Received May 14,—Read June 6, 1901.

(Abstract.)

A number of observations on the relations between the body temperature, and the temperature of the surrounding medium, and on the respiratory exchanges in monotremes and marsupials are recorded. The results are compared with those obtained in control experiments with cold-blooded animals (lizards) and higher mammals.

The main conclusions arrived at are—

1. Echidna is the lowest in the scale of warm-blooded animals. Its attempts at homothermism fail to the extent of 10° when the environment varies from 5° to 35° C. During the cold weather, it hibernates for four months, and at this time its temperature is only a few tenths of a degree above that of its surroundings. The production of heat in Echidna is proportional to the difference in temperature between animal and environment. At high temperatures, it does not increase the number and depth of its respirations. It possesses no sweat glands, and exhibits no evidence of varying loss of heat by vaso-motor adjustment of superficial vessels in response to external temperature.

2. Ornithorhyncus is a distinct advance upon Echidna. Its body temperature though low is fairly constant. It possesses abundant sweat glands upon the snout and frill, but none elsewhere. The production of carbonic acid with varying temperatures of environment indicates that the animal can modify heat-loss as well as heat-production. Its respiratory efforts do not increase with high temperatures.

3. Marsupials show evidence of utilising variations in loss to an extent greater than Ornithorhyncus, but less than higher mammals. Their *respirations* slightly increase in number at high temperatures.

4. Higher mammals depend principally upon variations in heat-loss, in which rapid respiration plays an important part.

5. Variation in production of heat is the ancestral method of homothermic adjustment. During the evolution of the warm-blooded animal it has, through developing a mechanism by means of which it can vary production in accordance with heat lost, overcome one disadvantage of cold-blooded animals, viz., that activity is dependent on external temperature. It has thereby increased its range in the direction of low temperatures. Later, by developing a mechanism controlling loss of heat, it has increased its range in the direction of high temperatures, and also rendered body temperature largely independent of activity; these advantages have been gained by a greater expenditure of energy.

"On the Elastic Equilibrium of Circular Cylinders under certain Practical Systems of Load." By L. N. G. FILON, M.A., B.Sc., Research Student of King's College, Cambridge; Fellow of University College, London; 1851 Exhibition Science Research Scholar. Communicated by Professor EWING, F.R.S. Received May 20,—Read June 6, 1901.

(Abstract.)

The paper investigates solutions of the equations of elasticity in cases of circular symmetry, and it applies them to discuss the elastic equilibrium of the circular cylinder under systems of surface loading which do not lead to the simple distributions of stress usually assumed in practice.

The analytical method employed has been to solve the equations of elasticity in cylindrical co-ordinates, obtaining solutions in the typical form $\begin{matrix}\cos\\ \sin\end{matrix}\left\{kz\right\} \times$ (function of r), r being the distance from the axis and z the distance measured along the axis.

More general solutions, not necessarily symmetrical about the axis, have been given by Professor L. Pochhammer* and by Mr. C. Chree.† Professor Pochhammer has used his results to deduce approximate solutions for the bending of beams. Neither Mr. Chree nor Professor Pochhammer has, so far as I am aware, worked out his solutions in detail for such problems as are discussed in the present paper.

I found that solutions in trigonometrical series would be sufficient to satisfy most conditions in the first of the three cases discussed, and all

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* 'Crelle's Journal,' vol. 81.

† 'Cambridge Phil. Soc. Trans.,' vol. 14.

[redacted]

conditions in the third. The second case required the introduction of other typical solutions, and the analysis was more intricate.

The three problems investigated are as follows:—

In the first I consider a cylinder under pull, the pull not being applied by a uniform distribution of tension across the plane ends, but by a given distribution of axial shear over two zones or rings, towards the ends of the cylinder.

The second is that of a short cylinder compressed longitudinally between two rough rigid planes, in such a manner that the ends are not allowed to expand.

The third case is that of the torsion of a bar in which the stress is applied, not by cross-radial shears over the flat ends, as the ordinary theory of torsion assumes, but by transverse shears over two zones or rings of the curved surface.

The first problem corresponds to conditions which frequently occur in tensile tests, namely, when the piece is gripped by means of projecting collars, the pull being in this case transmitted from the collar to the body of the cylinder by a system of axial shears.

Analytical solutions are found when this system of axial shears is arbitrarily given, there being given also an arbitrary system of radial pressures. Approximate expressions are deduced when the length of the cylinder is large compared with its diameter. These show that the strains and stresses may be calculated on the assumption that we have, over any cross-section, a uniform tension across the section, a constant radial pressure and an axial shear proportional to the distance from the axis, the last two occurring only over the lengths of the cylinder where such stresses are applied. The effects of local pressure and shear are thus, for a long cylinder, restricted to a small region and, in the free parts of the bar, we have, to this approximation, the state of things assumed by the ordinary theory.

In order, however, to study the effect of such a system of surface stresses, when no approximations are involved, I have worked out numerically a case where there is no radial pressure applied externally, and a uniform axial shear is applied between two zones. The solution gives zero tension across the plane ends; it is not, however, found possible to fulfil completely the condition of no stress, and we have over these limiting planes a self-equilibrating system of radial shears, which, however, will produce little effect at a distance from the ends. The length of the cylinder is taken to be $\pi/2$ times the diameter, this ratio being found to simplify the arithmetic. The two rings of shear extend each over one-sixth of the length and are at equal distances from the mid-section and the two ends.

In this and the other numerical examples, Poisson's ratio has been taken as one-fourth. This is not correct for most materials, but as the *object was to* find out the differences between the results of the simple and the modified theories, rather than to calculate the absolute stresses and displacements for any given material, the exact value of Poisson's ratio adopted was comparatively unimportant.

It is then found that the stress is greatest at the points where the shear is discontinuous, *i.e.*, at the ends of the collar in a practical case. At these points it is theoretically infinite. This result is true whatever the dimensions of the cylinder. For materials like cast iron or hard steel, which are brittle, such points would therefore be those of greatest danger; but in such a case as that of wrought iron or mild steel, for instance, the stress will be relieved by plastic flow.

The tensile stress varies considerably over the cross-section, and the distortion of the latter is large. Towards the middle of the bar, the axial displacement at the surface is, roughly, twice what it is at the centre.

In tensile experiments the elongation is usually measured by the relative displacement of two points on the outer skin of the cylinder, as recorded by an extensometer. When the test-piece is seized in this way, the surface stretches more than the interior, and consequently a negative correction should be applied to the readings of the extensometer. In the somewhat extreme case considered, this correction may amount to as much as 30 per cent.

The lateral contraction is very much smaller than the theory of uniform tension indicates, being in fact never so great as 60 per cent. of the amount calculated on that hypothesis. For points inside the material the discrepancy is still greater. These variations appear due to the fact that there are considerable radial and cross-radial tensions inside the material, these tensions being often equal to about one-fifth of the mean tension Q, which would give the same total pull.

Tables are given in the paper showing the values of the radial and axial displacements u and w, and of the four stresses $\widehat{rr}$, $\widehat{zz}$, $\widehat{rz}$, $\widehat{\phi\phi}$ (in the notation of Todhunter and Pearson's 'History of Elasticity,' $\widehat{st}$ being the stress, parallel to s, across a face perpendicular to t) for points in the cylinder at distances from the axis $= 0, \cdot 2a, \cdot 4a, \cdot 6a, a$; a being the radius of the cylinder; and for intervals of length parallel to the axis equal to tenths of the half-length. These tables are illustrated by curves and diagrams.

The second problem is of considerable importance, as it illustrates the crushing of blocks of cement or stone, when they are compressed between iron planes, or between sheets of mill-board, so that their ends are constrained not to expand.

The analytical solution is made up, partly of a finite number of terms which are algebraic and rational in r and z, and partly of infinite series involving sines and cosines containing z. By suitably combining these two types of terms all the conditions can be satisfied.

The numerical example taken was one in which the length is nearly

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equal to the diameter—the exact ratio, $\pi/3$, being chosen so as to simplify the arithmetic as far as possible.

As in the preceding example, tables of the stresses are given for a large number of points in the cylinder. From these the principal stresses and the principal stretch were calculated; and again from these, by interpolation, curves were drawn showing the loci of points in the cylinder where the greatest stress, the greatest stretch, or the greatest stress-difference had the same value.

The curves show that, whatever theory of yielding is adopted, namely, the greatest-stress theory of Navier and Lamé, or the greatest strain-theory of St. Venant, or the greatest stress difference (or greatest shear) theory which has more recently been put forward, failure of elasticity will begin to take place round the perimeter of the plane ends.

Thus, in the case of the stress, consider the regions where the stress is greater than a certain value S. When S is nearly equal to the greatest stress these regions are thin annuli round the ends. As S diminishes the regions become made up, partly of such annuli (of increasing thickness), partly of a closed region round the centre of the cylinder. When S reaches a certain critical value, S_0, these two regions join on to one another. The regions where the stress is less than S_0 consist of caps at the two ends and of cylindrical shells, forming the "skin" of the cylinder.

The regions of least stress consist only of caps or buttons of material at the two ends.

The variations of the principal stretch and of the principal stress-difference can be described in the same general terms.

For materials like stone and cement, which have no very definite yield point, the elastic distribution will give at least an indication of the state of stress almost up to the point of rupture, and if it be assumed that the latter takes place over the regions of greatest stress, or greatest strain, or greatest shear, according to the particular theory we adopt, the results above show that the fracture will start from the perimeter of the ends, and that caps or buttons, which may have an approximately conical shape, will probably be cut off at the ends.

The fact that yielding first occurs at the perimeter, when the stress exceeds 1/1·686 of the limiting stress for uniform pressure, leads to the conclusion that the strength of a cylinder under this system of stress is considerably less than the strength of a cylinder uniformly compressed. This result apparently contradicts the fact that the strength of stone and cement, when tested between lead plates, which allow of expansion, is very much less than when tested between mill-board which does not allow of expansion, a fact which has led Professor Perry to state that the true strength of such materials is about half their published strength. ('Applied Mechanics,' p. 345.)

The contradiction, however, seems to be explained by a remark of

Unwin's ('Testing of Materials of Construction,' p. 419), which is corroborated by Professor Ewing, to the effect that lead, which is a plastic material and flows easily, not only does not hinder expansion of the ends of the block, but *forces* it.

It is shown in the paper that, under such conditions, whenever the forced expansion exceeds the natural lateral expansion of the stone or cement, which it practically always does, then the points of failure, instead of being at the perimeter of the ends, are at the centre, and the limiting stress, under these circumstances, may be much less than that obtained for non-expanding ends. Further, this limiting stress depends upon the amount of flow of the lead and has no fixed value—a conclusion confirmed by the experimental results of Unwin. The mill-board test, on the other hand, should give consistent results, although it really introduces too large a factor of safety. The change in the form of the fracture, noticed by Unwin, is also accounted for by theory.

The values of the apparent Young's modulus and of the apparent Poisson's ratio are investigated. Young's modulus is shown to vary between its true value, when the cylinder is long, and the value of the ratio of stress to axial contraction, when lateral expansion is prevented by a suitable pressure, this last corresponding to the case when the cylinder is made very short.

In the given example, Poisson's ratio is apparently 0·269, the actual value assumed being 0·25. It should diminish down to zero as the cylinder becomes indefinitely short.

The third problem corresponds to the case of a cylinder whose ends are surrounded by a collar so that the applied torsion couple is transmitted to the inner core by means of transverse shear.

A general solution is first found for a given arbitrary system of transverse shear. Approximate expressions are given when the length of the cylinder is large compared with its diameter. These show that, to the first approximation, the cross-sections remain undistorted, radii originally straight remaining so. The shear across the section, at any point of it, is connected with the total torsion moment at that section by the same relation as in the ordinary theory of torsion. A transverse shear $\widehat{r\phi}$ varying as the square of the distance from the axis exists over the lengths of the cylinder subjected to external stress.

As a numerical example a cylinder is considered, whose length is $\pi/2$ times its diameter, and which is subjected, over lengths at the ends, each equal to one-fourth of the whole length, to a uniform transverse shear. Using the exact expressions found, the stresses and transverse displacement are calculated for various points, and these are compared with the values calculated from the approximate expressions when the cylinder is long.

It is found that the agreement is, on the whole, tolerably good, whence it is inferred that in torsion, the effect of local action dies out more rapidly than in tension or compression. The only case of obvious divergence is with regard to the shear $\widehat{r\phi}$. This shear persists inside, even at sections where no stress of this kind is applied to the outside of the cylinder, but it continually diminishes as we recede from the ends.

In the exact solution, the cross-sections do not remain undistorted, the transverse displacement increasing more rapidly than the radius. The distortion is small at sections where there is no external applied stress, but is very obvious near the ends.

Further, when the applied transverse shear varies discontinuously, as in this case, the other stress becomes infinite at the points of discontinuity. This suggests why it is that abrupt changes in the section of such a cylinder are dangerous. The projecting parts acting upon the inner core will introduce a sudden change in the transverse shear. It has been noticed that propeller shafts usually break at such points.

"The Measurement of Ionic Velocities in Aqueous Solution, and the Existence of Complex Ions." By B. D. STEELE, B.Sc., 1851 Exhibition Scholar (Melbourne). Communicated by Professor RAMSAY, F.R.S. Received May 10,—Read June 6, 1901.

(Abstract.)

The method of measuring ionic volocities described by Masson has been extended in such a manner that, by the present method, the use of gelatin solution and of coloured indicators is not necessary.

An aqueous solution of the salt to be measured is enclosed between two partitions of gelatin which contain the indicator ions in solution, the apparatus being always so arranged that the heavier solution lies underneath the lighter. On the passage of the current the ions of the measured solution move away from the jelly, followed at either end by the indicator ions; the boundary is quite visible in consequence of the difference in refractive index of the two solutions. The velocity of movement of the margins is measured by means of a cathetometer, and the ratio of the margin velocities gives at once the ratio of the ionic velocities.

It is found that, for the production and maintenance of a good refractive margin, a certain definite range of potential fall is required for any given pair of solutions, and this range differs very much for *different* boundaries—for example, the margin potassium acetate following potassium chloride, or K $\frac{ac}{cl}$ is stable with a potential fall of 0·82 volt, whilst for the stability of the $\frac{cd}{cu}$ SO_4 margin, a voltage of 2·54 volts at least is necessary.

The explanation of this is to be looked for, not in the fall of potential in the measured solution, to which the above figures refer, but rather to the change of potential fall on passing from the indicator solution to the latter, and is probably connected in some manner with the Nernst theory of liquid cells.

Certain regularities in the influence of different salts on the melting points of the jellies have been noted, and it seems that this influence is more or less of an additive nature, depending on the nature of the anion and of the cation. Amongst anions the SO_4 ion has the least, and the $\bar{\mathrm{I}}$ and $\overline{\mathrm{N}}\mathrm{O}_3$ ions the greatest, effect in lowering the melting point. Amongst cations, the K ion has a much less influence than the Li or Mg ions: these relations are as yet, however, only qualitative.

The values for the transport number that have been obtained show a remarkable agreement with Masson's figures, as measured in gelatin, for potassium and sodium chlorides. On the other hand, for lithium chloride and magnesium sulphate no such agreement exists. For all the salts a comparison with Hittorf's figures shows only an approximate agreement, being about as good at that shown by a comparison of the figures for the same salt, as measured by different investigators, by the indirect method of Hittorf.

From a knowledge of the specific resistance of the measured solution it is possible to calculate the potential fall in this part of the system, and from this the absolute average velocity $U = xu$, where $x =$ the coefficient of ionisation, and u the absolute ionic velocity. A very striking agreement holds between the sum of the velocities of anion and cation and the sum as calculated from Kohlrausch's conductivity figures. The velocities of a large number of ions at different concentrations of different salts have been calculated, and the velocity of the hydrogen and hydroxyl ions have been also measured, with the following results:—

	Found.	Calculated.
OH in KOH, 0·5 N	0·001435	0·00145
„ NaOH, 0·2 N	0·00158	0·00152
H in HNO_3, 0·2 N	0·00282 0·00272	0·00280

The ratio of the current, as measured by the galvanometer, to that calculated from the velocity of the margins in the manner indicated by Masson, is found to be equal to unity only for a few salts of the type of potassium chloride; for other salts this ratio has a value in some cases greater, in others less, than 1. The same irregularity has been previously pointed out by Masson for the gelatin solutions of the sulphates of magnesium and lithium.

The attempt is made to explain this deviation from the requirements of theory, and also the difficulty that Kohlrausch is unable to assign to dyad elements any value for the specific ionic velocity, which is the same when calculated from the measurements of different salts of the same metal, by the assumption, first advanced by Hittorf, that, in concentrated solutions of these salts ionisation takes place in such a manner that there are formed complex ions in addition to simple ones; and the conclusion is drawn that, in all cases where any considerable change in transport number occurs with changes in concentration, complex ions are present to a greater or less extent.

June 13, 1901.

Sir WILLIAM HUGGINS, K.C.B., D.C.L., President, in the Chair.

Mr. James Mansergh, Major Ronald Ross, Mr. Oldfield Thomas, Mr. William Watson, and Mr. William C. Dampier Whetham were admitted into the Society.

A List of the Presents received was laid on the table, and thanks ordered for them.

The Bakerian Lecture, "The Nadir of Temperature, and Allied Problems," was delivered by Professor JAMES DEWAR, F.R.S.

BAKERIAN LECTURE.—"The Nadir of Temperature, and Allied Problems. 1. Physical Properties of Liquid and Solid Hydrogen. 2. Separation of Free Hydrogen and other Gases from Air. 3. Electric Resistance Thermometry at the Boiling Point of Hydrogen. 4. Experiments on the Liquefaction of Helium at the Melting Point of Hydrogen. 5. Pyro-electricity, Phosphorescence, &c." By JAMES DEWAR, LL.D., D.Sc., F.R.S., Jacksonian Professor in the University of Cambridge, and Fullerian Professor of Chemistry, Royal Institution, London, &c. Delivered June 13, 1901.

(Abstract.)

Details are given in this paper which have led to the following results:—

The helium thermometer which records $20^{\circ}\cdot 5$ absolute as the boiling point of hydrogen, gives as the melting point 16° absolute. This value does not differ greatly from the value previously deduced from the use of hydrogen gas thermometers, viz., 16°·7. The lowest temperature recorded by gas thermometry is 14°·5, but with more complete isolation and a lower pressure of exhaustion, it will be possible to reach about 13° absolute, which is the lowest practicable temperature that can be commanded by the use of solid hydrogen. Until the experiments are repeated with a helium thermometer filled with helium, previously purified by cooling to the lowest temperature that can be reached by the use of solid hydrogen, the gas being under compression, no more accurate values can be deduced.

The latent heat of liquid hydrogen about the boiling point as deduced from the vapour pressures and helium-thermometer temperatures, is about 200 units, and the latent heat of solid hydrogen cannot exceed 16 units, but may be less.

The order of the specific heat of liquid hydrogen has been determined by observing the percentage of liquid that has to be quickly evaporated under exhaustion in order to reduce the temperature to the melting point of hydrogen, the vacuum vessel in which the experiment is made being immersed in liquid air. It was found that in the case of hydrogen the amount that had to be evaporated was 15 per cent. This value, along with the latent heat of evaporation, gives an average specific heat of the liquid between freezing and boiling point of about 6. When liquid nitrogen was similarly treated for comparison, the resulting specific heat of the liquid came out 0·43 or about 6 per atom. Hydrogen therefore appears to follows the law of Dulong and Petit, and has the greatest specific heat of any known substance, near its melting point.

The same fine tube used in water, liquid air, and liquid hydrogen gave respectively the capillary ascents of 15·5, 2 and 5·5 divisions. The relative surface tension of water, liquid air, and liquid hydrogen are therefore in the proportion of 15·5, 2, 0·4. In other words, the surface tension of hydrogen at its boiling point is about one-fifth that of liquid air under similar conditions. It does not exceed one thirty-fifth part the surface tension of water at the ordinary temperature.

The refractive index of liquid hydrogen determined by measuring the relative difference of focus for a parallel beam of light sent through a spherical vacuum vessel filled in succession with water, liquid oxygen, and liquid hydrogen, gave the value 1·12. The theoretical value of the liquid refractive index is 1·11 at the boiling point of the liquid. This result is sufficient to show that hydrogen, like oxygen and nitrogen in the liquid condition, has a refractivity in accordance with theory.

Free hydrogen, helium, and neon have been separated from air by two methods. The one depends on the use of liquid hydrogen to boil the dissolved gases out of air kept at a temperature near the melting point of nitrogen; the other on a simple arrangement for keeping the more volatile gases from getting into solution after separation by partial exhaustion. By the latter mode of working something like 1/34000th of the volume of the air liquefied appears as uncondensed gas. The latter method is only a qualitative one for the recognition and separation of a part of the hydrogen in air. In a former paper on the "Liquefaction of Air and the Detection of Impurities,"* it was shown that 100 c.c. of liquid air could dissolve 20 c.c. of hydrogen at the same temperature. The crude gas separated from air by the second method gave on analysis—hydrogen 32·5 per cent., nitrogen 8 per cent., helium, neon, &c., 60 per cent. After removing the hydrogen and nitrogen the neon can be solidified by cooling in liquid hydrogen and the more volatile portions separated.

There exists in air a gaseous material that may be separated without the liquefaction of the air. For this purpose air has to be sucked through a spiral tube filled with glass wool immersed in liquid air. After a considerable quantity of air has been passed, the spiral is exhausted at the low temperature of the liquid air bath. The spiral tube is now removed and allowed to heat up to the ordinary temperature, and the condensed gas taken out by the pump. After purification by spectroscopic fractionation, the gas filled into vacuum tubes gives the chief lines of xenon. The spectroscopic examination of the material will be dealt with in a separate paper by Professor Liveing and myself. A similar experiment made with liquid air kept under exhaustion, the air current allowed to circulate being, to prevent liquefaction, under a pressure less than the saturation pressure of the liquid, resulted in crypton being deposited along with the xenon.

A study of fifteen electric resistance thermometers as far as the boiling point of hydrogen has been made, and the results reduced by the Callendar and Dickson methods. The following table gives the results for seven thermometers, viz., two of platinum, one of gold, silver, copper, and iron, and one of platinum-rhodium alloy. It will be noted that the lowest boiling point for hydrogen was given by the gold thermometer. Next to it came one of the platinum thermometers, and then silver, while copper and the iron differ from the gold value by 26 and 32 degrees respectively. The gold thermometer would make the boiling point 23°·5 instead of the 20°·5 given by the gas thermometer. Then the reduction of temperature under exhaustion amounts to only 1° instead of 4° as given by the gas thermometer. The extraordinary reduction in resistance of some of the metals at the boiling point of hydrogen is very remarkable. Thus copper has only 1/105th, gold 1/30th, platinum 1/35th to 1/17th, silver 1/24th the resistance at melting ice, whereas iron is only reduced to 1/8th part of the same initial resistance. The real law correlating electric resistance

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* 'Chem. Soc. Proc.,' 1897.

Electric Resistance Thermometry at the Boiling Point of Hydrogen.

Metals.	Platinum (P_1).	Potassium (P_{27}).	Alloy platinum rhodium ($Pt\text{-}Rh_{20}$).	Gold (Au_{40}).	Silver (Ag_{17}).	Copper (Cu_{47}).	Iron (Fe_{38}).	
R_1	4·2050	39·655	36·87	16·10	8·336	11·572	4·290	
R_0	3·1037	28·851	31·93	11·58	5·990	8·117	2·765	
Resistance at CO_2	—	19·620						
„ „ liq. O	0·9473	7·662	22·17	3·380	1·669	1·589	0·633	
„ „ liq. N	—	—	—	—	—	1·149		
„ „ liq. Ox	—	4·634	20·73					
„ „ liq. H	0·183	0·826	18·96	0·381	0·244	0·077	0·356	
„ „ liq. Hx	—	0·705	18·90	0·298	0·226	0·071		
α	0·003548	0·003745	0·003607	0·003803	0·003917	0·004257	0·005515	
$\Omega' = -\frac{1}{\alpha}$	−281·81	−267·04	−646·37	−256·19	−255·33	−234·93	−181·31	
T. observed of liq. O	−182°·5 C.	−182°·34 C.	−182°·4 C.	−182°·37 C.	−182°·41 C.	−182°·41 C.	−182°·85 C.	
δ	2·5797	2·6767	4·7447	−0·18448	0·34553	1·2376	−8·3238	
Calculated temp. C.—								
At CO_2	—	−81°·48						
		−80°·18						
„ liq. O	−182°·505	−182°·342	−182°·401	−182°·37	−182°·41	−182°·413	−182°·855	Callendar.
	−182°·601	−181°·60	−183°·51	−182°·4	−182°·41	−183°·320	−182°·850	Dickson.
„ liq. N	—	—	—	—	—	−194°·42		
						−195°·22		
„ liq. Ox	—	−207°·12	−207°·87					
		−206°·55	−208°·99					
„ liq. H	−243°·61	−237°·88	−238°·73	−249°·37	−242°·06	−223°·54	−213°·82	C.
	−243°·13	−237°·55	−239°·75	−249°·5	−242°·06	−223°·99	−210°·29	D.
„ liq. Hx	—	−238°·85	−239°·77	−251°·23	−242°·84	−223°·70	—	C.
		−238°·48	−240°·78	−251°·1	−242°·82	−224°·15	—	D.
Ω	−258°·00	−244°·50	−543°·39	−257°·90	−252°·26	−225°·62	−258°·40	C.
	−257°·28	−244°·15	−530°·32	−257°·8	−252°·25	−226°·04	−246°·80	D.
Ratio $\frac{R_0}{\text{Res. at B.P. of H}}$	16·96	34·93	1·684	30·39	24·55	105·41	7·767	

R_1, R_0, are the resistances at 100° C. and 0° C. respectively. The remaining resistances are clear from the table.
x means that the liquid is boiling under exhaustion measured by about 30 mm. of mercury.
Ω′ is the temperature, in degrees of the metal in question, at which the resistance would vanish.
Ω is the temperature Centigrade at which the resistance would vanish, either on the Callendar or on the Dickson method.
Calculated temperatures—the upper, Callendar's method; the lower by Dickson's.
Callendar's α and δ are calculated from the given values of R_1, R_0, the resistance of liquid O, and the temperature observed in liquid O.

and temperature within the limits we are considering is unknown, and no thermometer of this kind can be relied on for giving accurate temperatures up to and below the boiling point of hydrogen. The curves are discussed in the paper, and I am indebted to Mr. J. H. D. Dickson and Mr. J. E. Petavel for help in this part of the work.

Helium separated from the gas of the King's Well, Bath, and purified by passing through a U-tube immersed in liquid hydrogen, was filled directly into the ordinary form of Cailletet gas receiver used with his apparatus, and subjected to a pressure of 80 atmospheres, while a portion of the narrow part of the glass tube was immersed in liquid hydrogen. On sudden expansion from this pressure to atmospheric pressure a mist from the production of some solid body was clearly visible. After several compressions and expansions, the end of the tube contained a small amount of a solid body that passed directly into gas when the liquid hydrogen was removed and the tube kept in the vapour of hydrogen above the liquid. On lowering the temperature of the liquid hydrogen by exhaustion to its melting point, which is about 16° absolute, and repeating the expansions on the gas from which the solid had separated by the previous expansions at the boiling point, or 20°·5, *no mist was seen.* From this it appears the mist was caused by some other material than helium, in all probability neon, and when the latter is removed no mist is seen, when the gas is expanded from 80 to 100 atmospheres, even although the tube is surrounded with solid hydrogen. From experiments made on hydrogen that had been similarly purified like the helium and used in the same apparatus, it appears a mist can be seen in hydrogen (under the same conditions of expansion as applied to the helium sample of gas) when the initial temperature of the expanding gas was twice the critical temperature, but it was not visible when the initial temperature was about two and a-half times the critical temperature. This experience applied to interpret the helium experiments, would make the critical temperature of the gas under 9° absolute.

Olszewski in his experiments expanded helium from about seven times the critical temperature under a pressure of 125 atmospheres. If the temperature is calculated from the adiabatic expansion, starting at 21° absolute, an effective expansion of only 20 to 1 would reach 6°·3, and 10 to 1 of 8°·3. It is now safe to say, helium has been really cooled to 9° or 10° absolute without any appearance of liquefaction. There is one point, however, that must be considered, and that is the small refractivity of helium as compared to hydrogen, which, as Lord Rayleigh has shown, is not more than one-fourth the latter gas. Now as the liquid refractivities are substantially in the same ratio as the gaseous refractivities in the case of hydrogen and oxygen, and the refractive index of liquid hydrogen is about 1·12, then the value for liquid helium should be about 1·03, both taken at their respective boiling points. In other words, liquid helium at its boiling point would have a refractive index of about the same value as liquid hydrogen at its critical point, and as a consequence, small drops of liquid helium forming in the gas near its critical point would be far more difficult to see than in the case of hydrogen similarly situated.

The hope of being able to liquefy helium, which would appear to have a boiling point of about 5° absolute, or one-fourth that of liquid hydrogen, is dependent on subjecting helium to the same process that succeeds with hydrogen; only instead of using liquid air under exhaustion as the primary cooling agent, liquid hydrogen under exhaustion must be employed, and the resulting liquid collected in vacuum vessels surrounded with liquid hydrogen The following table embodies the results of experience and theory :—

Initial temperature.	Initial temperature.	Critical temperature.	Boiling points.
Liquid helium ?	5°?	2°?	1°?
Solid hydrogen	15	6	4
Liquid ,,	20	8	5 (He ?)
Exhausted liquid air	75	30	20 (H)
52° C.	325	130	86 (Air)
Low red heat	760	304	195 (CO_2)

The first column gives the initial temperature before continuous expansion through a regenerator, the second the critical point of the gas that can be liquefied under such conditions, and the third the boiling point of the resulting liquid. It will be seen that by the use of liquid or solid hydrogen as a cooling agent we ought to be able to liquefy a body having a critical point of about 6° to 8° absolute and boiling point of about 4° or 5° absolute. Then, if liquid helium could be produced with the probable boiling point of 5° absolute, this substance would not enable us to reach the zero of temperature; another gas must be found that is as much more volatile than helium as it is than hydrogen in order to reach within 1° of the zero of temperature. If the helium group comprises a substance having the atomic weight 2, or half that of helium, such a gas would bring us nearer the desired goal. In the meantime the production of liquid helium is a difficult and expensive enough problem to occupy the scientific world for many a day.

A number of miscellaneous observations have been made in the course of this inquiry, among which the following may be mentioned. Thus the great increase of phosphorescence in the case of organic bodies cooled to the boiling point of hydrogen under light stimulation is very marked, when compared with the same effects brought

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about by the use of liquid air. A body like sulphide of zinc cooled to 21° absolute and exposed to light shows brilliant phosphorescence on the temperature being allowed to rise. Bodies like radium that exhibit self-luminosity in the dark, cooled in liquid hydrogen maintain their luminosity unimpaired. Photographic action is still active although it is reduced to about half the intensity it bears at the temperature of liquid air. Some crystals when placed in liquid hydrogen become for a time self-luminous, on account of the high electric stimulation brought about by the cooling causing actual electric discharges between the crystal molecules. This is very marked with some platino-cyanides and nitrate of uranium. Even cooling such crystals to the temperature of liquid air is sufficient to develop marked electrical and luminous effects.

Considering that both liquid hydrogen and air are highly insulating liquids, the fact of electric discharges taking place under such conditions proves that the electric potential generated by the cooling must be very high. When the cooled crystal is taken out of either liquid and allowed to increase in temperature, the luminosity and electric discharges take place again during the return to the normal temperature. A crystal of nitrate of uranium gets so highly charged electrically that, although its density is 2·8 and that of liquid air about 1, it refuses to sink, sticking to the side of the vacuum vessel and requiring a marked pull on a silk thread, to which it is attached, to displace it. Such a crystal rapidly removes cloudiness from liquid air by attracting all the suspended particles on to its surface. The study of pyro-electricity at low temperatures will solve some very important problems.

During this inquiry I have had the hearty co-operation of Mr. Robert Lennox, to whom my thanks are due, and Mr. J. W. Heath has also given valuable assistance.

June 20, 1901.

Sir WILLIAM HUGGINS, K.C.B., D.C.L., President, in the Chair.

Professor William Schlich and Professor Arthur Smithells were admitted into the Society.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On the Mathematical Theory of Errors of Judgment, with Special Reference to the Personal Equation." By Professor Karl Pearson, F.R.S.

II. "Mathematical Contributions to the Theory of Evolution. X.—Supplement to a Memoir on Skew Variation." By Professor Karl Pearson, F.R.S.

III. "On the Application of Maxwell's Curves to Three-colour Work, with Especial Reference to the Nature of the Inks to be employed, and to the Determination of the Suitable Light-filters." By Dr. R. S. Clay. Communicated by Sir W. Abney, K.C.B., F.R.S.

IV. "The Nature and Origin of the Poison of *Lotus Arabicus*." By W. R. Dunstan, F.R.S., and T. A. Henry.

V. "On the Structure and Affinities of *Dipteris*, with Notes on the Geological History of the Dipteridinæ." By A. C. Seward, F.R.S., and Miss E. Dale.

VI. "Further Observations on Nova Persei. No. 3." By Sir Norman Lockyer, K.C.B., F.R.S.

VII. "Total Eclipse of the Sun, May 28, 1900: Account of the Observations made by the Solar Physics Observatory Eclipse Expedition and the Officers and Men of H.M.S. 'Theseus,' at Santa Pola, Spain." By Sir Norman Lockyer, K.C.B., F.R.S.

VIII. "The Mechanism of the Electric Arc." By Mrs. H. Ayrton. Communicated by Professor Perry, F.R.S.

IX. "The Yellow Colouring Matters accompanying Chlorophyll and their Spectroscopic Relations. Part 2." By C. A. Schunck. Communicated by E. Schunck, F.R.S.

X. "Magnetic Observations in Egypt, 1883–1901." By Captain H. G. Lyons. Communicated by Professor Rücker, F.R.S.

XI. "A Determination of the Value of the Earth's Magnetic Field in International Units, and a Comparison of the Results with the Value given by the Kew Observatory Standard Instruments." By W. Watson, F.R.S.

XII. "Virulence of Desiccated Tubercular Sputum." By H. Swithinbank. Communicated by Sir H. Crichton Browne, F.R.S.

XIII. "The Effect of the Temperature of Liquid Air upon the Vitality and Virulence of the *Bacillus tuberculosis*." By H. Swithinbank. Communicated by Sir H. Crichton Browne, F.R.S.

XIV. "The Fermentation of Urea: a Contribution to the Study of the Chemistry of the Metabolism in Bacteria." By Dr. W. E. ADENEY. Communicated by Professor W. N. HARTLEY, F.R.S.

XV. "On the Seasonal Variation of Atmospheric Temperature in the British Isles and its Relation to Wind-direction, with a Note on the Effect of Sea Temperature on the Seasonal Variation of Air Temperature." By W. N. SHAW, F.R.S., and R. WALEY COHEN.

XVI. "On the Continuity of Effect of Light and Electric Radiation on Matter." By Professor J. C. BOSE. Communicated by LORD RAYLEIGH, F.R.S.

XVII. "On the Similarities between Radiation and Mechanical Strains." By Professor J. C. BOSE. Communicated by LORD RAYLEIGH, F.R.S.

XVIII. "On the Strain Theory of Photographic Action." By J. C. BOSE. Communicated by LORD RAYLEIGH, F.R.S.

XIX. "The Anomalous Dispersion of Sodium Vapour." By Professor R. W. WOOD. Communicated by Professor C. V. BOYS, F.R.S.

XX. "The Pharmacology of Pseudaconitine and Japaconitine considered in Relation to that of Aconitine." By Professor J. T. CASH, F.R.S., and Professor W. R. DUNSTAN, F.R.S.

XXI. "The Pharmacology of Pyraconitine and Methylbenzaconine considered in Relation to that of Aconitine." By Professor J. T. CASH, F.R.S., and Professor W. R. DUNSTAN, F.R.S.

XXII. "On the Separation of the Least Volatile Gases of Atmospheric Air, and their Spectra." By Professor LIVEING, F.R.S., and Professor DEWAR, F.R.S.

XXIII. "The Stability of a Spherical Nebula." By J. H. JEANS. Communicated by Professor G. H. DARWIN, F.R.S.

XXIV. "On the Behaviour of Oxy-hæmoglobin, Carbonic Oxide Hæmoglobin, Methæmoglobin, and certain of their Derivatives, in the Magnetic Field, with a Preliminary Note on the Electrolysis of the Hæmoglobin Compounds." By Professor GAMGEE, F.R.S.

XXV. "On the Resistance and Electromotive Forces of the Electric Arc." By W. DUDDELL. Communicated by Professor AYRTON, F.R.S.

XXVI. "On the Relation between the Electrical Resistances of Pure Metals and their Molecular Constants." By W. WILLIAMS. Communicated by Professor ANDREW GRAY, F.R.S.

The Society adjourned over the Long Vacation to Thursday, November 21, 1901.

"On the Mathematical Theory of Errors of Judgment, with Special Reference to the Personal Equation." By KARL PEARSON, F.R.S., University College, London. Received April 23,—Read June 20, 1901.

(Abstract.)

In 1896 I, with Dr. Alice Lee and Mr. G. A. Yule, made a series of experiments on the bisection of lines at sight. The object of these experiments was to test a development of the current theory of errors of observation, by which it seemed possible to me to determine the *absolute* steadiness of judgment of any individual by comparing the relative observations of three (instead of as usual two) observers. As a rule the absolute error of the observer is unknown and unknowable, and I was seeking for a quantitative test of steadiness in judgment to be based on relative judgments. If σ_{01} be the standard deviation of the absolute judgments of the first observer, σ_{12}, σ_{23}, σ_{31} the standard deviations of the relative judgments of the first and second, the second and third, and the third and first observers respectively, then

$$\sigma_{01}^2 = \tfrac{1}{2}(\sigma_{21}^2 + \sigma_{13}^2 - \sigma_{23}^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(i)}$$

on the basis of the current theory of errors. Thus it seemed possible to determine absolute steadiness of judgment from the standard deviations of *relative* judgments, which are all that the physicist or astronomer can usually make, provided three observers and not two were compared.

To my great surprise I found results such as (i) were not even approximately true, and that they failed to hold because the judgments of the observers were *substantially correlated*. It did not occur to me at first that judgments made as to the midpoints of lines by experimenters, in the same room it is true, but not necessarily bisecting the same line at the same instant, could be psychologically correlated, and I looked about for a source of correlation in the treatment of the data. We had taken 500 lines of different lengths and bisected them at sight; assuming that the error would be more or less proportional to the length of the line, I had adopted the deviation from the

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true midpoint to the right in terms of the length of the line as the error. I was then led to realise the importance of what I have termed "spurious correlation" in this use of indices or ratios, and I published a short notice of the subject in the 'Roy. Soc. Proc.,' vol. 60, p. 489, 1896.

It seemed necessary accordingly to make our judgments in a different manner, and a second series of 520 experiments was made by Dr. Alice Lee, Dr. W. F. Macdonell, and myself, in which we observed the motion of a narrow beam of light down a uniform strip of fixed length, and recorded its position at the instant, *à priori* unknown to us, at which a hammer struck a small bell. The experiment was made by means of a pendulum devised by Mr. Horace Darwin, and the record required a combination of ear, eye, and hand judgment. In the manipulation of the data there was no room for the appearance of "spurious correlation," but to my great surprise I again found substantial correlation in two out of the three cases of what one might reasonably suppose to be absolutely independent judgments.

This led to a thorough reinvestigation of the bisection experiments, absolute and not ratio errors being now dealt with. We found the same result, *i.e.*, correlation of apparently independent judgments. The absolute personal equations based on the average of twenty-five to thirty experimental sets were then plotted, and found to fluctuate in sympathy, and these fluctuations were themselves far beyond the order of the probable errors of random sampling. Nor were the fluctuations explicable solely by likeness of environment. For in the bright line experiments while the judgments of A and B were sensibly uncorrelated, those of C were substantially correlated with those of both A and B. Thus we were forced to the conclusion that judgment depends in the main upon some few rather than upon many personal characteristics, and that while A and B had practically no common characteristics, there were some common to A and C and others common to B and C. We are driven to infer—

(i.) That the fluctuations in personal equation are not of the order of the probable deviations due to random sampling.

(ii.) That these fluctuations in the case of different observers, recording absolutely independently, are sympathetic, being due to the influence of the immediate atmosphere of the observation or experiment on personal characteristics, probably few in number, one or more of which may be common to each pair of observers.

In this way we grasp how the judgments of "independent" observers may be found to be substantially correlated. In the memoir attention is drawn to the great importance of this, not only for the weighting of combined observations, but also for the problem of the stress to be laid on the testimony of apparently independent witnesses to the same phenomenon.

The current theory of the personal equation thus appears to need modification, and we require for the true consideration of relative judgments not only a knowledge of the variability of observers, but also of their correlation in judgment as necessary supplements to the simple personal equation.

Having obtained from our data twelve series of errors of observation considerably longer than those often or even exceptionally dealt with by observers, we had a good opportunity for testing the applicability of the current theory of errors, in particular the fitness of the Gaussian curve

$$y = y_0 \, e^{-x^2/(2\sigma^2)}$$

to describe the frequency of errors of observation. In a considerable proportion of the cases this curve was found to be quite inapplicable. Errors in excess and defect of equal magnitude were not equally frequent; skewness of distribution, sensible deviation of the mode from the mean, "crowding round the mean," even in the case of passable symmetry, all existed to such an extent as to make the odds against the error distributions being random samples from material following the Gaussian law of distribution enormous. It is clear that deviation of the mode from the mean, and the independence of at least the first four error moments, must be features of any theory which endeavours to describe the frequency of errors of observation or of judgment within the limits allowable by the theory of random sampling. The results reached will serve to still further emphasise the conclusions I have before expressed:

(*a.*) That the current theory of errors has been based too exclusively on mathematical axioms, and not tested sufficiently at each stage by comparison with actual observations or experiments.

(*b.*) That the authority of great names—Gauss, Laplace, Poisson—has given it an almost sacrosanct character, so that we find it in current use by physicists, astronomers, and writers on the kinetic theory of gases, often without a question as to its fitness to represent all sorts of observations (and even insensible phenomena !) with a high degree of accuracy.

(*c.*) That the fundamental requisites of an extended theory are that it must—

(i.) Start from the three basal axioms of the Gaussian theory and enlarge and widen them.

(ii.) Provide a systematic method of fitting theoretical frequencies to observed distributions with (α) as few constants as possible, (β) these constants easily determinable and closely related to the physical characters of the distribution, and

(iii.) When improbable isolated observations are rejected, give theoretical frequencies not differing from the observed frequencies by more than the probable deviations due to random sampling.

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I propose to consider these points in reference to the skew frequency distributions discussed in a memoir in the 'Phil. Trans.' for 1895 (A, vol. 186, *et seq.*) in another place. The present memoir, however, shows that these skew distributions give results immensely more probable than the Gaussian curve, and thus confirms in the case of errors of observation the results already reached in the case of organic variation.

"Mathematical Contributions to the Theory of Evolution.—X. Supplement to a Memoir on Skew Variation." By KARL PEARSON, F.R.S., University College, London. Received May 22,—Read June 20, 1901.

(Abstract.)

In the second memoir of this series a system of curves suitable for describing skew distributions of frequency was deduced from the solutions of the differential equation

$$\frac{1}{y}\frac{dy}{dx} = \frac{b_0 + b_1 x}{a_0 + a_1 x + a_2 x^2} \quad \text{.........................} \quad \text{(i).}$$

These solutions were found to cover satisfactorily a very wide range of frequency distributions of all degrees of skewness. Two forms of solution of this differential equation, depending upon certain relations among its constants, had, however, escaped observation, for the simple reason that all the distributions of actual frequency I had at that time met with fell into one or other of the four types dealt with in that memoir. A little later the investigation of frequency in various cases of botanical variation showed that none of the four types were suitable, and led me to the discovery that I had not found all the possible solutions of the differential equation above given. Two new types were found to exist—

Type V: $$y = y_0 x^p e^{-\gamma/x} \quad \text{.........................} \quad \text{(ii),}$$

with a range from $x = 0$ to $x = \infty$, and

Type VI: $$y = y_0 (x - a)^{m_1} x^{-m_2} \quad \text{.........................} \quad \text{(iii),}$$

with a range from $x = a$ to $x = \infty$.

These curves were found to be exactly those required in the cases which my co-workers and I in England, and one or two biologists in America, had discovered led in the earlier Types I and IV to impossible results, *i.e.*, to imaginary values of the constants.

In the present memoir the six types are arranged in their natural order, and a criterion given for distinguishing between them. They are illustrated by three examples: (*a*) age of bride on marriage for a

given age of husband; (*b*) frequency of incidence of scarlet fever at different ages; and (*c*) frequency of "lips" in the Medusa *P. pentata.*

It is perhaps of some philosophical interest to note that solutions of (i) that had escaped the analytical investigation were first obtained from actual statistics which could not be fitted to any of the curves of my first memoir without imaginary values of the constants. So great was my confidence in (i), however, that before I discarded it I re-investigated my analysis of it, and was so led to these two additional solutions.

"On the Structure and Affinities of *Dipteris*, with Notes on the Geological History of the Dipteridinæ."

By A. C. SEWARD, F.R.S., University Lecturer in Botany, Cambridge, and ELIZABETH DALE, Pfeiffer Student, Girton College, Cambridge.

Received May 21,—Read June 20, 1901.

(Abstract.)

The generic name *Dipteris* instituted by Reinwardt in 1828 is applied to four recent species—*Dipteris conjugata* (Rein.), *D. Wallichii* (Hook. and Grev.), *D. Lobbiana* (Hook.), and *D. quinquefurcata* (Baker). *Dipteris Wallichii* occurs in the sub-tropical region of Northern India; the other species are met with in the Malay Peninsula, Java, New Guinea, Borneo, and elsewhere. It has been customary to include *Dipteris* in the Polypodiaceæ, and to describe the sporangia as having an incomplete vertical annulus. The authors regard *Dipteris* as a generic type which should be separated from the Polypodiaceæ and placed in a family of its own—the Dipteridinæ, on the grounds that (1) the sporangia of *Dipteris* have a more or less oblique annulus; (2) the fronds possess well marked and distinctive characteristics; (3) the vascular tissue of the stem is tubular (siphonostelic), and not of the usual Polypodiaceous type.

For the material from Borneo and the Malay Peninsula, on which the anatomical investigation of *Dipteris conjugata* is based, the authors are indebted to Mr. R. Shelford, of Sarawak, and to Mr. Yapp, of Caius College, Cambridge. The fronds of the four species of *Dipteris* consist of a long and slender petiole and a large lamina, in some cases 50 cm. in length; in *D. conjugata* and *D. Wallichii* the lamina is divided by a deep median sinus into two symmetrical halves, but in *D. Lobbiana* and *D. quinquefurcata* the symmetrical bisection of the lamina is less obvious, the whole leaf being deeply dissected into narrow linear segments. The sori, which are without an indusium, consist of numerous sporangia and filamentous paraphyses, terminating in glandular cells. The sporangia are characterised by the more or less oblique annulus, and by the small output of bilateral spores. The sporangia of the same sorus are not developed simultaneously.

Anatomy.—The horizontal creeping rhizome, which is thickly covered with stiff ramental scales, contains a tubular stele limited both internally and externally by a definite endodermis. The xylem is mesarch in structure; the protoxylem groups of spiral tracheids occur in association with a few parenchymatous cells at regular intervals in a median position. At the point of origin of each leaf the tubular stele opens, and becomes U-shaped in section, the detached portion passes into the petiole as a horseshoe-shaped meristele of endarch structure. The meristele alters its form a short distance below the origin of the lamina, and becomes constricted into two slightly unequal portions; from the lower end of one of these a small vascular strand is gradually detached, and at a higher level a similar strand passes off from the other half of the stele. During their passage into the main ribs of the lamina the vascular strands, which are at first simply curved, become annular, and assume the form characteristic of *Marsilia.* The slender and branched roots are traversed by a triarch stele.

Geological History.—The genus *Dipteris* represents a type which had descended from the Mesozoic period with but little modification. The genera *Dictyophyllum* and *Protorhipis* are regarded as members of the Dipteridinæ, which were widely distributed in Europe during the Rhætic and Jurassic periods. Records of these fossil forms have been obtained from England, Germany, France, Belgium, Austria, Switzerland, Bornholm, Greenland, and Poland; also from North America, Persia, and the Far East. The genus *Matonia*, especially *M. pectinata* (R. Br.), possesses certain features in common with *Dipteris*, and this resemblance extends to the fossil types of the Matonineæ and Dipteridinæ. *Matonia pectinata* and *Dipteris conjugata*, growing side by side on the slopes of Mount Ophir in the Malay Peninsula, survive as remnants from a bygone age when closely allied ferns played a prominent part in the vegetation of northern regions.

"The Nature and Origin of the Poison of *Lotus arabicus.*" By Wyndham R. Dunstan, M.A., F.R.S., Director of the Scientific and Technical Department of the Imperial Institute, and T. A. Henry, B.Sc., Salters' Company's Research Fellow in the Laboratories of the Imperial Institute. Received May 30,—Read June 20, 1901.

(Abstract.)

The authors have already given a preliminary account[*] of this investigation and have shown that the poisonous property of this

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[*] 'Roy. Soc. Proc.,' vol. 67, p. 224, 1900.

Egyptian vetch is due to the prussic acid which is formed when the plant is crushed with water, owing to the hydrolytic action of an enzyme, *lotase*, on a glucoside, *lotusin*, which is broken up into hydrocyanic acid, dextrose, and lotoflavin, a yellow colouring matter.

The authors have continued the investigation with the object of ascertaining the properties and chemical constitution of lotoflavin and of lotusin, and also of studying the properties of lotase in relation to those of other hydrolytic enzymes.

Lotusin.

Lotusin can be separated from an alcoholic extract of the plant by a tedious process giving a very small yield, about 0·025 per cent.

Lotusin is a yellow crystalline glucoside, more soluble in alcohol than in water. When heated it gradually decomposes without exhibiting any fixed melting point. Combustions of specially purified material gave numbers agreeing with those deduced from the formula $C_{28}H_{31}NO_{16}$.

In the preliminary notice the formula $C_{22}H_{19}NO_{10}$ was provisionally assigned to lotusin on the assumption that one molecule of dextrose is formed by its hydrolysis. The formula given above, as the result of ultimate analysis, is confirmed by the observation that two molecules of dextrose are produced by acid hydrolysis, which is therefore represented by the equation—

$$\underset{\text{Lotusin.}}{C_{28}H_{31}NO_{16}} + 2H_2O = \underset{\text{Dextrose.}}{2C_6H_{12}O_6} + \underset{\substack{\text{Prussic}\\\text{acid.}}}{HCN} + \underset{\text{Lotoflavin.}}{C_{15}H_{10}O_6}.$$

When a solution of lotusin is warmed with dilute hydrochloric acid, hydrolysis readily occurs. The liquid acquires a strong odour of hydrocyanic acid and a yellow crystalline precipitate of lotoflavin is thrown down, whilst the solution strongly reduces Fehling's solution. Dilute sulphuric acid only very slowly effects the hydrolysis of lotusin.

When warmed with aqueous alkalis, lotusin is gradually decomposed, ammonia being evolved and an acid formed to which the name *lotusinic acid* has been given.

$$C_{28}H_{31}O_{16} + 2H_2O = C_{28}H_{32}O_{18} + NH_3.$$

Lotusinic acid is a monobasic acid furnishing yellow crystalline salts. It is readily hydrolysed by dilute acids forming lotoflavin, dextrose and heptogluconic acid (dextrose-carboxylic acid):

$$\underset{\substack{\text{Lotusinic}\\\text{acid.}}}{C_{28}H_{32}O_{18}} + 2H_2O = \underset{\text{Lotoflavin.}}{C_{15}H_{10}O_6} + \underset{\text{Dextrose.}}{C_6H_{12}O_6} + \underset{\substack{\text{Heptogluconic}\\\text{acid.}}}{C_7H_{14}O_8}.$$

[redacted]

With the exception of amygdalin, lotusin is the only glucoside definitely known which furnishes prussic acid as a decomposition product.

Lotoflavin.

Lotoflavin is a yellow crystalline colouring matter readily dissolved by alcohol or by hot glacial acetic acid, and also by aqueous alkalis forming bright yellow solutions. It is always present to some extent in the plants, especially in old plants. Ultimate analysis leads to the formula $C_{15}H_{10}O_6$. It is therefore isomeric with luteolin, the yellow colouring matter of *Reseda luteola*, and with *fisetin*, the yellow colouring from young fustic, *Rhus cotinus*. *Morin*, from *Morus tinctoria*, appears to be hydroxylotoflavin.

Lotoflavin does not form compounds with mineral acids. It furnishes a tetracetyl derivative and two isomeric mutually convertible trimethyl ethers which are capable of forming one and the same acetyl-trimethyl-lotoflavin. By the action of fused potash lotoflavin is converted into phloroglucin and β-resorcylic acid.

Dextrose.

The sugar resulting from hydrolysis has been found to correspond in all properties with ordinary dextrose.

Hydrocyanic acid.

The amount of prussic acid given by plants at different stages of growth has been ascertained. Mature plants bearing seed-pods have furnished 0·345 per cent. of this acid, calculated on the air-dried material which corresponds with 5·23 per cent. of lotusin. Younger plants bearing flower buds gave 0·25 per cent., whilst still smaller quantities were furnished by very young plants and hardly any by quite old plants from which the seeds had fallen.

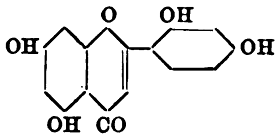
The formation of the poison, therefore, seems to reach its maximum at about the seeding period, and after this period to diminish rapidly. The Arabs are aware that the plant is safe to use as a fodder when the seeds are quite ripe, but not before. We have found that it is the lotusin which disappears during the ripening of the seeds. Old plants contain some lotase and lotoflavin, but little or no lotusin.

Lotase.

In its general properties lotase resembles other hydrolytic enzymes, from which, however, it differs in several important respects. It may be compared with emulsin, the enzyme of bitter almonds. Emulsin, however, only attacks lotusin very slowly, whilst lotase has but a feeble action on amygdalin, the glucoside of bitter almonds. Lotase is much more readily injured and deprived of its hydrolytic power than emulsin. On this account it is difficult to isolate in the solid state. Its power is not only rapidly abolished by heat, but is also gradually destroyed by contact with alcohol or glycerine. Besides lotase, the plant contains an amylolytic and a proteolytic enzyme.

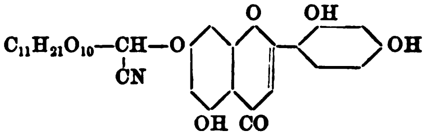
Constitution of Lotoflavin and Lotusin.

Having regard to its reactions and especially to the production, by the action of fused alkali, of β-resorcylic acid and phloroglucin, the authors conclude that lotoflavin should be represented by the formula :



which is that of a compound belonging to the same class, of phenylated pheno-γ-pyrones, as its isomerides luteolin and fisetin. The peculiarity shown by lotoflavin of containing four hydroxyl groups, but furnishing only a *tri*methyl ether, is accounted for by one of the hydroxyl groups being in the ortho position to a carbonyl group.

The reactions of lotusin are best represented by the formula :



which is that of a lotoflavin ether of maltose-cyanhydrin.

This formula satisfactorily accounts for the partial hydrolysis of the glucoside by alkalis giving lotusinic acid and ammonia, and for the decomposition of the substance by acids giving lotoflavin and maltose-carboxylic acid which is immediately decomposed into dextrose and heptogluconic acid. It also accounts for the hydrolysis of lotusin, by acids, into lotoflavin and maltose, which is further changed to dextrose.

In order to definitely localise the position of the cyanogen group in lotusin, the behaviour of several cyanhydrins of known constitution have been examined with reference to the question as to whether they would furnish hydrocyanic acid when acted on by dilute hydrochloric acid. It was found that mandelic nitrile, lævulose cyanhydrin and pentacetyl gluconitrile, in which the cyanogen group is known to occupy a position similar to that assumed for it in the formula suggested for lotusin, are, like lotusin, easily decomposed by dilute hydrochloric acid, forming prussic acid and the corresponding aldehyde or ketone.

The authors wish again to express their obligations to Mr. Ernest A. Floyer, of Cairo, Member of the Egyptian Institute, who has spared neither trouble nor expense in collecting in Egypt, and despatching to this country, the material required for this investigation.

"The Pharmacology of Pseudaconitine and Japaconitine considered in relation to that of Aconitine."

By J. THEODORE CASH, M.D., F.R.S., Regius Professor of Materia Medica in the University of Aberdeen, and WYNDHAM R. DUNSTAN, M.A., F.R.S., Director of the Scientific Department of the Imperial Institute. Received June 11—Read June 20, 1901.

(Abstract.)

In a previous paper on the Pharmacology of Aconitine and some of its principal derivatives,[*] we have given an account of the physiological action of this, the highly toxic alkaloid of Monkshood (*Aconitum Napellus*), and of its principal derivatives, and we have also discussed the ascertained physiological effects of these substances in relation to their chemical constitution. The results of this investigation have proved to be of much practical importance in connection with the pharmaceutical and medical employment of aconite, especially in demonstrating the partial antagonism to aconitine of benzaconine, and in a greater degree of aconine, both of which derivatives accompany the parent alkaloid in the plant and in the pharmaceutical preparations made from it, which have been hitherto used medicinally. Although it seems likely that these separate alkaloids, and especially aconine, may be useful as therapeutic agents, it is now clear that for the purpose for which aconite is employed, the pure alkaloid, aconitine, should be used in the place of the indefinite mixture of physiologically antagonistic alkaloids contained in pharmaceutical preparations made from the plant.

In a series of papers communicated to the Chemical Society, and published in the 'Journal of the Chemical Society' (1891–99), one of us, in conjunction with his pupils, has described the chemical properties of the toxic alkaloid contained in two other species of alkaloid, viz., *Aconitum ferox* or Indian or Nepaul Aconite, and *Aconitum Fischeri* or Japanese Aconite. The medicinal employment of these potent drugs

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[*] 'Phil. Trans.,' B, 1898, vol. 190, p. 239.

has been very restricted in the absence of any definite knowledge as to the nature of their constituents and the physiological action to which they give rise.

Aconitum ferox has long been known to botanists and travellers in India as a poisonous plant of great virulence. It is used in Indian medical practice under the vernacular name of "Bikh." There appear however to be several varieties of aconite passing under this vernacular name. This is a subject which we are at present investigating with the assistance of the Government of India.

In 1878 Alder Wright isolated a crystalline, highly toxic alkaloid, from the root of the plant, and named it pseudaconitine. In 1897* one of us gave an account of a complete investigation of the chemistry of this alkaloid, the results of which have led to a modification in certain important respects of the conclusions arrived at by Wright and his co-workers. Our results have been confirmed by Freund and Niederhofheim.†

For details of the chemistry of pseudaconitine and its derivatives, reference must be made to the paper already referred to.‡ We may here briefly record the chief properties of the alkaloid.

Pseudaconitine is a crystalline alkaloid whose composition differs from that of aconitine, being expressed by the formula $C_{36}H_{49}NO_{12}$. The crystals melt at 202°, and are sparingly soluble in water, but readily in alcohol. The salts are usually crystalline and soluble in water. Their solution and those of the base produce, in excessively minute quantities, a persistent tingling of the tongue, lips, and other surfaces with which they are placed in contact, in this respect resembling aconitine and its salts, which produce the same effect.

When heated in the dry state at its melting point pseudaconitine evolves a molecular proportion of acetic acid, leaving another alkaloid, pyropseudaconitine. This alkaloid, like the corresponding pyro-derivative of aconitine, does not give rise to the characteristic tingling effects of the parent base.

When a salt of pseudaconitine is heated in a closed tube with water, as in the case of aconitine, partial hydrolysis occurs with the loss of a molecule of acetic acid, an alkaloid, veratryl-pseudaconine, being left. This alkaloid, like the corresponding benzaconine, derived by similar means from aconitine, produces neither the tingling sensation nor the toxic effects of the parent base.

The complete hydrolysis of pseudaconitine, which is reached when the above-mentioned veratryl-pseudaconine is heated with alkalis, produces, instead of the benzoic acid furnished by aconitine, veratric or dimethylprotocatechuic acid, together with a base, pseudaconine, not

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* 'Proc. Chem. Soc.,' 1895, p. 154; 'Trans. Chem. Soc.,' 1897, p. 350.

† 'Ber.,' vol. 29, pp. 6, 852.

‡ *Loc. cit.*

susceptible of further hydrolysis. Whilst there is thus a strong general resemblance in chemical constitution between pseudaconitine and aconitine, the benzoic radical of aconitine is replaced in pseudaconitine by the veratric radical of veratric acid, whilst there are probably also constitutional differences in the central nucleus.

The composition and properties of the toxic alkaloid present in Japanese aconite, "Kuza-uzu," regarded by botanists as *Aconitum japonicum* or *A. Fischeri*, has been the subject of some dispute among chemists who have examined it. Wright regarded it as chemically different from aconitine, both in composition and in structure, being an anhydro- or apo-derivative formed by the loss of water and conjugation of 2 molecules of an unknown alkaloid of the aconitine type. He assigned to it the formula $C_{66}H_{88}N_2O_{21}$. Lübbe afterwards studied the properties of japaconitine, and pronounced it to be identical with aconitine, and, more recently, Freund and Beck have reached the same conclusion. Later, one of us, in conjunction with H. M. Read,* subjected japaconitine to a very detailed investigation, in the course of which its properties and those of its principal derivatives were defined and compared closely with those of aconitine. We believe that these results leave little room for doubting that japaconitine is a distinct alkaloid different from aconitine, although Wright was mistaken in the view he took of its composition and constitution. Superficially japaconitine bears a very strong resemblance to aconitine; it is, however, richer in carbon, and the physical properties of its derivatives do not agree with those of aconitine. To this alkaloid we have provisionally assigned the formula $C_{34}H_{49}NO_{11}$, and have retained for it the name of japaconitine suggested by Wright.

In general, the decomposition of japaconitine resembles that of aconitine, but the physical properties of the resulting derivatives are not the same. By the action of heat it furnishes acetic acid and jappyraconitine; on partial hydrolysis, japbenzaconine is obtained besides acetic acid; whilst on complete hydrolysis, the products are acetic acid, benzoic acid, and japaconine. Whilst therefore the constitution of the central nucleus appears to be different, both aconitine and japaconitine contain the acetyl and benzoyl groups, whilst in pseudaconitine the acetyl and veratryl groups are present.

In the present paper the physiological action of specially purified pseudaconitine and japaconitine is recorded and compared with aconitine.

The differences found are nearly always differences of degree and not differences of kind, a result which bears out the close constitutional relationship which is to be inferred from their chemical reactions. Although there are probably constitutional differences in the central nuclei of the three alkaloids, the same constitutional type is to

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* 'Journ. Chem. Soc.,' 1899.

be seen in each, and the substitution of a veratryl group (in pseudaconitine) for an acetyl group (in aconitine) counts for little in influencing the characteristic physiological action.

In order to bring the action of aconitine, pseudaconitine, and japaconitine into a contrast, which may be readily apprehended at a glance, the following summary will be useful.

Heart.—All three alkaloids have a similar effect upon the heart of such mammals as have been observed. Pseudaconitine is quantitatively more energetic than the other two, towards cats, but is certainly not nearly twice as toxic when artificial respiration is practised. Towards the frog's heart pseudaconitine is slightly less powerful than the other two, of which japaconitine is rather the more active.

Vagus Nerve and Inhibitory Mechanism in Heart.—Heart slowing from increased central vagus activity is produced by all these alkaloids, and similar results follow section and stimulation of the nerve at this and later stages of poisoning by one and all of them, both in mammals and frogs.

Respiration.—There is less tendency to acceleration of respiration in mammals poisoned by pseudaconitine than when the other two alkaloids are employed; further, the dyspnœal conditions develop more suddenly and the central depression of respiration is greater. Japaconitine is at first slightly more depressant than aconitine, but thereafter the tendency to acceleration of respiration is sooner developed, otherwise the general features of their action are similar.

Blood.—All the aconitines produce a deleterious effect upon the hæmoglobin and coloured corpuscles of the blood when they are given repeatedly in large doses. As far as has been ascertained this is due to impairment in the nutrition of the animal rather than to a direct action.

Frogs kept in a watery medium or in contact with a moist surface develop œdema after receiving any of the aconitines, but this condition is most marked and the hydræmia of the blood is more pronounced and lasting after pseudaconitine.

Brain and Cord.—All aconitines appear to have a similar effect qualitatively on the brain and cord of rabbits, pigeons, and frogs.

Temperature.—The initial elevation of temperature often seen in rabbits which have received aconitine or japaconitine is less frequently observed after pseudaconitine. A slightly greater and more enduring fall of internal temperature is witnessed after the latter, when the dose is large and bears a like relationship to the lethal amount.

Repeated Administration.—Some tolerance is established on the part of rabbits towards all the aconitines, and this is manifested with reference to temperature reduction, to the cardiac effect, and, to a lesser extent, to respiration; the general toxicity undergoing a reduction which is not, however, extensive. Less tolerance is shown towards pseudaconitine than towards the other two: it has been found impossible hitherto to determine how far rapidity of elimination varies between the alkaloids.

Sensory Nerves.—Local applications of the aconitine ointments of equal strengths are followed by a somewhat more powerfully depressant and enduring effect when these contain aconitine or japaconitine than pseudaconitine. This statement has reference to cutaneous sensory and thermic impressions in the human subject. The difference is at most but slight.

Motor Nerve and Muscle.—The action of the individual alkaloids is much the same whether specimens of *R. esculenta* or *R. temporaria* are used. It is more difficult to reduce reaction or to produce insensitiveness of the intramuscular motor nerves by pseudaconitine than by the other alkaloids. The so-called curare-like action has been found for all the alkaloids to be much feebler than was at one time supposed.

Direct contact of the alkaloidal solutions with muscle-nerve preparations reduces excitability, the muscle being affected by solutions containing less than 1 in 1,000,000, and the nerve by solutions still weaker. Pseudaconitine is recognised as producing a rather weaker effect than the two other alkaloids, which are nearly equal to one another, japaconitine being slightly the more energetic.

The results of the experiments detailed in this paper do not in all respects agree with previous observations; especially is this the case with regard to the relative toxicities of the three aconitines. The general order of toxicity towards mammals is pseudaconitine, japaconitine, and aconitine, which is the least toxic. Pseudaconitine has been found (roughly speaking) twice as toxic as aconitine towards the small mammals and birds used in the research. This agrees closely with the results of Adelheim* and Böhm and Ewers.† Cloetta‡ states that pseudaconitine is the stronger alkaloid, but gives no proportion. Our results differ from those of Nothnagel and Rossbach,§ who state that pseudaconitine is seventeen times as active as aconitine, and of Harnack and Meunicke,‖ who find the under margin of active dosage equal. Kobert¶ finds pseudaconitine and aconitine to be in activity "ziemlich gleich."

The relative toxicity of japaconitine to aconitine is approximately as ten to about nine towards the small mammals and birds which were used. Previously japaconitine has been seldom contrasted with the

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* Adelheim, 'Forens. Chem. Untersuch,' Dorpat, 1860.

† Böhm and Ewers, 'Arch. f. Exp. Path. u. Pharm.,' 1873, Bd. 1, p. 385.

‡ Cloetta, 'Lehbr. d. Arzneim. u. Arzneiverordnungsl..' Freib., 1885.

§ Nothnagel u. Rossbach, 'Mat. Med. u. Therap.' (Fr.), 1880, 685.

‖ Harnack and Meunicke, 'Berl. Klin. Wchsch.,' 1883, No. 43, p. 657.

¶ Kobert, 'Lehbr. d. Intox.,' p. 657.

other two aconitines, but has been recognised as stronger than aconitine by Langaard,[*] and in one series of observations by Harnack and Meunicke. Kobert, on the other hand, does not separate japaconitine from aconitine and pseudaconitine in toxicity.

Dosage.—Based upon the observations made, the relative doses for therapeutical purposes would be approximately, regarding that for aconitine as the unit, for pseudaconitine 0·4 to 0·45, and for japaconitine 0·8.

Towards frogs the toxicity of these alkaloids is by no means so great (per gramme body-weight) as it is towards the same unit of the mammals and birds included in this research. Thus the lethal dose per kilo. mammalian weight may only be lethal to 140 to 170 grammes of frog weight, or even to less, according to the time of year. A medium-sized rabbit may therefore be poisoned by a dose of aconitine or japaconitine which would suffice to destroy six or eight frogs.

Japaconitine is slightly more toxic towards both mammals and frogs than is aconitine, but the higher toxicity of pseudaconitine towards birds and mammals is not associated with an equal activity towards frogs, for it exerts towards both *R. esculenta* and *R. temporaria* a slightly lower toxicity than do either of the other alkaloids.

There is no essential difference in the reaction of *R. esculenta* and *R. temporaria* respectively to individual aconitines beyond a greater or less accentuation of one or other symptom, as for example more excited movement in the latter, more reduction of reflex in the former, but in all parallel series of observations the resistance of *R. esculenta* has proved to be slightly greater to all the aconitines examined.

As concerns the local action of the aconitines upon sensory (cutaneous) structures in man, the differences are so trifling as to be negligible.

As regards the therapeutical employment of aconitine, japaconitine, and pseudaconitine, the great similarity in their physiological actions, amounting almost to a qualitative identity, which is established by this investigation, justifies the employment of any one for internal administration, provided that the dosage is properly regulated. Given in the proportions mentioned above, the three alkaloids would exert the same action. We strongly recommend the use of a pure alkaloidal salt in preference to preparations made from the plants, since the latter would be difficult to standardise, and even if this were done, the action of the aconitines would be modified to a greater or less extent by the other alkaloids present in the vegetable preparation.

For local applications the three alkaloids may be introduced into ointments in identical proportions. The greater toxicity of pseudaconitine need not prevent its use in this department of treatment if it

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[*] Langaard, 'Arch. f. Path. Anat.,' 1880, 79, s. 229.

is remembered that all applications of the aconitines, externally, are to be considered dangerous if any abrasion of the skin is present.

The chemical part of this inquiry has been conducted in the Laboratories of the Scientific Department of the Imperial Institute, with the assistance and co-operation of the Government of India. Our thanks are specially due to Dr. George Watt, C.I.E., Reporter on Economic Products to the Government of India, for the interest he has shown in the investigation, and for the care he has taken in the collection of the necessary material.

The physiological experiments have been conducted in the Department of Materia Medica and Pharmacology of the University of Aberdeen, and have been assisted by a grant made by the Royal Society from the Government Fund. The assistance of Drs. Esslemont and Fraser has been very valuable in carrying out some of the observations entailed in this department of the research.

"The Pharmacology of Pyraconitine and Methylbenzaconine considered in Relation to their Chemical Constitution." By J. THEODORE CASH, M.D., F.R.S., Regius Professor of Materia Medica in the University of Aberdeen, and WYNDHAM R. DUNSTAN, M.A., F.R.S., Director of the Scientific Department of the Imperial Institute. Received June 11,—Read June 20, 1901.

(Abstract.)

In a previous paper* we have shown that an entire change in the physiological action ensues on the withdrawal of the acetyl group from aconitine as is seen in the action of benzaconine, the first hydrolytic product of aconitine, from which it differs in containing an atom of hydrogen in the place of one acetyl group. This alkaloid is devoid of the characteristic physiological action and extraordinary toxicity of aconitine, whilst in respect of its action on the heart it is in the main antagonistic to that of the parent alkaloid. In order to study further the remarkable dependence of the physiological action on the presence of the acetyl group, we have examined the action of two derivatives of aconitine which we have obtained in this research, viz., pyraconitine and methylbenzaconine.

Pyraconitine was first prepared by one of us† by heating aconitine at its melting point, when the acetyl group is expelled as one molecule of acetic acid and the alkaloid pyraconitine remains. This compound

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* 'Phil. Trans.,' B, 1898, vol. 190, p. 239.

† Dunstan and Carr, 'Trans. Chem. Soc.,' 1894, vol. 65, p. 176.

therefore differs in composition from aconitine by the loss of one molecule of acetic acid, and from benzaconine by one molecule of water.

Methylbenzaconine was obtained from aconitine by heating it with methyl alcohol in a closed tube.* A remarkable reaction takes place, in which the acetyl group is ejected as acetic acid, a methyl group taking its place. This alkaloid therefore differs from aconitine in containing a methyl group in the place of the acetyl group, and from benzaconine in containing a methyl group in the place of one atom of hydrogen. The examination of its physiological action would therefore be the means of studying the result of replacing in aconitine the negative radical acetyl by the positive methyl group, and also of studying the effect of the introduction of methyl in modifying the physiological action of benzaconine.

The acetyl group of aconitine evidently occupies an exceptional position in the molecule of aconitine. So far as we are aware it is the only acetyl compound at present known, which exchanges this group for methyl when it is heated with methyl alcohol. We have examined the behaviour of numbers of different types of acetyl derivatives from this point of view and can find none analogous to aconitine.

For the study of their physiological action these alkaloids have been specially purified and employed as hydrobromides in aqueous solution.

Contrasting the physiological action of pyraconitine with that of aconitine, as described in the present paper, we find, as might be anticipated from our previous results, that through the removal of the acetyl group the great toxicity of aconitine is nearly entirely abolished and the characteristic features of aconitine poisoning are no longer produced by pyraconitine.

Contrasting the physiological actions of benzaconine and pyraconitine which differ from each other empirically by one molecule of water, pyraconitine, the anhydride, is the more active compound. Both these alkaloids, divested of the acetyl group of aconitine, are relatively weak and feebly toxic when compared with the parent alkaloid.

Although benzaconine and pyraconine exhibit a strong similarity in the physiological effects they produce, there are differences between them which are probably more considerable than they would be if pyraconitine were merely the anhydride of benzaconine.

The substitution in aconitine of methyl for acetyl which occurs in the formation of methyl benzaconine has led to a very considerable reduction in toxicity and has introduced a curare-like effect similar to that first observed by Crum Brown and Fraser† to result from the

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* 'Proc. Chem. Soc.,' 1896, p. 159.

† 'Trans. Roy. Soc. Edinb.,' 1869, vol. 25, p. 192.

introducton of methyl into the molecule of an alkaloid. Methyl benzaconine is however more toxic and generally more powerful than benzaconine, owing to the presence of the methyl group.

Action of Pyraconitine.

The main effects of pyraconitine may be thus summarised. Its local application is devoid of the effects characteristic of the aconitines. Its chief action upon the heart is to cause slowing, partly from vagus irritation, partly from depression in function of intrinsic rhythmical and motor mechanisms.

There is less tendency to want of sequence in the cardiac chamber walls than is observed after the aconitines and benzaconine.

The vagus apparatus remains active in degree after doses somewhat in excess of the lethal, the slowed heart of pyraconitine being accelerated both by vagotomy and by atropine.

Activity of respiration is reduced (by central depression) to a degree incompatible with life, as is the case after aconitine and benzaconine. The peripheral motor nerves and muscular tissues are not at this time markedly affected. Artificial respiration prolongs life, but the slowed heart and greatly reduced blood pressure tend to a fatal issue.

The spinal cord is impaired in its reflex function, apparently secondarily to reduced circulation in its structure. A tendency to tonic spasm in frogs is late in appearing and of moderate degree. It has not been seen after destruction of brain and medulla. It is further associated with a curious condition of exaggerated motility.

Neither muscular nor intramuscular nervous tissue are strongly influenced by pyraconitine in lethal or somewhat hyperlethal doses. The lethal dose per kilo. frog's weight is practically about twelve times that which is lethal per kilo. rabbit's weight.

Contrasted Effects of Pyraconitine and Benzaconine.

Of these two alkaloids, pyraconitine is approximately six to seven times more toxic towards mammals (rabbits and guinea-pigs) than benzaconine, and five to six times more so towards frogs. They are alike in their action upon mammals, in so far as they are non-irritant, that they slow the respiration without preliminary acceleration, that they slow the heart and reduce the blood pressure to a very low level, that they cause paresis and in guinea-pigs clonic movements, and that respiratory failure is the immediate cause of death. They differ in so far that pyraconitine acts more rapidly, but for a shorter period, whilst fatal termination of poisoning is preceded by convulsions, which are very rare after benzaconine. Benzaconine alters the sequence of the ventricles upon the auricles much more usually and to a greater extent than pyraconitine, though if a sequence is developed it has the same general character (the auricular second beat being blocked from the ventricle).

Whilst pyraconitine stimulates the cardiac vagus both centrally and within the heart (section and atropine causing acceleration), and finally occasions only a limited reduction in its activity, benzaconine produces but little stimulation, and ultimately suspends the vagus inhibitory action. Under these conditions atropine is, of course, inoperative. Both accelerate the heart in small, but slow it in large, dose, and both may disorder the sequence, but vagus inhibition is much more interfered with by benzaconine. Frogs poisoned by benzaconine lose the power of voluntary movement, then reflex disappears, and finally the circulation is arrested; but after pyraconitine, reflex outlasts the heart's action. Late spasm occurs after the latter, not after the former. Whilst in lethal doses pyraconitine has no effect beyond somewhat favouring fatigue and reducing excitability of motor nerves, benzaconine greatly impairs their function, and in thorough poisoning may suspend it entirely.

Action of Methylbenzaconine.

The action of methylbenzaconine may be summed up as follows: It is very feeble in its toxicity when contrasted with aconitine, but is somewhat stronger than benzaconine.

Small and medium doses, whilst slowing the heart, do not cause any failure in sequence, but larger doses have this effect. They act upon the rhythm of the organ, involving the movement of the auricle and ventricle whilst ultimately the sequence of the latter upon the former is impaired, so that it follows only a certain proportion of the auricular "leads." This block is not removed by atropine. Whilst the passage of the ventricle into the diastole is at first retarded, the contractile power of the myocardium is ultimately reduced by methylbenzaconine.

The cardiac vagus is depressed in action and its inhibitory function is ultimately suspended by large doses, neither section of the vagus nor atropine administration relieving the slow and faulty action of the organ.

There is evidence of slight primary stimulation of reflex cord centres when ligature of vessels prevents the masking of this condition by the peripheral action of the poison. The subsequent impairment in cord reflexes is later in occurring and of much shorter duration than the action of methylbenzaconine upon intramuscular motor nerves.

In mammals the paralytic symptoms are predominant, the fall of temperature is in part attributable to this cause as well as to changes in the circulation. The clonic movement and salivation (observed in

[redacted]

a certain stage of the action of methylbenzaconine, especially upon guinea-pigs) are suggestive of the action of a near ally of aconitine. In frogs, however, there is no semblance to an aconitine effect, unless its very feeble action towards sensory nerves or its much more powerful action upon motor nerves, be thus viewed. Motor nerves are greatly affected by doses which are distinctly below the lethal for cold-blooded animals, the action being curare-like in character. Muscular tissue is after the action of large doses more susceptible of fatiguing influences. Fibrillation in muscles to which the poison has access is more common than after aconitine or any other derivative examined.

These observations support in the main the contention of Crum Brown with Fraser that the introduction of methyl into the molecule of certain spasm-producing alkaloids, marks the effect of these by occasioning a curare-like action at the periphery.

Contrasted Effects of Methylbenzaconine and Aconitine.

The toxicity of aconitine is, roughly, eighty to one hundred times that of methylbenzaconine towards rabbits and guinea-pigs, and much the same proportion holds for summer and winter frogs respectively. Whilst slight tendency to salivation and retching movements are produced by methylbenzaconine, and are in so far suggestive of a slight aconitine action, the absence of initial acceleration of respiration, of local irritation, and dyspnœal convulsions, and the predominance of paralytic symptoms, are points of difference. The action upon the heart is entirely distinct, for the pulse is slowed by methylbenzaconine, the auricles eventually beating more rapidly than the ventricles, the action of the poison proceeds uniformly and without the intermissions which characterises aconitine, whilst the early phenomena of vagus stimulation have little in common. The general symptoms of poisoning in frogs have scarcely a point of similarity, quiescence, rapid failure of reflex, and voluntary movement, without impairment of the cardiac action, are distinctive of methylbenzaconine, whilst excitement with great motility and persistence of voluntary movement follow aconitine. Fibrillation is much more pronounced after the former, though it is only a transitory phenomenon. The action on the heart differs widely in frogs as it does in mammals, whilst the curare-like action of the derivative on motor nerves is not produced by aconitine in doses which just suffice to arrest the heart.

It is true that large but sublethal doses of aconitine are followed by a condition of almost complete paralysis, which lasts for several days, but during this time there is slight voluntary and reflex movement, the nerve-endings are not put out of action, and the circulation is usually of the feeblest character, all conditions which are not found in the eriod of quiescence following methylbenzaconine.

Contrasted Effects of Methylbenzaconine and Benzaconine.

Methylbenzaconine is from three to four times more toxic towards rabbits and guinea-pigs than benzaconine, and from twice to thrice as toxic towards frogs (*R. temp.* and *R. esc.*). In mammals, slight salivation, retching movements, and muscular tremor are characteristic effects of the former, but dyspnœa, ataxia, and paresis are also seen after benzaconine. Of the two, methylbenzaconine is distinctly less depressant towards the heart. Slowing of the pulse and want of sequence of ventricular upon auricular action occurs after both, but is a much earlier symptom after benzaconine, which causes more disorder in the motor mechanism. On the other hand, the intracardiac vagus is put out of function more readily by methylbenzaconine. Death after either poison is rarely preceded by spasm. Neither of the two compounds cause any local irritation in frogs, but methylbenzaconine produces active fibrillation in the muscles, to which it gains access and develops a complete curare-like action much more prominently than does benzaconine, the heart continuing to beat strongly. Benzaconine, in dose sufficient to cause such an effect at the periphery, acts disastrously upon the circulation. In partial poisoning by methylbenzaconine the characteristic rapid failure of the intramuscular motor nerves on stimulation is well marked, but the subsequent recovery on resting, so characteristic of benzaconine, has not been observed.

"On the Separation of the Least Volatile Gases of Atmospheric Air, and their Spectra."

By G. D. Liveing, M.A., Sc.D., F.R.S., Professor of Chemistry in the University of Cambridge, and James Dewar, M.A., LL.D., F.R.S., Jacksonian Professor in the University of Cambridge, Fullerian Professor of Chemistry, Royal Institution, London. Received June 15,—Read June 20, 1901.

Our last communication to the Society* related to the most volatile of the atmospheric gases, that which we now beg leave to offer relates to the least volatile of those gases. The former were obtained from their solution in liquid air by fractional distillation at low pressure, and separation of the condensible part of the distillate by cooling it in liquid hydrogen. The latter were, in the first instance, obtained from the residue of liquid air, after the distillation of the first fraction, by allowing it to evaporate gradually at a temperature rising only very slowly. The diagram, fig. 1, will make the former process intelligible.

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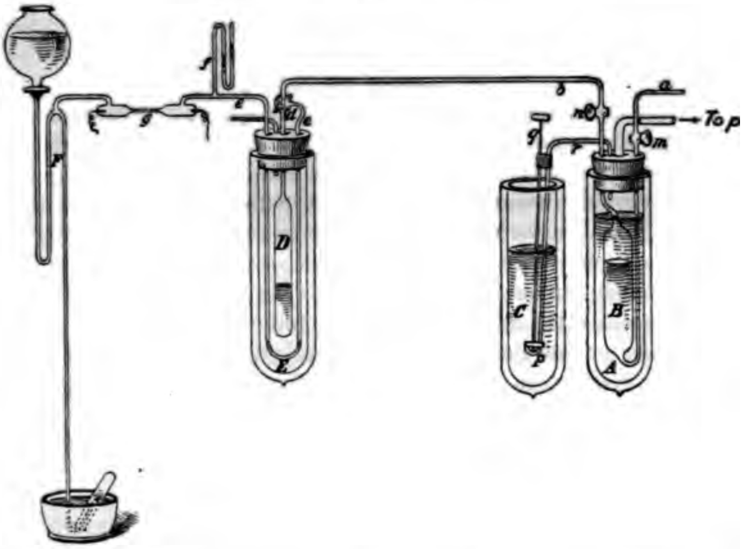
* 'Roy. Soc. Proc.,' vol. 67, p. 467.

A represents a vacuum-jacketed vessel, partly filled with liquid air, which a second vessel, *B*, was immersed. From the bottom of tube, *a*, passed up through the rubber cork which closed *A*, and fr the top of *B* a second tube, *b*, passed through the cork and on to rest of the apparatus. Each of these tubes had a stopcock, *m* and and the end of tube *a* was open to the air. A wider tube a passed through the cork of *A* and led to an air-pump, whereby

FIG. 1.



pressure above the liquid air in *A* was reduced, and the temperat of the liquid reduced by the consequent evaporation. To keep inner vessel, *B*, covered with liquid, a fourth tube, *r*, passed throu the cork, and its lower end, furnished with a valve, *p*, which could opened and closed by the handle *q*, dipped into liquid air contained the vessel *C*. As the pressure above the liquid in *A* was less th that of the atmosphere, on opening the valve *p* some of the liquid was forced through *r* into *A* by the pressure of the atmosphere, and this way the level of liquid in *A* maintained at the required height.

Since *B* was maintained at the temperature of liquid air boiling reduced pressure the air it contained condensed on its sides, and wh the stopcock *n* was closed and *m* opened, more air passed in throu the open end of *a*, and was in turn condensed. In this way *B* co be filled completely with liquid air, the whole of the most volatile ga being retained in solution in the liquid.

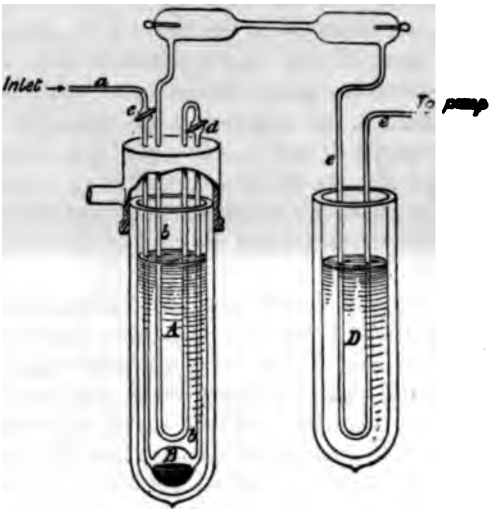
The tube, *b*, passing from the top of *B*, was connected with a thr way stop-cock *d*, by which *c* could be put in communication with the closed vessel, *D*, or with the tube *e*, by which also *D* and *e* could be connected. The tube *e* passed down nearly to the bottom of the vacuum jacketed vessel *E*, and out again through the cork; and on to a gauge *f*, and through a sparking tube *g* to a mercury pump *F*. The stopcock *n* being still closed, the whole of the apparatus between *n* and the pump, including the vessel *D*, was exhausted, and liquid hydrogen introduced into *E*. The three-way cock *d* was then turned so as to connect *c* with *D*, and close *e*, and then *n* opened. *B* was thereby put in communication with *D*, which was at a still lower temperature than *B*, and the gas dissolved in the liquid in *B*, along with some of the most volatile part of that liquid, distilled over, and the latter condensed in a solid form in *D*. When a small fraction of the liquid in *B* had thus distilled, the stop-cock *d* was turned so as to close the communication between *D* and *c*, and open that between *D* and *e*. Gas from *D* passed into the vacuous tubes, but in so doing it had to pass through the portion of *e* which was immersed in liquid hydrogen, so that condensible matter carried forward by the stream of gas was frozen out.

For separating the least volatile part of the gases, the vessel *E*, with its contents, was dispensed with, and the tube *c* made to communicate directly with that connected with the gauge, sparking tube, and pump; and generally several sparking tubes were interposed between the gauge and pump, so that they could be sealed off successively. The bulk of the liquid in *B* consisted of nitrogen and oxygen. These were allowed gradually to evaporate, the temperature of *B* being still kept low so as to check the evaporation of the gases less volatile than oxygen. When a great part of the nitrogen and oxygen had thus been removed, the stopcock *n* was closed, and the tubes partially exhausted by the pump, electric sparks passed through *g*, and the gases examined spectroscopically. More gas was then evaporated from *B*, and the spectroscopic examination repeated from time to time.

The general sequence of spectra, omitting those of nitrogen, hydrogen, and compounds of carbon, which were never entirely removed by the process of distillation alone, was as follows: The spectrum of argon was first noticed, and then as the distillation proceeded the brightest rays, green and yellow, of krypton appeared, and then the intensity of the argon spectrum waned, and it gave way to that of krypton until, as predicted by Runge, when a Leyden jar was in the circuit, the capillary part of the sparking tube had a magnificent blue colour, while the wide ends were bright pale yellow. Without a jar the tube was nearly white in the capillary part, and yellow about the poles. As the distillation proceeded, the temperature of the vessel containing the residue of liquid air being allowed to rise slowly, the brightest of the xenon rays began to appear, namely, the green rays about λ 5420, 5292, and 4922, and then the krypton rays soon died ou and were superseded by the xenon rays. At this stage the capillary part of the sparking tube is, with a jar in circuit, a brilliant green and is still green, though less brilliant, without the jar. The xenon formed the final fraction distilled.

Subsequently an improved form of apparatus was used for the fractionation. It is represented in fig. 2. A gasholder containing the gases to be separated, that is to say, the least volatile part of atmospheric air, was connected with the apparatus by the tube *a*, furnished with a stopcock *c*. This tube passed on to the bulb *B*, which in turn communicated through the tube *b* and stopcock *d* with a sparking tube, and so on through the tube *e*, with a mercurial pump.* Stopcock *d* being closed and *c* opened, gas from the holder was allowed to pass into *B*, maintained at low temperature, and there condensed in the solid form. Stopcock *c* was then closed and *d* opened, and gas from *B* allowed to pass into the exhausted tubes between *B* and the pump. The tube *e* was partly immersed in liquid air in order to condense vapour of mercury, which would otherwise pass from the pump into the sparking tube. The gas passing into the sparking tube would, of course, have a pressure corresponding to the temperature of *B*, and this was further ensured by making the connecting tube pass through the liquid in which *B* was immersed. The success of the operation of separating all the gases which occur in air and which boil at different

Fig. 2.



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* The Sprengel pump shown in figure is simply diagrammatic.

temperatures depends on keeping the temperature of B as low as possible, as will be seen from the following consideration :—

The pressure p, of a gas G, above the same material in the liquid state, at temperature T, is given (approximately) by the formula

$$\log p = A - \frac{B}{T},$$

where A and B are constants for the same material. For some other gas G' the formula will be

$$\log p_1 = A_1 - \frac{B_1}{T},$$

and

$$\log \frac{p}{p_1} = A - A_1 + \frac{B_1 - B}{T}.$$

Now for argon, krypton, and xenon respectively the values of A are 6·782, 6·972, and 6·963, and those of B are 339, 496·3, and 669·2 ; so that for these substances and many others $A - A_1$ is always a small quantity, while $\frac{B_1 - B}{T}$ is considerable and increases as T diminishes. Hence the ratio of p to p_1 increases rapidly as T diminishes, and by evaporating the gases always from the solid state and keeping the solid at as low a temperature as possible, the gas first removable at the lowest pressure consists in by far the greatest part of that which has the lowest boiling point, which in this case is nitrogen, and is succeeded, with comparative abruptness, by the gas which has the next higher boiling point. By this method the nitrogen and oxygen are removed without the necessity of sparking or absorption. The change from one gas to another is easily detected by examining the spectrum in the sparking tube, and the reservoirs into which the gases are pumped can be changed when the spectrum changes, and the fractions separately stored. Or, if several sparking tubes are interposed in such a way as to form parallel communications between the tubes b and e, any one of them can be sealed off at any desired stage of the fractionation.

The variation of the spectra of both xenon and krypton with variation in the character of the electric discharge is very striking, and has already been the subject of remark, in the case of krypton, by Runge, who has compared krypton with argon in its sensitiveness to changes in the electric discharge. Runge distinguishes krypton rays which are visible without a jar and those which are only visible with a jar discharge. The difference in the intensity of certain rays, according as the discharge is continuous or oscillatory, is no doubt very marked, but, with rare exceptions, we have found that the rays which are intensified by the oscillatory discharge can be seen with a continuous discharge when the slit of the spectroscope is wide. Runge used a grating, whereas we have, for the sake of more light, used a prism spectroscope throughout, and were therefore able to observe many more rays than he.

There is one very remarkable change in the xenon spectrum produced by the introduction of a jar into the circuit. Without the jar xenon gives two bright green rays at about λ 4917 and λ 4924, but on putting a jar into the circuit they are replaced by a single still stronger ray at about λ 4922.[*] In no other case have we noticed a change so striking as this on merely changing the character of the discharge. Changes of the spectrum by the introduction of a jar into the circuit are, however, the rule rather than the exception, and there are changes in the spectrum of krypton which seem to depend on other circumstances. In the course of our examination of many tubes filled with krypton in the manner above indicated, we have found some of them to give with no jar the green ray λ 5571, the yellow ray λ 5871, and the red ray λ 7600 very bright, while other rays are very few, and those few barely visible. Putting a jar into the circuit makes very little difference; the three rays above mentioned remain much the brightest, nearly, though not quite, so bright as before, and the blue rays, so conspicuous in other tubes, though strengthened by the use of the jar, are still very weak. In other tubes the extreme red ray is invisible, the rays at λ 5571 and 5871 absolutely, as well as relatively, much feebler, while the strong blue rays are bright, even brighter than the green and yellow rays above named. In one tube the blue rays could be seen, though not the others. This looks very much as if two different gases were involved, but we have not been able to assure ourselves of that. The case seems nearly parallel with that of hydrogen. There are some hydrogen tubes which show the second spectrum of hydrogen very bright, and others which show only the first spectrum; the second spectrum is enfeebled or extinguished by introducing a jar into the circuit, while the first spectrum is strengthened; and the conditions which determine the appearance of the ultra-violet series of hydrogen rays have not yet been satisfactorily made out.

It is to be noted that putting the jar out of circuit does not in general immediately reduce the brightness of the rays which are strengthened by the jar discharge. Their intensity fades gradually, and is generally revived, more or less, by reversing the direction of the current, but this revival gets less marked at each reversal until the intensity reaches its minimum. The rays strengthened by the jar discharge also sometimes appear bright, without a jar, on first passing the spark when the electrodes are cold, and fade when the electrodes get hot, reappearing when the tube has cooled again. Moreover, if

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[*] This line is almost identical with a strong helium line, but the yellow line of helium was not seen.

the discharge be continued without a jar, the resistance in the krypton tubes increases rather rapidly, the tube becomes much less luminous and finally refuses to pass the spark. With an oscillatory discharge the passage of the spark and the brightness of the rays are much more persistent. This seems to point to some action at the electrodes, which is more marked in the case of krypton than in that of xenon.

The wave-lengths of the xenon and krypton rays in the tables below were determined, in the visible part of the spectrum, with a spectroscope having three white flint-glass prisms of 60° each, by reference to the spark spectrum of iron, except in the cases of the extreme red ray of krypton, which was referred to the flame spectrum of potassium, and its fainter neighbour, which we saw but did not measure. The in digo, violet, and ultra-violet rays were measured in photographs, taken with quartz lenses and two calcite prisms of 60° each. The spectrum of the iron spark was photographed at the same time as that of the tube, the former being admitted through one-half of the slit, and the latter through the other half.

The xenon spectrum is characterised by a group of four conspicuous orange rays of about equal intensities, a group of very bright green rays of which two are especially conspicuous, and several very bright blue rays. The only list of xenon rays we have seen is that published by Erdmann, with which our list does not present any close agreement except as to the strongest green lines. The number of xenon rays we have observed is very considerable, and some of them lie very near to rays of the second spectrum of hydrogen, but inasmuch as these rays are more conspicuous with a jar in circuit than without, which is not the character of the second spectrum of hydrogen, and, moreover, many of the brightest of the hydrogen rays are absent from the spectrum of the tubes, we conclude that these rays are not due to hydrogen. Certain rays, which we have tabulated separately, have been as yet observed in only one tube: they include a very strong ultra-violet ray of unknown origin, and either due to some substance other than xenon, or to some condition of the tube which has not been repeated in the other tubes.

Our krypton rays agree much more closely with Runge's list, but outnumber his very considerably, as might be expected when prisms were used instead of a grating. Prisms, of course, cannot compete with gratings in the accuracy of wave-length determinations. We think that the krypton used by Runge must have contained some xenon, and that the rays for which he gives the wave-lengths 5419·38, 5292·37, and 4844·58 were really due to xenon, as they are three of the strongest rays emitted by our xenon tubes, and are weak in, and in some cases absent from, the spectra of our krypton tubes.

Our thanks are due to Mr. R. Lennox, to whose skill in manipulation we are much indebted.

Tables of the approximate Wave-lengths of Xenon and Krypton Rays.

Rays observed only with a Leyden jar in circuit have an * prefixed, those observed only when no Leyden jar was in circuit have a † prefixed.

The intensities indicated are approximately those of the rays when a jar is in circuit, except in the case of the two rays to which a † is prefixed, which are not seen when a jar is in circuit. Rays which are equally intense whether a jar is in circuit or not have a || prefixed to the number indicating their intensities; those which are less intense with a jar than without have a < prefixed to the number expressing their intensities. The rest are, in general, decidedly more intense with a jar than without.

Xenon Rays.

Wave-lengths.	Intensity.	Wave-lengths.	Intensity.	Wave-lengths.	Intensity.	Wave-lengths.	Intensity.
*6596	4	5532	4	4883	—	4471	2
* 14	1	5473	3	76	4	62	10
6472	‖1	61	3	44	10	49	6
6358	1	* 51	1	30	‖1	40	1
45	3	39	3	23	3	34	2
20	‖1	20	10	* 18	3	15	8
02	1	5372	6	07	<1	07	3
6278	3	* 68	1	4793	1	4396	4
71	3	39	6	87	2	93	4
6183	‖1	13	1	79	2	86	3
81	‖1	09	1	69	2	75	4
66	‖1	5292	10	40	1	69	4
6097	6	62	2	34	<1	56	1
51	6	60	2	31	1	43	1
36	5	40	—	23	1	37	3
5976	6	27	1	14	1	31	10
72	—	02	1	4698	‖3	22	3
46	2	5192	6	4677	band of	11	3
35	<1	89	3	to	close	4297	3
06	1	85	3	4668	lines	86	3
5895	‖1	79	3	52	4	72	3
76	‖1	26	3	34	2	69	3
56	‖1	23	1	24	<2	63	2
25	2	07	3	16	3	51	3
17	—	5080	2	02	8	45	10
5777	4	68	5	4592	3	39	8
59	4	52	1	86	‖5	27	1
51	5	45	6	77	3	23	5
27	4	25	<1	56	2	15	10
20	4	4988	4	45	3	14	6
00	6	72	2	41	3	09	8
5668	4	† 24	†4	35	2	04	‖1
60	1	* 22	8	25	‖5	01	1
17	—	† 17	†4	22	1	4198	1
09	1	4890	3	00	‖1	93	‖6
5583	1	87	—	4486	1	81	10
73	1	84	4	81	5	76	1

Xenon Rays—*continued*

Wave-lengths.	Intensity.	Wave-lengths.	Intensity.	Wave-lengths.	Intensity.	Wave-lengths.	Intensity.
4172	1	3981	1	3815	1	3655	2
63	3	75	1	11	3	50	1
59	3	73	2	07	1	45	6
46	3	57	‖1	01	1	41	2
42	1	55	4	3792	1	32	2
32	2	51	<6	87	1	24	10
21	1	44	3	83	1	16	1
12	2	39	1	81	6	13	4
09	6	26	1	76	3	10	2
06	3	23	6	73	1	07	4
00	2	15	1	70	1	02	1
4099	3	08	4	66	1	3597	3
93	1	06	1	63	2	84	8
79	<1	03	1	62	1	80	8
74	1	3894	3	57	1	65	4
60	1	85	3	46	3	56	3
58	6	80	3	37	1	53	5
50	6	77	3	31	2	43	6
44	1	70	2	21	2	23	4
43	1	62	2	17	3	10	2
37	6	58	2	12	2	04	1
29	1	55	1	08	1	01	4
25	3	50	2	3689	1	3468	2
21	1	49	1	77	3	61	1
02	3	42	4	73	2	54	1
3994	2	29	1	64	1		
91	3	26	1	62	2		
86	1	24	1	58	1		

Wave-lengths of rays of unknown origin observed in the spectrum of one tube containing xenon but not present in the spectrum of other tubes :—

Wave-lengths.	Intensity.	Wave-lengths.	Intensity.
4589	—	3890	1
4071	1	72	1
67	1	3797	5
63	—	41	4
11	1	3684	10
3998	1	3573	2

[redacted]

Krypton Rays.

Wave-lengths.	Intensity.	Wave-lengths.	Intensity.	Wave-lengths.	Intensity.	Wave-lengths.	Intensity.
7600	8	5186	1	4387	3	3859	1
‡7587	2	72	1	76	3	58	1
6771	1	66	5	63	2	47	1
6578	1	43	4	56	12	44	2
42	3	26	6	23	2	42	1
11	2	5087	8	20	‖8	39	1
6487	3	78	1	19	‖3	37	2
58	<1	73	2	18	3	17	2
51	3	57	8	01	7	06	2
20	<4	34	1	4293	10	05	3
6305	3	23	4	83	‖3	3784	10
6170	2	14	‖2	74	‖4	79	8
6095	1	4980	1	69	3	72	4
82	1	60	1	60	1	59	2
56	2	46	1	56	1	55	6
21	1	03	2	51	5	46	6
11	2	4847	2	37	4	42	6
5992	3	45	2	4185	3	36	3
5873	1	* 33	5	72	1	34	4
71	<10	26	3	45	8	22	5
5771	2	12	3	40	2	19	10
53	2	4766	10	4119	3	15	1
5690	5	63	3	09	6	3691	1
82	5	39	10	4099	8	87	5
50	1	4694	3	89	8	81	7
32	2	80	5	65	7	70	7
5571	<10	59	8	58	6	67	1
63	3	50	1	45	4	64	3
53	1	35	6	38	2	61	3
44	1	20	8	08	2	54	10
23	2	15	6	05	1	49	3
06	2	10	3	3997	3	38	4
00	2	4598	1	94	6	32	10
5483	1	93	2	88	2	24	1
46	2	83	4	65	1	08	6
29	1	77	8	55	2	00	6
24	1	25	3	39	1	3590	3
03	1	05	‖2	28	3	74	1
5319	1	4490	2	21	8	54	2
05	1	75	6	18	2	45	6
5278	1	64	‖3 pairs	13	6	03	2
29	1	54	‖1	07	6	3489	2
18	1	37	6	01	1	70	1
15	1	32	6	3896	3	60	3
* 09	5	23	2	76	7		
03	1	00	1	62	1		

‡ This is taken from Runge's number for the wave-length, omitting the fraction.

"Further Observations on Nova Persei. No. 3." By Sir NORMAN LOCKYER, K.C.B., F.R.S.

Received May 17,—Read June 20 1901.

In the last paper[*] I gave an account of the observations of the Nova made at Kensington between March 5 and March 25 inclusive. The observations are now brought up to midnight of May 7. Between March 25 and the latter date, estimates of the magnitude of the Nova have been made on thirty-three evenings, visual observations of the spectrum on twenty-five evenings, and photographs of the spectrum on six evenings.

The 10-inch refractor with a McClean spectroscope has generally been used for eye observations. The 6-inch prismatic camera has not been available for photographing the spectrum owing to the faintness of the Nova, but photographs have been secured by Dr. Lockyer with the 30-inch reflector on the nights of March 27, April 1 and 12, and by Mr. Fowler on March 26 and April 4. With the 9-inch prismatic reflector the spectrum was photographed by Mr. Hodgson on March 30, April 1 and 4.

Change of Brightness.

Since March 25 the magnitude of the Nova has been undergoing further periodic variations, and although observations have not been made on every night since that date, owing to unfavourable weather, yet sufficient data have been gathered to enable a general idea of the light changes to be obtained, and the few gaps can be filled up later by other observers who experienced clearer skies on these occasions.

The following table is a continuation of the observations for magnitude. Columns (1), (2), and (3) denote the observations made by Dr. Lockyer, Mr. Fowler, and Mr. Butler respectively, and Column (4) includes other estimates made by Mr. Baxandall and Mr. Shaw. The numbers in brackets represent the Greenwich mean time at which the observations (against which they are printed) were made, and refer to the evening hours (P.M.), except where otherwise stated.

Magnitudes of Nova Persei.

	(1)	(2)	(3)	(4)
March 26	4·2 (10.30)	4·2 (10 30)	—	—
,, 27	3·9	4·2	—	4·2 F.E.B.
,, 28	—	5·3	5·3	<5·0 H.S.
,, 30	—	—	4·2	4·2 H.S.
,, 31	4·3	4·3	—	—
April 1	4·4	—	4·4	—
,, 4	4·3 (7.0)	4·4	4·5	—

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[*] Page 230, *suprà*.

Magnitudes of Nova Persei—*continued.*

	(1)	(2)	(3)	(4)
April 5	4·8 (10.0)	4·5	—	—
" 6	5·5 (8.30)	—	—	—
" 7	6·0 (7.30)	5·5	—	—
" 8	4·2 (11.0)	—	—	—
" 9	4·7 (11.30)	4·5	5·0	4·8 F.E.B.
" 10	5·7 (8.45)	—	5·5	—
" 11	5·8	—	5·6 or 7	—
" 12	5·2 (8.45) 4·9 (9.40)	—	5·3	5·0 F.E.B.
" 13	4·6 (11.30)	—	4·2 (8.0)	—
" 14	5·4 (9.30)	—	5·5	—
" 15	6·0 or fainter (8.0) 5·8 or 9 (10.30)	—	6·0	—
" 16	5·5 (11.0)	—	—	—
" 17	5·2 (8.30)	—	5·1 (8.30)	—
" 18	4·2 (9.0)	4·2	4·2	4·3 H.S.
" 19	5·2 (8.0)	—	—	—
" 20	5·9 or 6·0 (8.30)	<5·5 (8.25)	5·6 (8.30)	—
" 21	6·1 (9.0)	—	6·0 or 1 (9.0)	—
" 22	5·7 (9.0)	—	—	—
" 24	<5·5 (8.30)	—	—	—
" 25	5·7 or 8 (8.15)	5·7	5·6 (9.0)	—
" 26	5·6 (9.0)	5·5 (9.0)	5·5 (9.0)	—
" 27	4·4 (9.15)	—	4·5 (8.0)	4·4 H.S.
" 30	<5·6 (9.15)	5·8 (9.40)	—	—
May 3	5·7 (9.0)	—	—	—
" 4	6·0 (2.15 A.M.)	5·8	5·8	—
" 5	—	—	5·6	—

It is interesting to note that the length of the period of variability, reckoning from maximum to maximum, began after March 27 to increase from *three* days to *four* days.

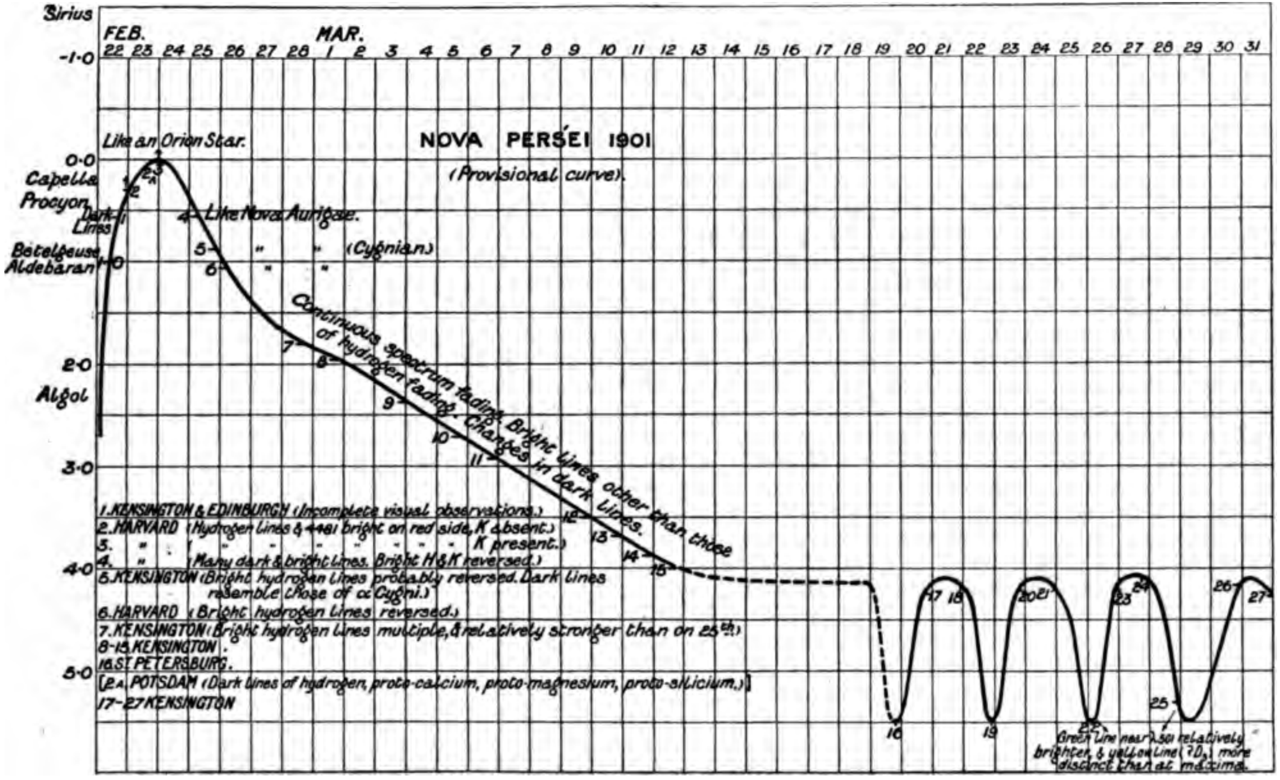
The two following maxima, after that of April 8, occurred on the 13th and 18th, so that the period became still more lengthened, namely, to about *five* days. Further observations up to May 5 seem to indicate that the five-day period is shortening.

Another interesting observed fact was that the light of the Nova at the minimum on the 25th was more intense than at the preceding minimum on the 21st, the estimated difference of magnitude at these times being about 4-tenths of a magnitude. Unfortunately the increasing twilight and the unfavourable position of the Nova make it very difficult now to determine the magnitudes correctly.

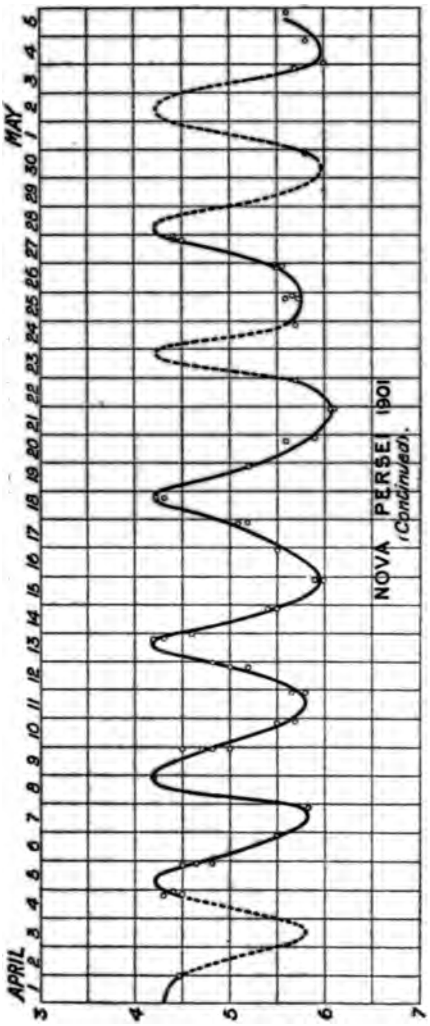
The two plates accompanying this paper illustrate graphically the various fluctuations of the light of the Nova from February 22, when it had not quite attained its maximum brilliancy, to May 5.

The curve is drawn to satisfy as far as possible all the observations made at Kensington. The dotted portions represent the possible light-curve for those times when no estimates for magnitude could be secured.

In the plates the abscissæ represent the time element and the ordinates that of magnitude.


NOVA PERSEI 1901
(Provisional curve).
FEB.
22 23 24 25 26 27 28
MAR.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Sirius
-1·0
0·0
Capella
Procyon
Dark Lines
Betelgeuse
Aldebaran
2·0
Algol
3·0
4·0
5·0
Like an Orion Star.
Like Nova Aurigae.
" " (Cygnian)
Continuous spectrum fading. Bright lines other than those of hydrogen fading. Changes in dark lines.
1 2 2A 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
1. KENSINGTON & EDINBURGH (Incomplete visual observations.)
2. HARVARD (Hydrogen lines & 4481 bright on red side, K absent.)
3. " (" " " " " " K present.)
4. " (Many dark & bright lines. Bright H & K reversed.)
5. KENSINGTON (Bright hydrogen lines probably reversed. Dark lines resemble those of α Cygni.)
6. HARVARD (Bright hydrogen lines reversed.)
7. KENSINGTON (Bright hydrogen lines multiple, & relatively stronger than on 25th.)
8-15. KENSINGTON.
16. ST. PETERSBURG.
[2A. POTSDAM (Dark lines of hydrogen, proto-calcium, proto-magnesium, proto-silicium.)]
17-27 KENSINGTON
Green line near λ501 relatively brighter, & yellow line (? D3) more distinct than at maxima.

[redacted]



Colour.

In the first part of the period covered by the later observations, the colour of the Nova has been generally described as yellowish-red, red with a yellow tinge, and yellow with a reddish tinge. Since April 25 the colour has been perhaps more red than formerly, and sometimes noted as very red.

It is interesting to remark that the colour varies periodically with the change in magnitude. At maximum it is of a distinct yellowish-red hue, but at or near minimum the yellowish tinge disappears and the Nova appears very red.

The Visual Spectrum.

In the continued observations the C and F lines of hydrogen have always been recorded as "conspicuous," other prominent lines being near λ 447, λ 465, and λ 501 (the last named being sometimes as bright as F or even brighter), and a line in the yellow which recent measures show to be D_3.

The strong lines in the green at λλ 4924, 5019, 5169, and 5317, which occurred in the earlier photographs, and which were ascribed to iron, are either absent from the later photographs or appear only as very weak lines.

It has been noted that the lines 447, 501, and D_3 appear to vary with the magnitude of the star, becoming relatively more prominent towards a minimum.

The continuous spectrum has been described throughout as "weak" or "very weak."

On the evening of April 25, Messrs. Fowler and Butler made comparisons of the Nova spectrum with the spectra of hydrogen, helium, and that furnished by an air spark between poles of iron and zinc. For this purpose a Hilger two-prism star spectroscope was used with the 10-inch refractor. The hydrogen line F and the helium line D_3 were found to be sensibly coincident with Nova lines. The middle of the strong green line, previously mentioned as λ 501, practically coincided with the nitrogen line 5005·7, and therefore there is little doubt that it is identical with the chief nebular line λ 5007·6. This line was also compared with the asterium line at λ 5015·7, but was found to be decidedly non-coincident with it, though of sufficient breadth to nearly reach it.

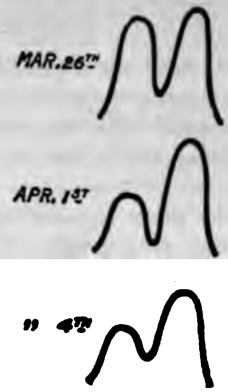
Photographic Spectrum.

In so far as the number and positions of the lines are concerned, the few photographs available for discussion were obtained in the early part of the period dealt with in the present paper (March 26 to May 7), and show a spectrum very similar to that of March 25, which was described in detail in the last paper. The chief lines shown in the photographs are $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$, and $H\xi$, together with 4471 and 4650.

Characteristics of $H\beta$.

In continuation of the series of light curves of $H\beta$ reproduced in the last paper, I give those plotted by Mr. Baxandall from the later photographs.

It will be seen that the line $H\beta$ still shows two maxima of intensity. As recorded in the previous paper, the less refrangible component gave



LIGHT CURVE OF H_β
(30-inch reflector).

indications of becoming brighter than the more refrangible member. These further photographs indicate that by April 4 the less refrangible had become twice as intense.

"Total Eclipse of the Sun, May 28, 1900.—Account of the Observations made by the Solar Physics Observatory Eclipse Expedition and the Officers and Men of H.M.S. 'Theseus' at Santa Pola, Spain." By Sir NORMAN LOCKYER, K.C.B., F.R.S., Received May 21,—Read June 20, 1901.

(Abstract.)

The Report gives details as to the erection of coronagraphs, prismatic cameras, and other instruments, and of the results obtained by their use during the eclipse, which was observed under very favourable circumstances. Some of the more obvious results have already been stated in a Preliminary Report,* and the following remarks may now be added.

A comparison of the photographs taken with the coronagraph of 16 feet focus with those taken about two hours earlier in America indicates that while some of the prominences changed greatly in appearance in the interval, no changes were detected in the details of the corona.

The spectrum of the chromosphere, as photographed with the prismatic cameras, so greatly resembles that of 1898 that it has not been considered necessary to make a complete reduction of wave-

* 'Roy. Soc. Proc.,' vol. 67, p. 341.

lengths. The prominences visible during totality had comparatively simple spectra, the greatest number of lines recorded being 36.

The heights above the photosphere to which many of the vapours can be traced in the photographs are tabulated and compared with the results obtained in 1898; the two sets of figures are sufficiently accordant, except in the case of the shorter arcs, the value 475 miles derived for the lowest measurable vapours in 1898 being represented in 1900 by two strata, one reaching to 700 miles and the other to 270 miles above the photosphere.

The bright-line spectrum of the corona was decidedly less bright than in 1898, and a much smaller number of rings is seen in the photographs. The three brightest rings are at wave-lengths 5303·7, 4231·3, and 3987·0, and it may be noted that these were also the brightest in the eclipses of 1893, 1896, and 1898. The conclusion that the different rings do not originate in the same gas, arrived at from a discussion of the photographs of 1898, has been confirmed.

A drawing is given to illustrate the fact that while the details of the green coronal ring are seen in the inner corona, they have no apparent relation to the positions of the great streamers or prominences. For an investigation of this nature the photographs taken with the prismatic camera of 20 feet focal length are specially valuable.

"Preliminary Statement on the Prothalli of *Ophioglossum pendulum* (L.), *Helminthostachys zeylanica* (Hook), and *Psilotum*, sp."

By WILLIAM H. LANG, M.B., D.Sc., Lecturer in Botany, Queen Margaret College, University of Glasgow. Communicated by Professor F. O. BOWER, Sc.D., F.R.S.

Received May 20,—Read May 23, 1901.

During a recent visit to Ceylon and the Malay Peninsula[*] the author found prothalli of *Ophioglossum pendulum* and *Helminthostachys zeylanica*, as well as a single specimen, which there is reason to regard as the prothallus of *Psilotum*. As the examination of the material will occupy a considerable time, it has seemed advisable to give a brief description of the mode of occurrence and external morphology of the prothallus in these three plants, without entering into details of structure or discussing the phylogenetic bearing of the facts.

The chief gaps in our present knowledge of the gametophytes of the more isolated living *Pteridophyta* concern the *Ophioglossaceæ* and *Lycopodiaceæ*, to which groups the prothalli described below belong. The

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[*] The expenses of the visit to the Malay Peninsula were defrayed by a grant from the Royal Society.

prothallus of *Ophioglossum pedunculosum*[*] was described by Mettenius in 1856. It was subterranean, consisting of a small tuber, from which an erect cylindrical body proceeded. On the latter, which in some instances was observed to reach the surface and turn green, the sexual organs were borne. The first divisions in the germinating spore of *O. pendulum*[†] are described and figured by Campbell. The prothalli of two species of *Botrychium* are known, both of which are subterranean. That of *B. virginianum*[‡] is thick and flattened, and in its structure and in the localisation of the sexual organs on the upper surface clearly dorsiventral. The prothalli of *B. Lunaria*,[§] however, have sexual organs on all sides. In the *Lycopodiaceæ* the prothallus is well known in the heterosporous forms and in *Lycopodium*. The sexual generation is entirely unknown in the *Psilotaceæ* and in *Phylloglossum*. If the author is correct in attributing the prothallus to be described below to *Psilotum*, the only two isolated genera of existing Vascular Cryptogams in which the gametophyte is entirely unknown are *Tmesipteris* and *Phylloglossum*.


FIG. 1.


FIG. 2.


FIG. 3.

Fig. 1. *Ophioglossum pendulum*, old prothallus from above. (× 7.)

Fig. 2. *Helminthostachys zeylanica*, prothallus, bearing antheridia, from the side. (× 7.)

Fig. 3. *Psilotum*, sp., prothallus from the side and slightly from above. (× 7.)

Ophioglossum pendulum.

The sporophyte of this plant was, for the most part, found growing on the humus collected by such epiphytic ferns as *Polypodium quercifolium* and *Asplenium nidus*. A large mass of the former, with the *Ophioglossum* growing upon it, was collected in the Barrawa Forest

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[*] 'Filices Horti Bot. Lipsiensis,' Leipzig, 1856, p. 119.

[†] 'Mosses and Ferns,' London, 1895, p. 224.

[‡] Jeffrey, 'Trans. Canadian Institute,' 1896–7, p. 265.

[§] Hofmeister, 'Higher Cryptogamia,' London, 1862, p. 307.

Reserve,* near to Hanwella, in Ceylon. On the humus contained in this being carefully examined prothalli of various ages were found. They were distributed throughout the humus, the majority being found near the bottom of this, often embedded among the ramenta which clothe the rhizome.

The very young prothalli are button-shaped, the slightly conical lower part expanding above. The basal region is brownish, the surface of the upper portion a uniform dull white. The latter tint is due to the close covering of paraphyses, which, at this age, extends uninterruptedly from just above the base over the whole surface of the prothallus. The youngest prothalli are thus clearly radially symmetrical. In slightly older prothalli, seen from above, the circular outline is lost, owing to the more active growth of two or three points on the margin. This continues, and there thus arise a corresponding number of cylindrical branches, the prothallus becoming irregularly star-shaped. At first the branches spread out in a horizontal plane, though with a slight upward tendency. But when the branches themselves subdivide all suggestion of this secondary dorsiventrality is lost, and the larger prothalli consist of branches radiating in all directions into the humus (fig. 1).

From a short distance behind the smooth, bluntly conical apex the surface of the branch is covered with short, wide, unicellular paraphyses analogous to those known in prothalli of *Lycopodium Phlegmaria.* These are only absent above the sexual organs.

The prothalli are monœcious, antheridia and archegonia being found close together on the same branch. The surface projects very slightly above the large sunken antheridium; the neck of the archegonium, which, as seen from above, is composed of four rows of cells, hardly projects from the prothallus. The sexual organs thus resemble those of *O. pedunculosum*, as described by Mettenius.

Rhizoids have not been seen on any of the numerous prothalli examined. An endophytic fungus occupies a middle zone of tissue in all the branches, the superficial layers and a central core of cells being free from it.

Helminthostachys zeylanica.

The prothalli of this plant were also found in the Barrawa Forest Reserve, a low-lying jungle subject to frequent floods. Young plants still attached to the prothallus were fairly abundant in certain spots, and, by searching in the rotting leaf mould around, prothalli of various ages were obtained. The prothalli were found at a depth of about 2 inches.

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* I am indebted to my friend Mr. F. Lewis, who guided me to this locality, for the assistance he afforded me in my search for the prothallus of *Ophioglossum* and *Helminthostachys.*

The youngest prothallus obtained was a short cylindrical body a little over one-sixteenth of an inch in length. The lower end was darker in tint and bore a number of short rhizoids, while above this, where the antheridia were situated, the surface was of a lighter colour. The apex itself was bluntly conical and almost white. In slightly larger prothalli the contrast between these two regions was more strongly marked. The lower, vegetative region increases in size and becomes lobed, while the antheridia are confined to the cylindrical upper portion, which continues to increase in length. This latter region appears to be longer and the lobed basal part relatively less developed in prothalli which bear the antheridia (fig. 2). Seven of the young prothalli found were male; the other two bore archegonia only. These female prothalli were stouter and more lobed than the male ones, and the diameter of the short apical region, on the surface of which the archegonia were situated, was almost the same as that of the vegetative region. There thus appears to be a partial sexual differentiation in the prothalli of *Helminthostachys*, but both antheridia and archegonia may occur on the same prothallus, as some of the latter attached to young plants have shown. The antheridia are large and often closely crowded together. They hardly project from the surface, the wall being only slightly convex. The archegonial neck, which is formed of four rows of cells, projects distinctly from the prothallus.

The distinction made above between a vegetative and a reproductive region in this prothallus is supported by the distribution of the endophytic fungus. This is entirely absent from the reproductive region, but in the basal part occupies a wide zone between the two or three superficial layers of cells and the central tissue, which are free from the fungus.

The young plants attain a considerable size while still attached to the prothallus. Plants with three leaves and as many roots have been seen, the prothallus of which showed no sign of decay. The first leaf is ternate and has a leaf-stalk of variable length. The lamina is green and reaches the light. A single root corresponds to each of the early leaves.

Examination of the prothalli connected with young plants indicates the position they occupied in the soil. Most commonly the long axis of the prothallus was vertical; sometimes, however, it was oblique, and occasionally horizontal.

Psilotum, sp.

The prothallus of this plant was looked for without success in Ceylon, both in the mountain region and on the roots at the base of *Cocos* palms near the coast. In the localities visited on the west coast of the Malay Peninsula *Psilotum* was not abundant. On Maxwell's

Hill, in Perak, I found it scantily on stems of tree-ferns, the rhizome growing among the roots of the fern, which cover the stem. No young plants were found; but a single prothallus, embedded among the roots of the fern in close proximity to a plant of *Psilotum*, was obtained. This prothallus, as will be evident from fig. 3 and the description below, could only belong to *Psilotum*, or be that of some species of *Lycopodium*, the gametophyte of which has not been described. From the position in which it was found, the former supposition is the more probable one, but such evidence of association is of course not conclusive, *and the specimen can only be described as the prothallus of* Psilotum *with the reservation expressed above.*

The prothallus when fresh measured about one-quarter of an inch in length by about three-sixteenths of an inch at the widest part, which, as fig. 3 shows, is above. The lower portion is cylindrical and rounded below. To one side near the lower end is a well-marked conical projection directed obliquely downwards, which clearly corresponds to the primary tubercle of the prothallus of *Lycopodium cernuum*. The surface of the lower three-fourths of the prothallus was brown and bore rhizoids. The latter were absent from the upper part, which widens out suddenly, the increase in width being due to the projection of the thick, coarsely lobed margin of the summit of the prothallus. The central region of the summit is smooth and somewhat depressed. The upper portion of the prothallus had a faint green tint when fresh, but no chlorophyll grains could be detected.

In the tissue of the overhanging margin the numerous sunken antheridia occur, closely crowded together. Archegonia have not been observed on external examination.

In its form this prothallus evidently presents resemblances to prothalli of *Lycopodium*. In the lower part it resembles the prothalli of the *Lycopodium cernuum* type, while the appearance of the upper portion suggests a comparison with prothalli of *L. clavatum* or *L. annotinum*. There seems no reason to doubt that the meristem will be found at the junction of the upper and lower regions.

Probably this prothallus was completely embedded among the roots of the fern. As some of the roots had been removed before the prothallus was noticed, this point was not definitely settled; but the general appearance of the upper portion, and the absence of assimilating lobes, makes it probable that the upper surface was not exposed to the light.

That the facts stated above bear on the relationship of the plants to which these prothalli belong will be obvious from the brief description given. The discussion of this will, however, be best deferred until the full account, which is in course of preparation, is completed.

"The Mechanism of the Electric Arc." By (Mrs.) Hertha Ayrton. Communicated by Professor Perry, F.R.S.

Received June 5,—Read June 20, 1901.

(Abstract.)

The object of the paper is to show that, by applying the ordinary laws of resistance, of heating and cooling, and of burning to the arc, considered as a gap in a circuit furnishing its own conductor by the volatilisation of its own material, all its principal phenomena can be accounted for, without the aid of a large back E.M.F., or of a "negative resistance," or of any other unusual attribute.

The Apparent Large Back E.M.F.

It is shown how volatilisation may begin, even without the self-induction to which the starting of an arc, when a circuit is broken, is usually attributed; and it is pointed out that, when the carbons are once separated, all the material in the gap cannot retain its high temperature. The air must cool some of it into carbon *mist* or *fog*, just as the steam issuing from a kettle is cooled into water mist at a short distance from its mouth. The dissimilar action of the poles common to so many electric phenomena displays itself in the arc at this point. Instead of *both* poles volatilising the *positive* pole alone does. It is considered, therefore, that the arc consists of (1) a thin layer of carbon vapour issuing from the end of the positive carbon, (2) a bulb of carbon mist joining this to the negative carbon, and (3) a sheath of burning gases, formed by the burning of the mist, and the hot ends of the carbons, and surrounding both. The vapour appears to be indicated in images of the arc by a sort of gap between the arc and the positive carbon, the mist by a purple bulb, and the gases by a green flame.

The flame is found to be practically insulating, so that nearly the whole of the current flows through the vapour and mist alone. It is suggested that the vapour has a high specific resistance compared with that of the mist, and that it is to the great resistance of this vapour-film that the high temperature of the crater is due, and not to any large back E.M.F. of which it is the seat.

Volatilisation can only take place at the surface of contact between the vapour film and the positive carbon. When that surface is smaller than the cross-section of the end of the carbon, it must dig down into the solid carbon and make a pit. The sides of the pit, however, must be hot enough to burn away where the air reaches them, hence there is a race between the volatilisation of the centre of the carbon and the burning of its sides that determines the shape of the carbon. When the arc is short, the air cannot get so easily to the sides of the pit, hence it remains concave. When the arc is long, the burning of the sides gains over the volatilisation of the centre, and the surface of volatilisation becomes flat, or even slightly convex.

The peculiar shaping of the negative carbon is shown to be due to its tip being protected from the air by the mist, and its sides being burnt away under the double action of radiation from the vapour film and conduction from the mist, to a greater or less distance, according to the length of the arc and the cross-section of the vapour film.

It is shown that if the crater be defined as being that part of the positive carbon that is far brighter than the rest, then the crater must be larger, with the same current, the longer the arc, although the area of the volatilising surface is *constant* for a constant current.

By considering how the cross-section of the vapour film must vary with the current and the length of the arc, it is found that its resistance f, must be given by the formula

$$f = \frac{h}{A} + \frac{k + ml}{A^2},$$

where h, k, and m are constants, l is the length of the arc, and A the current. This is the same form as was found by measuring the P.D. between the positive carbon and the arc by means of an exploring carbon, and dividing the results by the corresponding currents. Hence the existence of a thin film of high-resisting vapour in contact with the crater would not only cause a large fall of potential between the positive carbon and the arc, exactly as if the crater were the seat of a large back E.M.F., but it would cause that P.D. to vary with the current and the length of the arc exactly as it has been found to vary by actual measurement.

The Apparent "Negative Resistance."

As nearly all the current flows through the vapour and mist, the surrounding flame being practically an insulator, the resistance of a solid carbon arc, apart from that of the vapour, must depend entirely on the cross-section of the mist. To see how this varies with the current, images of an arc of 2 mm. were drawn, with the purple part—the mist—very carefully defined, for currents of 4, 6, 8, 10, 12, and 14 amperes. The mean cross-section of the mist was found to increase more rapidly than the current, consequently its resistance diminishes more rapidly than the current increases. As the formula for the resistance of the vapour film shows that it too diminishes faster than the current increases, it follows that the whole resistance of the arc does the same, and that consequently the P.D. must diminish as the current increases. Hence if δV and δA be corresponding increments of

[redacted]

P.D. and current $\delta V/\delta A$ must be negative, although the resistance of the arc is positive.

It is found, from the above measurements of the cross-sections of the mist, that the connection between m, the resistance of the mist, and the current, is of the form,

$$m = \frac{\alpha}{A} + \frac{\beta}{A^2}.$$

If m varies directly with the length of the arc, then

$$m = \left(\frac{\alpha}{A} + \frac{\beta}{A^2}\right) l.$$

Adding this equation to (1), we get

$$f + m = r = \frac{p+ql}{A} + \frac{s+tl}{A^2}$$

for the whole resistance of the arc, which is exactly the form that was found by dividing direct measurements of the P.D. between the carbons by the corresponding currents. Hence there is no reason why this ratio should not represent the *true* resistance of the arc.

Under what circumstances $\delta V/\delta A$ measures the True Resistance of the Arc.

When the current is changed it takes some time for the vapour film to alter its area to its fullest extent, and still more time for the carbon ends to change their shapes. All the time these changes are going on the resistance of the arc, and, consequently, the P.D. between the carbons, must be altering also. Both these, therefore, depend not only on the current and the length of the arc, but also, till everything has become steady again, *i.e.*, till the arc is "normal" again, on how lately a change has been made in either. At the first instant after a change of current, before the volatilising area has had time to alter at all, δV and δA must have the same sign, just as they would if the arc were a wire, but as the volatilising surface alters, the sign of δV changes. If, therefore, a small alternating current is applied to the direct current of an arc, it will depend on the frequency of that current whether $\delta V/\delta A$ is positive or negative. When the frequency is so high that the volatilising surface never changes at all, $\delta V/\delta A$ will measure the true resistance of the arc, unless it has a back E.M.F. which varies with the alternating current.

The measurements of the true resistance of the arc made in this way by various experimenters have given very various results, because probably the frequency of the alternating currents employed has been too low not to alter the resistance of the arc. A curve is drawn showing how the value of $\delta V/\delta A$ with the same direct current and length of arc varies with the frequency of the alternating current, and it is pointed out that even if the arc has as large a back E.M.F. as is usually supposed, the *true* resistance cannot be measured with an alternating current of lower frequency than 7000 complete alternations per second.

The exact conditions under which the *true* resistance of the arc can be measured in this way are examined, and the precautions that it is necessary to take to ensure the fulfilment of these conditions are enumerated.

The Changes introduced into the Resistance of the Arc by the Use of Cored Carbons.

A core in either or both carbons has a great effect on both the P.D. between the carbons and the *change* of P.D. that accompanies a given *change* current. It lowers the first, and makes the second more positive, *i.e.*, gives it a smaller negative or larger positive value, as the case may be. It is pointed out that this might be due to the influence of cores either on the cross-section of the arc, or on its specific resistance, or on both.

To see the effect on the cross-section, enlarged images were drawn of 2 mm. arcs with currents increasing by 2 amperes from 2 to 14 amperes, between four pairs of carbons, + solid − solid, + solid − cored, + cored − solid, + cored − cored. Two sets of images were drawn with each pair of carbons—the one immediately after a change of current, to get the "non-normal" change, and the other after the arc had become normal again. The mean cross-section of the mist was calculated in each case, and its cross-section where it touched the crater was taken to be a rough measure of the cross-section of the vapour film.

It was found that the mean cross-section of the mist with a given current was largest when both carbons were solid, less when the negative carbon alone was cored, less still when the positive alone was cored, and least when both were cored. Coring either the positive carbon alone, or both carbons, had the same effect on the cross-section of the vapour film as on that of the mist, but coring the negative alone only diminished this cross-section immediately after a change of current, but not when the arc had become normal again. Hence it was deduced that if the cores altered the *cross-sections* of the arc only they would *increase* its resistance, and, consequently, the P.D. between the carbons. As they *lower* this, however, they must do it by lowering the specific resistance of the arc more than they increase its cross-section. The vapour and mist of the core must therefore have lower specific resistances than the vapour and mist of the solid carbon.

When it is the positive carbon that is cored, all the vapour and mist

[redacted]

come from the *cored* carbon. When the negative, they come from the *uncored* carbon, and it is only because the metallic salts in the core have a lower temperature of volatilisation than carbon that the mist is able to volatilise these and so lower its own specific resistance.

The effect of a core in either carbon, or in both, must depend on the current, because the larger the current the more solid carbon will the volatilising surface cover, and the less therefore will the specific resistances of the mist and vapour be lowered. The way in which the core acts in each case is traced, and the alterations in the specific resistances and cross-sections due to the core are shown to bring about changes in the P.D. exactly similar to those found by actual measurements of the P.D. between the carbons. It is shown, for instance, how these changes entirely account for the fact established by Professor Ayrton* that, with a constant length of arc, while the P.D. diminishes continuously as the current increases, when both carbons are solid, it sometimes remains constant over a wide range of current, or even increases again, after having diminished, when the positive carbon is cored.

The alterations in the value of $\delta V/\delta A$ introduced by the cores are next discussed, and it is shown that the changes in the resistance of the arcs that *must* follow the observed changes in its cross-section, coupled with the alterations that must ensue from the lowering of its specific resistance, would modify $\delta V/\delta A$ just in the way that Messrs. Frith and Rodgers† found that it was modified by direct measurement. Thus all the principal phenomena of the arc, with cored and with solid carbons alike, may be attributable to such variations in the specific resistances of the materials in the gap as it has been shown *must* exist, together with the variations in the cross-sections of the arc that have been observed to take place. Hence it is superfluous to imagine either a large back E.M.F. or a "negative resistance."

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* Electrical Congress at Chicago, 1893.

† "The Resistance of the Electric Arc," 'Phil. Mag.,' 1896, vol. 42, p. 407.

Report of Magnetical Observations at Falmouth Observatory for the Year 1900. Latitude 50° 9′ 0″ N., Longitude 5° 4′ 35″ W.; height, 167 feet above mean sea-level.

The Declination and the Horizontal Force are deduced from hourly readings of the photographic curves, and so are corrected for the diurnal variation.

The results in the following tables, Nos. I, II, III, IV, are deduced from the magnetograph curves, which have been standardised by observations of deflection and vibration. These were made with the Collimator Magnet, marked 66A, and the Declinometer Magnet, marked 66C, in the Unifilar Magnetometer No. 66, by Elliott Brothers, of London. The temperature correction (which is probably very small) has not been applied.

In Table V, H is the mean of the absolute values observed during the month (generally three in number), uncorrected for diurnal variations and for any disturbance. V is the product of H and of the tangent of the Observed Dip (uncorrected likewise for diurnal variation).

In Table VI the Inclination is the mean of the absolute observations, the mean time of which is 3 P.M. The Inclination was observed with the Inclinometer No. 86, by Dover, of Charlton, Kent, and needles 1 and 2, which are 3½ inches in length.

The Declination and the Horizontal Force values given in Tables I to IV are prepared in accordance with the suggestions made in the Fifth Report of the Committee of the British Association on comparing and reducing magnetic observations, and the time given is Greenwich Mean Time, which is 20 minutes 18 seconds earlier than local time.

The following is a list of the days during the year 1900 which were selected by the Astronomer Royal as suitable for the determination of the magnetic diurnal variations, and which have been employed in the preparation of the magnetic tables:—

January ...	3, 8, 9, 30, 31.	February ...	3, 6, 7, 13, 28.
March ...	5, 11, 21, 27, 28.	April... ...	3, 8, 15, 22, 25.
May ...	9, 10, 14, 21, 28.	June... ...	10, 11, 16, 20, 25.
July ...	14, 15, 18, 22, 30.	August ...	6, 9, 10, 23, 30.
September	2, 7, 21, 25, 26.	October ...	2, 7, 13, 19, 31.
November	5, 6, 11, 16, 30.	December	3, 6, 15, 23, 24.

EDWARD KITTO,
Magnetic Observer.

Table I.—Hourly Means of Declination at the Falmout
on Five selected quiet Days

(18° + West.)

Hours	Mid.	1	2	3	4	5	6	7	8	9	10	11
						Winter.						
1900.	′	′	′	′	′	′	′	′	′	′	′	′
an. ..	30·8	30·9	31·2	31·4	31·5	31·3	31·1	30·8	30·4	30·3	30·9	32·0
eb. ..	30·3	30·5	30·5	30·7	30·8	30·5	30·1	29·8	29·9	29·9	30·4	31·2
arch .	29·6	29·7	29·6	29·5	29·3	29·0	28·9	28·3	27·3	26·8	27·6	29·7
ct. ..	27·4	28·0	28·2	27·9	27·9	27·8	27·9	27·6	26·7	26·5	26·7	28·7
ov. ..	25·3	25·6	25·9	26·1	26·0	25·8	25·6	25·2	24·7	24·4	25·5	26·9
ec. ..	26·8	27·1	27·3	27·4	27·4	27·3	27·1	26·9	26·6	26·6	26·9	27·7
Means	28·4	28·6	28·8	28·8	28·8	28·6	28·5	28·1	27·6	27·4	28·0	29·4
						Summer.						
	′	′	′	′	′	′	′	′	′	′	′	′
pril ..	29·2	29·2	29·0	29·0	28·7	28·5	27·9	27·0	26·1	25·8	27·3	30·1
ay ..	29·1	29·2	29·2	28·8	28·4	27·5	26·4	25·7	25·4	26·2	28·0	30·0
une ..	28·6	28·5	28·4	28·4	28·2	27·5	26·4	25·9	25·7	25·9	27·6	30·1
uly ..	28·5	28·7	28·5	28·1	27·8	26·7	25·6	25·7	25·1	25·2	26·1	28·3
ugust.	29·0	29·0	28·8	28·8	28·3	27·9	26·8	25·9	25·6	26·6	29·0	31·3
ept. ..	28·5	28·4	28·5	28·3	28·1	28·0	27·5	26·8	25·8	26·3	28·4	31·3
Means	28·8	28·8	28·7	28·7	28·3	27·7	26·8	26·2	25·6	26·0	27·7	30·2

* Mean of four days—2nd, 7th, 13th, 31st.

Table II.—Diurnal Inequality of the Falmouth

Hours	Mid.	1	2	3	4	5	6	7	8	9	10	11
						Summer mean.						
	′	′	′	′	′	′	′	′	′	′	′	′
	−0·4	−0·4	−0·5	−0·5	−0·9	−1·5	−2·4	−3·0	−3·6	−3·2	−1·5	+1·0
						Winter mean						
	′	′	′	′	′	′	′	′	′	′	′	′
	−0·6	−0·4	−0·2	−0·2	−0·2	−0·4	−0·5	−0·9	−1·4	−1·6	−1·0	+0·4
						Annual mean.						
	′	′	′	′	′	′	′	′	′	′	′	′
	−0·5	−0·4	−0·4	−0·4	−0·6	−1·0	−1·5	−2·0	−2·5	−2·4	−1·3	+0·7

Note.—When the sign is + the magnet points

Observatory, determined from the Magnetograph Curves each Month during 1900.

Noon	1	2	3	4	5	6	7	8	9	10	11	Mid.
						Winter.						
′	′	′	′	′	′	′	′	′	′	′	′	′
33·2	34·0	33·3	32·6	32·1	32·3	31·7	31·1	30·8	30·7	30·8	30·8	30·8
32·5	33·6	33·8	32·6	31·5	31·0	30·7	30·5	30·5	30·1	30·3	30·4	30·7
32·0	33·7	33·8	32·7	31·0	29·7	29·4	29·7	29·7	29·7	29·6	29·6	29·8
31·5	32·8	32·4	31·1	29·4	29·0	28·6	28·4	28·3	27·8	27·8	27·7	28·0
28·0	28·3	27·5	26·4	26·0	25·9	25·6	25·4	25·2	25·1	25·1	25·1	25·4
28·6	28·9	28·6	27·9	27·5	27·1	26·7	26·3	26·3	26·2	26·2	26·1	26·5
31·0	31·9	31·6	30·6	29·6	29·2	28·8	28·6	28·5	28·3	28·3	28·3	28·5
						Summer.						
′	′	′	′	′	′	′	′	′	′	′	′	′
32·5	34·1	34·3	33·0	31·5	30·3	29·7	29·6	29·5	29·4	29·5	29·1	29·0
32·1	33·8	33·6	32·1	30·6	29·6	29·0	28·8	28·8	28·9	29·2	29·2	29·2
33·2	34·2	34·5	33·8	32·6	30·9	29·8	28·9	28·6	28·5	28·3	28·4	28·5
31·7	34·0	34·1	32·6	31·2	30·1	29·2	29·1	29·2	29·0	28·6	28·6	28·8
33·6	34·8	34·0	32·7	30·7	29·4	28·9	29·0	28·9	29·0	29·0	28·9	29·0
34·0	34·6	33·2	31·1	29·4	28·3	28·3	28·8	28·7	28·7	28·7	28·7	28·5
32·9	34·3	34·0	32·6	31·0	29·8	29·2	29·0	29·0	28·9	28·9	28·8	28·8

Declination as deduced from Table I.

Noon	1	2	3	4	5	6	7	8	9	10	11	Mid
						Summer mean.						
′	′	′	′	′	′	′	′	′	′	′	′	′
+3·7	+5·1	+4·8	+3·4	+1·8	+0·6	0·0	−0·2	−0·2	−0·3	−0·3	−0·4	−0·4
						Winter mean.						
	′	′	′	′	′	′	′	′	′	′	′	′
+2·0	+2·9	+2·6	+1·6	+0·6	+0·2	−0·2	−0·4	−0·5	−0·7	−0·7	−0·7	−0·
						Annual mean.						
′	′	′	′	′	′	′	′	′	′	′	′	′
+2·9	+4·0	+3·7	+2·5	+1·2	+0·4	−0·1	−0·3	−0·4	−0·5	−0·5	−0·6	−0·

to the west of its mean position.

Table III.—Hourly Means of the Horizontal Force at Falmout
on Five selected quiet Days i

0·18000 + (C.G.S. units).

Hours	Mid.	1	2	3	4	5	6	7	8	9	10	11
						Winter.						
1900.												
Jan. ..	**671**	**670**	**671**	**671**	**673**	**674**	**676**	**677**	**675**	**669**	**668**	**660**
Feb. ..	**672**	**672**	**672**	**673**	**673**	**674**	**675**	**674**	**673**	**669**	**668**	**662**
March .	**679**	**680**	**679**	**679**	**679**	**679**	**678**	**678**	**675**	**666**	**662**	**657**
***Oct.** ..	**696**	**696**	**694**	**695**	**697**	**698**	**699**	**698**	**695**	**685**	**676**	**672**
Nov. ..	**706**	**706**	**706**	**706**	**707**	**708**	**708**	**707**	**703**	**696**	**692**	**694**
Dec. ..	**701**	**701**	**702**	**703**	**703**	**704**	**704**	**704**	**704**	**703**	**701**	**699**
Means	**688**	**688**	**687**	**688**	**689**	**690**	**690**	**690**	**688**	**681**	**676**	**674**
						Summer.						
April ..	687	686	686	687	686	686	685	686	683	678	**668**	**665**
May ..	687	685	683	683	682	680	676	672	668	666	**666**	**667**
June ..	700	699	697	697	698	698	695	692	687	681	**675**	**673**
July ..	702	701	699	698	698	697	695	693	687	679	**671**	**672**
Aug. ..	701	700	698	698	697	697	693	688	681	673	**674**	**680**
Sept. ..	707	705	704	703	704	702	701	697	691	685	**681**	**681**
Means	697	696	695	694	694	693	691	688	683	677	**673**	**673**

* Mean of four days—2nd, 7th, 13th, 31st.

Table IV.—Diurnal Inequality of the Falmout

Hours	Mid.	1	2	3	4	5	6	7	8	9	10	11
						Summer mean.						
	+ ·00006	+ ·00004	+ ·00003	+ ·00002	+ ·00002	+ ·00001	− ·00001	− ·00004	− ·00009	− ·00015	− ·00019	− ·0001
						Winter mean.						
	+ ·00002	+ ·00002	+ ·00001	+ ·00002	+ ·00003	+ ·00004	+ ·00004	+ ·00004	+ ·00002	− ·00005	− ·00010	− ·0001
						Annual mean.						
	+ ·00004	+ ·00003	+ ·00002	+ ·00002	+ ·00003	+ ·00003	+ ·00002	·00000	− ·00004	− ·00010	− ·00015	− ·0001

Note.—When the sign is + **the readin**

Observatory, determined from the Magnetograph Curves each Month during 1900.

Noon	1	2	3	4	5	6	7	8	9	10	11	M
						Winter.						
662	667	671	671	671	670	671	672	674	675	673	673	6
662	664	667	668	669	672	673	673	674	674	674	675	6
662	669	675	679	681	681	681	683	685	684	684	684	6
673	681	688	691	693	695	697	698	699	699	699	699	7
696	699	703	704	705	706	708	708	708	707	705	705	7
699	700	701	703	704	705	705	704	704	703	702	701	7
676	680	684	686	687	688	689	690	691	690	690	690	6
						Summer.						
670	678	687	692	693	691	693	694	695	694	693	692	6
670	673	674	677	680	685	691	694	693	691	691	691	6
678	684	691	700	699	700	704	705	704	703	700	699	6
680	684	689	693	698	698	698	701	702	704	703	703	7
691	697	698	700	700	699	699	704	704	704	703	703	7
688	698	701	702	704	702	704	708	707	707	705	708	7
680	686	690	694	696	696	698	701	701	701	699	699	6

Horizontal Force as deduced from Table III.

Noon	1	2	3	4	5	6	7	8	9	10	11	M
						Summer mean.						
− ·00012	− ·00006	− ·00002	+ ·00002	+ ·00004	+ ·00004	+ ·00006	+ ·00009	+ ·00009	+ ·00009	+ ·00007	+ ·00007	+ ·
						Winter mean.						
− ·00010	− ·00006	− ·00002	·00000	+ ·00001	+ ·00002	+ ·00003	+ ·00004	+ ·00005	+ ·00004	+ ·00004	+ ·00004	+ ·
						Annual mean.						
− ·00011	− ·00006	− ·00002	+ ·00001	+ ·00003	+ ·00003	+ ·00005	+ ·00007	+ ·00007	+ ·00007	+ ·00006	+ ·00006	+ ·

is above the mean.

Table V.—Magnetic Intensity. Absolute Observations.
Falmouth Observatory, 1900.

1900.	C.G.S. measure.	
	H or Horizontal force.	V or Vertical force.
January	0·18665	0·43503
February	0·18660	0·43474
March	0·18661	0·43476
April	0·18676	0·43508
May	0·18677	0·43500
June	0·18682	0·43463
July	0·18686	0·43458
August	0·18681	0·43460
September	0·18696	0·43495
October	0·18683	0·43489
November	0·18696	0·43499
December	0·18696	0·43495
Means	0·18680	0·43485

Table VI.—Magnetic Inclination. Absolute Observations.
Falmouth Observatory, 1900.

Month.		Mean.
January	10	66° 46′·8
	24	66 46·6
	31	66 46·7
		66 46·7
February	10	66 45·9
	21	66 46·6
	28	66 46·0
		66 46·2
March	10	66 46·6
	21	66 46·6
	30	66 45·5
		66 46·2
April	10	66 47·0
	20	66 45·8
	28	66 45·5
		66 46·1
May	10	66 47·2
	21	66 45·7
	30	66 44·4
		66 45·8
June	11	66 44·8
	20	66 43·6
	29	66 44·9
		66 44·4
July	10	66° 43′ 7
	20	66 44·4
	30	66 43·9
		66 44·0
August	12	66 43·9
	26	66 44·3
	31	66 45·0
		66 44·4
September	13	66 44·4
	19	66 44·3
		66 44·4
October	8	66 44·3
	20	66 44·9
	22	66 45·0
	30	66 46·3
		66 45·1
November	10	66 45·7
	21	66 43·9
	29	66 43·8
		66 44·5
December	11	66 43·5
	19	66 45·9
	31	66 43·7
		66 44·4

THE NATIONAL PHYSICAL LABORATORY.

Report on the Observatory Department for the Year ending December 31, 1900.

The work at the Kew Observatory in the Old Deer Park at Richmond, now forming the Observatory Department of the National Physical Laboratory, has been continued during the year 1900 as in the past.

This work may be considered under the following heads:—

I. Magnetic observations.
II. Meteorological observations.
III. Seismological observations.
IV. Experiments and Researches in connexion with any of the departments.
V. Verification of instruments.
VI. Rating of Watches and Chronometers.
VII. Miscellaneous.

I. MAGNETIC OBSERVATIONS.

The Magnetographs have been in constant operation throughout the year, and the usual determinations of the Scale Values were made in January.

The ordinates of the various photographic curves representing Declination, Horizontal Force, and Vertical Force were then found to be as follows:—

Declinometer: 1 cm. = 0° 8′·7.
Bifilar, January, 1900, for 1 cm. δH = 0·00051 C.G.S. unit.
Balance, January, 1900, for 1 cm. δV = 0·00049 C.G.S. unit.

The distance between the dots of light upon the vertical force cylinder having become too small for satisfactory registration, the dots were separated on June 20 by slightly altering the position of the zero mirror.

The curves have been quite free from any large fluctuations; indeed, no unusual disturbance has been registered for some time past. The principal variations that were recorded during the year took place on the following days:—

January 19th–20th; March 8th–9th and 13th; May 5th.

The hourly means and diurnal inequalities of the magnetic elements for 1900, for the quiet days selected by the Astronomer Royal, will be found in Appendix I.

A correction has been applied for the diurnal variation of temperature, use being made of the records from a Richard thermograph as well as of the eye observations of a thermometer placed under the Vertical Force shade.

The mean values at the noons preceding and succeeding the selected quiet days are also given, but these of course are not employed in calculating the daily means or inequalities.

The following are the mean results for the entire year:—

Mean Westerly Declination…………	16° 52′·7
Mean Horizontal Force ……………	0·18428 C.G.S. unit.
Mean Inclination ……………………	67° 11′·8
Mean Vertical Force…………………	0·43831 C.G.S. unit.

Observations of absolute declination, horizontal intensity, and inclination have been made weekly as a rule.

A table of recent values of the magnetic elements at the Observatories whose publications are received at Kew will be found in Appendix IA to the present Report.

A course of magnetic instruction was given to Captain Denholm Fraser, R.E., charged with a magnetic survey of India, and facilities were afforded him for making experiments with a view to improving the instrumental outfit for the survey.

A new magnetic hut was erected early in the year by Mr. Eldridge. It is larger and better lighted than the old hut, and has proved very useful.

II. METEOROLOGICAL OBSERVATIONS.

The several self-recording instruments for the continuous registration of Atmospheric Pressure, Temperature of Air and Wet-bulb, Wind (direction, pressure and velocity), Bright Sunshine, and Rain have been maintained in regular operation throughout the year, and the standard eye observations for the control of the automatic records have been duly registered.

The tabulations of the meteorological traces have been regularly made, and these, as well as copies of the eye observations, with notes of weather, cloud, and sunshine, have been transmitted, as usual, to the Meteorological Office.

With the sanction of the Meteorological Council, data have been supplied to the Council of the Royal Meteorological Society, the Institute of Mining Engineers, and the editor of 'Symons' Monthly Meteorological Magazine.' On the initiative of the Meteorological Office, some special cloud observations have been made in connection with the International scheme of balloon ascents.

Electrograph.—This instrument worked generally in a satisfactory manner during the year.

The small glass beaker mentioned in last year's Report is still employed, and by removing the sulphuric acid at regular periods—generally fourteen or fifteen days—the troubles previously experienced with the "setting" of the needle and with the shift of zero has been largely overcome.

No systematic use has been made of the thirty-six Clark cells mentioned in the 1898 Report, but they have been employed to check the scale values of the two portable electrometers.

Scale-value determinations of the electrograph were made on April 2, July 14, and October 25, and the potential of the battery has been tested weekly. Forty cells only have been employed during the year, giving about 30 volts.

With a view to promoting uniformity in procedure, the Superintendent, at the suggestion of the Meteorological Office, had an interview with Mr. C. T. R. Wilson, F.R.S., and Mr. W. Nash, of Greenwich Observatory, who were shown the electrograph arrangements and the means adopted for standardising the curves. The stoppage this entailed in the working of the instrument was utilised in giving it a thorough cleaning. A new bifilar suspension was also fitted to the needle, and the wire leading from the can to the electrometer was bedded in paraffin wax in hopes of improving the insulation.

Inspections.—In compliance with the request of the Meteorological Council, the following Observatories and Anemograph Stations have been visited and inspected:—North Shields, Glasgow, Aberdeen, Alnwick Castle, Deerness (Orkney), Falmouth, and Fort William, by Mr. Baker; and Radcliffe Observatory (Oxford), Stonyhurst, Fleetwood, Armagh, Dublin, Valencia, and Yarmouth, by Mr. Constable.

III. SEISMOLOGICAL OBSERVATIONS.

Professor Milne's "unfelt tremor" pattern of seismograph has been maintained in regular operation throughout the year; particulars of the time of occurrence and the amplitude in seconds of arc of the largest movements are given in Table I, Appendix III.

The "disturbance" on January 20 was particularly noticeable.

The movement was the largest that has yet been fully recorded at the Observatory, the maximum amplitude being 15 mm., or 12·6 seconds of arc. The next largest disturbance was on October 29, with a maximum of 12 mm., or 9·5 seconds of arc.

The action of the boom was not altogether satisfactory during August and September, and on September 27 the old boom was replaced by a new one of standard pattern. The balance weights are at 117 mm. and the tie at 127 mm. from the cup end of the boom.

The point of the bearing pivot on the stand was also improved.

A detailed list of the movements recorded from January 1 to December 31, 1900, was made and sent to Professor Milne, and will be found in the 'Report' of the British Association for 1901, "Seismological Investigations Committee's Report."

During October a Milne seismograph, No. 31, intended to be set up at the University Observatory, Coimbra, was fitted up in the seismograph room, at the same height and in the same N.—S. direction as the Kew Instrument, and a series of comparisons were carried out till the end of the year. Several interesting features were noticed, and the results have been embodied in a paper by the Superintendent.

IV. EXPERIMENTAL WORK.

Fog and Mist.—The observations of a series of distant objects, referred to in previous 'Reports,' have been continued. A note is taken of the most distant of the selected objects which is visible at each observation hour.

Atmospheric Electricity.—The comparisons of the potential, at the point where the jet from the water-dropper breaks up, and at a fixed station on the Observatory lawn, referred to in last year's 'Report,' have been continued, and the observations have been taken since March on every day when possible, excluding Sundays and wet days. The ratios of the "curve" and the "fixed station" readings have been computed for each observation, and these have thrown considerable light upon the action of the self-recording electrometer, especially with reference to its insulation. Some direct experiments have also been made on this point.

The reservoir holding the supply of water for the water-dropper of the self-recording electrometer is supported upon six large "Mascart" insulators, and it was thought that perhaps this system of insulating the tank could be improved upon.

A quantity of fine paraffin wax, with a high melting point, was procured from Price's Candle Company, Limited, in rectangular blocks, and a number of cylinders of sulphur were cast at the Observatory. Three similar water tanks were supported upon three wax blocks, three sulphur blocks, and three Mascart insulators respectively. Each received a similar definite charge, and the rate of loss of charge was observed.

The observations—which are to be regarded only as preliminary—extended through May, June, and July, under various hygrometric conditions. The sulphur and paraffin when new and clean gave much the best values, but after the lapse of a few weeks the rate of loss became very similar for all three species of insulator. The deterioration was apparently due to accumulation of dust, &c. The provision of a hood or cover to the sulphur and paraffin blocks would undoubtedly improve the permanency of their insulating qualities.

Platinum Thermometry.—The paper by the Superintendent, referred to in last year's Report, has been published in the Royal Society's 'Proceedings,' vol. 67, p. 3.

V. VERIFICATION OF INSTRUMENTS.

The subjoined is a list of the instruments examined in the year 1900, compared with a corresponding return for 1899 :—

	Number tested in the year ending December 31.	
	1899.	1900.
Air-meters	6	9
Anemometers	23	1
Aneroids	175	197
Artificial horizons	9	27
Barometers, Marine	92	139
„ Standard	85	57
„ Station	15	23
Binoculars	404	963
Compasses	43	51
Deflectors	6	1
Hydrometers	241	173
Inclinometers	9	17
Photographic Lenses	160	136
Magnets	3	1
Telescopes	561	1,345
Rain Gauges	19	4
Rain-measuring Glasses	44	29
Scales	—	1
Sextants	876	813
Sunshine Recorders	6	3
Theodolites	24	12
Thermometers, Avitreous or Immisch's	5	—
„ Clinical	16,020	20,476
„ Deep sea	19	83
„ High Range	62	40
„ Hypsometric	39	66
„ Low Range	103	33
„ Meteorological	2,892	2,786
„ Solar radiation	—	2
„ Standard	104	61
Unifilars	5	5
Vertical Force Instruments	1	14
Declinometers	—	1
Total	22,051	27,569

Duplicate copies of corrections have been supplied in 56 cases.

The number of instruments rejected in 1899 and 1900 on account of excessive error, or for other reasons, was as follows :—

	1899.	1900.
Thermometers, clinical	149	116
" ordinary meteorological	78	79
Sextants	151	122
Telescopes	49	116
Binoculars	21	31
Various	14	28

Four Standard Thermometers have been constructed during the year.

There were at the end of the year in the Observatory, undergoing verification, 16 Barometers, 285 Thermometers, 15 Sextants, 250 Telescopes, 30 Binoculars, 2 Hydrometers, 4 Rain Measures, 2 Rain Gauges, and 4 Unifilar Magnetometers.

VI. RATING OF WATCHES AND CHRONOMETERS.

The number of watches sent for trial this year is slightly less than in 1899, the total entries being 403, as compared with 469 in the preceding year.

The "especially good" class A certificate was obtained by 98 movements.

This is a marked increase on the number obtained in 1899, and the general performance has been decidedly better.

The following figures show the percentage number of watches obtaining the distinction "especially good," as compared to the total number obtaining class A certificates :—

Year	1895.	1896.	1897.	1898.	1899.	1900.
Percentage "especially good"	16·6	30·5	28·0	22·1	26·6	35·4

The percentage is thus higher than in any previous year.

The 403 watches received were entered for trial as below :—

For class A, 320; class B, 60; and 23 for the subsidiary trial. Of these 21 passed the subsidiary test, 55 failed from various causes to gain any certificate, 50 were awarded class B, and 277 class A certificates.

In Appendix II will be found a table giving the results of trial of the 51 watches which gained the highest number of marks during the year. The highest place was taken by Mr. A. E. Fridlander, of Coventry, with the keyless going-barrel Karrusel lever watch, No. 25,582, which obtained 90·1 marks out of a maximum of 100.

This is the first English lever watch to reach the 90 marks limit, and its performance is the best since 1892.

Marine Chronometers.—During the year, 53 chronometers have been entered for the Kew A trial and 1 for the B trial. Of these 44 gained A certificates, 1 a B certificate, and 9 failed.

The mean-time chronometer Arnold 86, and the hack chronometer Molyneux 2123 have been cleaned and re-timed.

VII. MISCELLANEOUS.

Commissions.—The work under this heading has been of a very varied character during the year. The following instruments have been procured, examined, and forwarded to the various Observatories on whose behalf they were purchased:—

For Lisbon and Portuguese W. Africa, a transit theodolite, a declinometer, a dip circle with two needles, a centre-seconds watch, and two chronometers.

For Mauritius, a Mason's hygrometer, an ordinary maximum and two solar maximum thermometers.

For the Central Physical Observatory, St. Petersburg, and the Baron Toll Expedition: A dip circle with six needles, two prismatic compasses, two aneroïd barometers, a Robinson cup anemograph, a chronometer, and a deck watch.

For de Bilt (Utrecht), a vertical force magnet.

Paper.—Prepared photographic paper has been supplied to the Observatories at Hong Kong, Mauritius, Lisbon, Toronto, St. Petersburg, Stonyhurst, Oxford (Radcliffe); and through the Meteorological Office to Aberdeen, Fort William, and Valencia.

Photographic paper has also been sent in quarterly instalments to the India Office for use at Colaba (Bombay), Calcutta, and Madras.

Anemograph and Sunshine Sheets have also been sent to Hong Kong, Mauritius, and St. Petersburg; Papier Saxe to Coimbra; and Seismograph rolls to Mauritius.

Pendulum Observations.—In June, Mr. Putnam, of the U.S. Coast and Geodetic Survey, swung half-second pendulums in the wooden room in the basement.

Library.—During the year the library has received publications from—

19 Scientific Societies and Institutions of Great Britain and Ireland,

96 Foreign and Colonial Scientific Establishments, as well as from several private individuals.

The card catalogue has been proceeded with.

Audit, &c.—The accounts for 1900 have been audited by Messrs. W. B. Keen and Co., chartered accountants. The balance sheet is appended.

PERSONAL ESTABLISHMENT.

The staff employed is as follows:—

R. T. Glazebrook, Sc.D., F.R.S., Director of the Laboratory.
C. Chree, Sc.D., F.R.S., Superintendent of the Observatory Department.
T. W. Baker, Chief Assistant.

E. G. Constable W. Hugo J. Foster T. Gunter W. J. Boxall	Senior Assistants in the Observatory Department.
G. E. Bailey E. Boxall G. Badderly	Junior Assistants.

Eight other Assistants.
A Caretaker and a Housekeeper are also employed.

In addition to the above, Dr. J. A. Harker has been employed in the capacity of an Assistant in the Laboratory.

(Signed) R. T. GLAZEBROOK,
Director.

List of Instruments, Apparatus, &c., the Property of the National Physical Laboratory Committee, at the present date out of the custody of the Director, on Loan.

To whom lent.	Articles.	Date of loan.
Executors of G. J. Symons, F.R.S.	Portable Transit Instrument	1869
The Science and Art Department, South Kensington.	Articles specified in the list in the Annual Report for 1893	1876
Professor W. Grylls Adams, F.R.S.	Unifilar Magnetometer, by Jones, No. 101, complete	1883
	Pair 9-inch Dip Needles with Bar Magnets	1887
Lord Rayleigh, F.R.S.	Standard Barometer (Adie, No. 655)	1885
Mr. P. Baracchi (Melbourne University).	Unifilar Magnetometer, by Jones, marked N.A.B.C., complete	1899
	Dip Circle, by Barrow, with one pair of Needles and Bar Magnets	1899
	Tripod Stand	1899
The Borchgrevink-Newnes Antarctic Expedition.	Dip Circle, by Barrow, No. 24, with four Needles and Bar Magnets	1898
C. T. R. Wilson, F.R.S.	Electrograms for 1897	1899

THE NATIONAL PHYSICAL LABORATORY.

Balance Sheet, 31st December, 1900.

LIABILITIES.	£	s.	d.	£	s.	d.
To Sundry Creditors				215	15	2
„ Treasury Grant—						
Three months received in advance				1,000	0	0
„ Balance, being excess of Assets over Liabilities, viz.:—						
General Account—						
Assets transferred from Kew Committee	2,760	11	4			
Treasury Grant for three months to 31st December, 1899 ..	1,000	0	0			
Excess of Income over Expenditure for the year	1,495	14	3			
	5,256	5	7			
Building Fund Account	5,064	11	0			
Pension Fund Account	405	3	4			
				10,725	19	11
Carried forward				£11,941	15	1

ASSETS.	£	s.	d.	£	s.	d.
By Sundry Debtors—						
For Tests, &c...	684	0	0			
„ Commissions	118	19	3			
„ Rents receivable	3	0	0			
	805	19	3			
Less—Reserve for Discounts	35	13	7			
				770	5	8
„ Meteorological Office—						
Quarter's Allowance due	100	0	0			
Postages due	1	3	11			
				101	3	11
„ Investments—						
General Account—						
£2,025 5*s.* 3*d.* 2¾ per cent. Consolidated Stock at cost	2,000	0	0			
£1,300 India 3½ per cent. Stock at 108½, value on 1st January, 1900..	1,410	10	0			
				3,410	10	0
Carried forward				£4,281	19	7

LIABILITIES.

	£	s.	d.
Brought forward	11,941	15	1
	£11,941	15	1

ASSETS.

	£	s.	d.	£	s.	d.
Brought forward				4,281	19	7
By Investments—*continued*—						
Building Fund Account—						
£5,006 10*s*. 3*d*. 2¾ per cent. Consolidated Stock at cost				5,064	11	0
Pension Fund Account—						
£395 5*s*. 1*d*. 2¾ per cent. Consolidated Stock at cost				400	0	0
„ Cash at Bankers—						
General Account—						
Bank of England (Western Branch)	1,986	15	0			
London and County Bank Revenue Account	110	7	1			
London and County Bank Expenditure Account	71	18	7			
Pension Fund Account—						
Bank of England (Western Branch)	5	3	4			
„ Cash in hands of Clerk	21	0	6			
				2,195	4	6
				£11,941	15	1

Income and Expenditure Account for the Year ended 31st December, 1900.

INCOME.

	£	s.	d.	£	s.	d.
Treasury Grant for Year				4,000	0	0
Fees for Tests	2,661	9	1			
Less—Discounts allowed	111	10	7			
				2,549	18	6
Meteorological Office, Allowance				400	0	0
Dividends on India 3½ Per Cent. Stock, April, July, and October				32	12	3
Gassiot Trust Fund—						
One Year's Interest				454	4	1
Rents Receivable				10	3	0
Charges to Colonial and Foreign Institutions in respect of Commissions.. ..				647	3	0
Donation from Sir Andrew Noble.. ..				200	0	0
Carried forward				£8,294	0	10

EXPENDITURE.

	£	s.	d.	£	s.	d.
Administrative Expenditure—						
Rents, Rates, Gas, and Insurance—						
Rent of Kew Observatory	27	5	0			
Lighting and Heating	73	19	10			
Water..	5	15	0			
Insurance	23	9	3			
				130	9	1
Salaries, Wages, and Allowances—						
Director's Salary	1,300	0	0			
Transfer to Pension Fund	400	0	0			
Salaries and Wages of Staff	2,711	11	0			
Director's Travelling Expenses ..	72	1	10			
Secretarial Services at Committee Meetings, &c.	13	13	0			
				4,497	5	10
General Incidental Expenses—						
General Repairs	26	19	3			
House and Garden Expenses	30	13	11			
Stationery, &c...	44	15	1			
Printing Minutes, Reports, &c. ..	31	14	6			
Miscellaneous	77	2	3			
				211	5	0
Carried forward				£4,838	19	11

INCOME.

	£	s.	d.
Brought forward	8,294	0	10
Carried forward	£8,294	0	10

EXPENDITURE.

	£	s.	d.	£	s.	d.
Brought forward				4,838	19	11
Observatory, Incidental Expenses—						
Photographic Paper and Chemicals ..	42	15	5			
Repairs to Instruments, &c.	5	9	0			
Miscellaneous	7	19	7			
				56	4	0
Tests, Incidental Expenses—						
New Apparatus and Instruments ..	25	13	7			
Repairs to Apparatus and Instruments	3	3	0			
Printing, Books and Stationery	72	16	0			
Rent of Time Signal Wire	21	0	0			
Materials for Tests	21	8	9			
Miscellaneous	50	11	3			
				191	12	7
Laboratory and Workshop Incidental Expenses—						
Materials and Sundries for Laboratory	121	18	4			
" " Workshop	36	17	9			
Miscellaneous	22	12	5			
Repairs	16	12	0			
	198	0	6			
Less received from Liverpool and London and Globe Insurance Company ..	23	10	0			
				174	10	6
Carried forward				£5,264	7	0

	£	s.	d.
Brought forward	8,294	0	10
	£8,294	0	10

	£	s.	d.	£	s.	d.
Brought forward..				5,264	7	0
Purchase of Instruments, &c., for Colonial and Foreign Institutions on Commission				614	17	11
Total Ordinary Expenditure ..				5,879	4	11
Extraordinary Expenditure—						
Building Account.	508	19	4			
Director's Expenses of Removal ..	150	0	0			
Furnishing Director's Office	44	18	6			
Apparatus and Instruments for Laboratory	139	5	8			
Tools for Workshop	75	18	2			
				919	1	8
				6,798	6	7
Balance, being Excess of Income over Expenditure for the year..				1,495	14	3
				£8,294	0	10

Building Fund Account, 31st December, 1900.

£5,006 10*s.* 3*d.* 2¾ per cent. Consolidated Stock.

		£	*s.*	*d.*			£	*s.*	*d.*
	To Treasury Grant applied in purchase of £4,941 5*s.* 5*d.* 2¾ per cent. Consolidated Stock..	5,000	0	0	1900. December 31.	By Balance carried down	5,064	11	0
	,, Dividends on £4,941 5*s.* 5*d.* 2¾ per cent. Consols, applied in purchase of £65 4*s.* 10*d.* 2¾ per cent. Consolidated Stock..	64	11	0					
		£5,064	11	0			£5,064	11	0
		£	*s.*	*d.*					
1901. January 1.	To Balance brought down	£5,064	11	0					

Pension Fund Account, 31st December, 1900.

£395 5*s.* 1*d.* 2¾ per cent. Consolidated Stock.
£5 3*s.* 4*d.* Balance at Bank of England, Western Branch.

		£	*s.*	*d.*			£	*s.*	*d.*
	To transfer from General Revenue Account applied in purchase of £395 5*s.* 1*d.* 2¾ per cent. Consolidated Stock	400	0	0	1900. December 31.	By Balance carried down	405	3	4
	,, Dividends on £395 5*s.* 1*d.* 2¾ per cent. Consols ..	5	3	4					
		£405	3	4			£405	3	4
		£	*s.*	*d.*					
1901. January 1.	To Balance brought down	£405	3	4					

I have examined the above Balance Sheet and Accounts with the Books and Vouchers, and certify them to be in accordance therewith. I have also verified the Bank balances and the securities for Investments.

3, CHURCH COURT, OLD JEWRY, E.C.
6th February, 1901.

(Signed) W. B. KEEN,
Chartered Accountant.

APPENDIX I.

MAGNETICAL OBSERVATIONS, 1900.

Made at the Kew Observatory, Old Deer Park, Richmond, Lat. 51° 28′ 6″ N. and Long. $0^h\ 1^m\ 15^s{\cdot}1$ W.

The results given in the following tables are deduced from the magnetograph curves which have been standardised by observations of deflection and vibration. These were made with the Collimator Magnet K.C. I. and the Declinometer Magnet marked K.O. 90 in the 9-inch Unifilar Magnetometer by Jones.

The Inclination was observed with the Inclinometer by Barrow, No. 33, and needles 3½ inches in length.

The Declination and Force values given in Tables I to VIII are prepared in accordance with the suggestions made in the fifth report of the Committee of the British Association on comparing and reducing Magnetic Observations.

The following is a list of the days during the year 1900 which were selected by the Astronomer Royal, as suitable for the determination of the magnetic diurnal inequalities, and which have been employed in the preparation of the magnetic tables :—

January	3, 8, 9, 30, 31.
February	3, 6, 7, 13, 28.
March	5, 11, 21, 27, 28.
April	3, 8, 15, 22, 25.
May	9, 10, 14, 21, 28.
June	10, 11, 16, 20, 25.
July	14, 15, 18, 22, 30.
August	6, 9, 10, 23, 30.
September	2, 7, 21, 25, 26.
October	2, 7, 13, 19, 31.
November	5, 6, 11, 16, 30.
December	3, 6, 15, 23, 24.

Table I.—Hourly Means of the Declination, as determined from th

Hours	Preceding noon.	Mid.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
(16° +) West						Winter.							
1900. Months.	′	′	′	′	′	′	′	′	′	′	′	′	′
Jan. ..	56·7	54·1	54·1	54·4	54·5	54·4	54·3	54·2	54·0	53·6	53·8	54·4	55·7
Feb. ..	57·1	54·0	54·3	54·6	54·5	54·5	54·3	54·0	53·9	54·0	54·1	54·6	55·
March.	57·5	53·3	53·4	53·4	53·1	52·9	52·8	52·5	51·8	50·9	50·8	52·0	54·
Oct. ..	55·0	51·0	51·2	51·8	51·2	51·1	51·0	50·9	50·2	49·3	48·8	50·0	52·
Nov. ..	54·2	50·6	50·9	51·1	51·1	51·1	51·0	50·7	50·4	49·9	49·9	51·3	52·
Dec. ..	52·1	50·0	50·3	50·3	50·3	50.4	50·3	50·3	50·0	49·8	49·8	50·5	51·
Means	55·4	52·2	52·4	52·5	52·5	52·4	52·3	52·1	51·7	51·2	51·2	52·1	53·7
						Summer.							
	′	′	′	′	′	′	′	′	′	′	′	′	′
April ..	57·0	53·0	53·0	52·8	52·8	52·4	52·2	51·6	50·6	49·8	49·9	51·5	54·5
May ..	57·1	52·4	52·5	52·2	51·9	51·6	50·5	49·4	49·0	49·4	50·1	52·3	54·8
June ..	56·1	52·4	52·3	52·1	52·0	51·6	50·8	49·9	49·4	49·5	50·2	52·1	54·9
July ..	57·0	52·2	52·3	52·1	51·8	51·2	49·8	49·4	49·3	49·4	50·0	51·0	53·4
Aug. ..	57·0	51·6	51·6	51·4	51·3	50·8	50·3	49·4	48·6	48·8	50·2	52·6	55·3
Sept. ..	57·2	51·4	51·3	51·2	51·0	50·7	50·6	50·0	49·1	48·8	49·7	52·2	54·8
Means	56·9	52·2	52·2	52·0	51·8	51·4	50·7	50·0	49·3	49·3	50·0	52·0	54·6

Table II.—Diurnal Inequality of th

Hours	Mid.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
						Summer Means.						
	′	′	′	′	′	′	′	′	′	′	′	′
	−0·5	−0·5	−0·7	−0·9	−1·3	−2·0	−2·7	−3·4	−3·4	−2·7	−0·7	+1·9
						Winter Means.						
	′	′	′	′	′	′	′	′	′	′	′	′
	−0·6	−0·4	−0·3	−0·3	−0·4	−0·5	−0·7	−1·1	−1·5	−1·6	−0·6	+0·9
						Annual Means.						
	′	′	′	′	′	′	′	′	′	′	′	′
	−0·6	−0·5	−0·5	−0·6	−0·8	−1·2	−1·7	−2·2	−2·4	−2·1	−0·7	+1·4

NOTE.—When the sign is + the magn
" " − "

selected quiet Days in 1900. (Mean for the Year = 16° 52′·7. West.)

Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mid.	Succeed noon
						Winter.							
′	′	′	′	′	′	′	′	′	′	′	′	′	′
56·8	57·3	56·2	55·6	55·4	55·5	55·0	54·3	54·0	53·9	53·9	53·9	53·9	56·7
56·9	57·5	57·2	55·6	55·0	55·0	54·7	54·4	54·4	54·1	54·1	54·1	54·2	58·0
56·7	57·7	57·6	56·2	54·5	53·5	53·4	53·7	53·8	53·7	53·5	53·5	53·3	56·5
54·8	55·6	55·1	53·7	52·5	51·9	51·8	51·7	51·5	51·2	51·2	51·2	51·0	55·0
53·6	53·5	52·6	51·7	51·4	51·3	51·2	51·1	50·8	50·8	50·7	50·8	51·0	53·5
52·0	52·1	51·6	51·0	50·6	50·4	50·1	49·8	49·8	49·6	49·5	49·7	50·1	52·9
55·1	55·6	55·0	54·0	53·2	52·9	52·7	52·5	52·4	52·2	52·1	52·2	52·2	55·4
						Summer.							
′	′	′	′	′	′	′	′	′	′	′	′	′	′
57·1	58·1	57·7	56·1	54·7	53·9	53·5	53·4	53·1	53·1	53·2	52·9	52·7	57·1
56·9	57·6	56·8	55·3	53·7	52·7	52·2	52·2	52·2	52·3	52·6	52·7	52·6	56·6
57·9	58·7	58·4	57·5	56·4	54·6	53·4	52·6	52·5	52·5	52·5	52·5	52·5	57·2
56·4	58·1	57·8	56·2	54·7	53·6	52·7	52·8	52·9	52·8	52·4	52·4	52·0	56·2
57·4	57·9	56·7	55·3	53·3	52·1	51·5	51·9	51·7	51·9	51·7	51·9	51·7	58·1
57·2	57·4	55·6	53·5	52·0	51·3	51·4	51·6	51·5	51·6	51·4	51·4	51·3	56·7
57·2	58·0	57·2	55·7	54·1	53·0	52·5	52·4	52·3	52·4	52·3	52·3	52·1	57·0

Kew Declination as deduced from Table I.

Noon	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mi
						Summer Means.						
′	′	′	′	′	′	′	′	′	′	′	′	
+4·5	+5·3	+4·5	+3·0	+1·4	+0·3	−0·2	−0·3	−0·4	−0·3	−0·4	−0·4	−0
						Winter Means.						
′	′	′	′	′	′	′	′	′	′	′	′	
+2·4	+2·9	+2·3	+1·2	+0·5	+0·2	−0·1	−0·3	−0·4	−0·6	−0·6	−0·6	−0
						Annual Means.						
′	′	′	′	′	′	′	′	′	′	′	′	
+3·4	+4·1	+3·4	+2·1	+1·0	+0·3	−0·2	−0·3	−0·4	−0·4	−0·5	−0·5	−0

points to the west of its mean position.

„ east „ „

Table III.—Hourly Means of the Horizontal Force in C.G.S. units (correcte
(The Mean for th

Hours	Preceding noon.	Mid.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
0·18000 +						Winter.							
1900. Months.													
Jan. ...	407	414	413	414	414	416	417	418	419	416	412	405	406
Feb. ...	404	414	415	415	416	416	417	419	417	415	412	408	407
March..	408	421	421	421	421	420	421	419	419	415	408	401	399
Oct. ...	422	443	443	442	443	444	446	443	444	439	427	421	420
Nov. ...	436	441	442	441	442	443	443	443	441	437	432	430	431
Dec. ...	441	443	443	443	443	443	443	443	444	444	444	443	441
Means..	420	429	429	429	430	430	431	431	431	428	422	418	417
						Summer.							
April...	405	425	425	425	425	425	424	424	424	420	412	404	402
May ...	400	422	422	419	420	418	416	412	408	404	401	404	405
June ...	421	436	435	433	434	435	435	430	427	423	415	409	409
July ...	425	446	442	441	440	440	439	436	433	427	419	415	417
Aug. ...	421	437	436	435	435	433	432	429	422	414	409	411	416
Sept. ...	428	439	438	436	436	436	434	432	427	421	416	413	416
Means..	417	434	433	432	432	431	430	427	423	418	412	409	411

Table IV.—Diurnal Inequality of t

Hours	Mid.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
						Summer Means.						
	+ ·00006	+ ·00004	+ ·00003	+ ·00003	+ ·00003	+ ·00002	– ·00001	– ·00005	– ·00010	– ·00017	– ·00019	– ·0001
						Winter Means.						
	+ ·00001	+ ·00001	+ ·00001	+ ·00002	+ ·00002	+ ·00003	+ ·00003	+ ·00003	·00000	– ·00006	– ·00010	– ·0001
						Annual Means.						
	+ ·00003	+ ·00003	+ ·00002	+ ·00002	+ ·00002	+ ·00002	+ ·00001	– ·00001	– ·00005	– ·00011	– ·00015	– ·0001

Note.—When the sign is + t

[redacted]

for Temperature) as determined from the selected quiet Days in 1900. Year = 0·18428.)

Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mid.	Succeedin noon.
						Winter.							
407	413	415	414	414	413	414	414	415	416	416	415	416	412
407	411	413	418	413	416	416	417	418	418	417	418	417	411
405	413	418	421	422	423	424	426	427	425	425	426	426	410
423	431	436	440	441	443	444	445	445	444	445	445	445	430
433	438	440	441	441	442	443	443	443	443	442	441	441	431
440	443	442	444	445	446	445	445	444	444	443	442	442	438
419	425	427	429	429	430	431	432	432	432	431	431	431	422
						Summer.							
411	418	424	428	429	427	429	430	431	430	429	429	429	410
409	412	414	414	417	422	428	431	429	429	428	428	428	407
416	424	432	435	435	438	441	441	440	439	436	435	434	410
424	431	435	440	443	442	443	446	446	446	445	444	444	430
429	435	435	437	435	434	435	439	438	439	438	439	439	427
428	434	435	435	436	436	438	442	440	439	437	440	439	437
420	426	429	431	432	433	436	438	437	437	436	436	436	420

Kew Horizontal Force as deduced from Table III.

Noon	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mid
						Summer Means.						
− ·00009	− ·00003	+ ·00001	+ ·00003	+ ·00004	+ ·00005	+ ·00007	+ ·00010	+ ·00009	+ ·00008	+ ·00007	+ ·00007	+ ·00
						Winter Means.						
− ·00009	− ·00003	− ·00001	+ ·00001	+ ·00001	+ ·00002	+ ·00003	+ ·00004	+ ·00004	+ ·00004	+ ·00003	+ ·00003	+ ·00
						Annual Means.						
− ·00009	− ·00003	·00000	+ ·00002	+ ·00002	+ ·00003	+ ·00005	+ ·00007	+ ·00006	+ ·00006	+ ·00005	+ ·00005	+ ·00

reading is above the mean.

Table V.—Hourly Means of the Kew Vertical Force in C.G.S. units (correcte
(The Mean for the

Hours.	Preceding noon.	Mid.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
	0·43000 +					Winter.							
1900. Months.													
Jan. ...	842	845	845	845	844	844	843	843	842	841	842	842	[illegible]
Feb. ...	828	833	832	832	832	832	831	831	830	828	829	827	[illegible]
March ..	842	853	853	853	853	852	851	851	852	851	850	846	[illegible]
Oct. ...	832	846	845	845	844	844	843	843	844	845	842	840	[illegible]
Nov. ...	816	819	819	819	819	818	818	818	818	818	817	815	[illegible]
Dec. ...	801	803	803	803	803	803	803	803	802	802	800	797	[illegible]
Means	827	833	833	833	833	832	832	832	831	831	830	828	[illegible]
						Summer.							
April ...	841	858	857	856	855	854	854	853	852	851	848	844	[illegible]
May ...	823	842	841	841	841	841	843	842	841	838	834	828	[illegible]
June ...	818	836	835	834	834	835	835	834	836	836	833	830	[illegible]
July ...	821	835	834	834	833	834	834	834	835	834	828	823	816
Aug. ...	777	794	794	793	792	792	794	794	793	789	784	781	[illegible]
Sept. ...	825	836	836	836	835	835	835	837	836	834	829	824	[illegible]
Means	817	834	833	832	832	832	832	832	832	830	826	822	817

Table VI.—Diurnal Inequality of th

Hours	Mid.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
					Summer Means.							
	+ ·00003	+ ·00002	+ ·00002	+ ·00001	+ ·00001	+ ·00002	+ ·00002	+ ·00002	·00000	– ·00004	– ·00009	[illegible]
					Winter Means.							
	+ ·00001	+ ·00001	+ ·00001	+ ·00001	·00000	·00000	·00000	– ·00001	– ·00001	– ·00002	– ·00004	[illegible]
					Annual Means.							
	+ ·00002	+ ·00002	+ ·00001	+ ·00001	+ ·00001	+ ·00001	+ ·00001	+ ·00001	– ·00001	– ·00003	– ·00006	[illegible]

NOTE.—When the sign is + th

for Temperature), as determined from the selected quiet Days in 1900. Year = 0·43831.)

Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mid.	Succeedi noon.
						Winter.							
841	844	846	846	844	844	845	845	844	844	843	843	843	840
827	829	833	835	835	835	834	833	833	832	832	831	831	823
841	842	847	852	854	855	854	854	854	853	853	852	852	839
833	837	839	844	847	847	847	847	848	847	848	847	847	833
816	818	822	822	821	820	821	822	821	820	820	819	819	814
800	803	805	806	806	805	805	805	805	805	805	804	804	802
826	829	832	834	834	834	834	834	834	833	833	833	833	825
						Summer.							
838	842	847	852	855	857	859	858	857	856	856	855	854	832
819	824	831	835	840	844	843	842	842	841	840	839	839	820
828	823	829	832	836	840	842	843	843	841	841	840	839	822
818	822	825	833	838	842	842	842	841	841	840	839	838	825
775	778	783	789	792	795	795	794	794	793	792	792	791	771
821	826	832	838	841	841	839	840	839	840	839	839	837	823
817	819	824	830	834	837	837	837	836	835	835	834	833	815

Kew Vertical Force as deduced from Table V.

Noon	1.	2.	3.	4.	5.	6.	7.	8.	9.	10	11.	M
						Summer Means.						
− ·00014	− ·00011	− ·00006	− ·00001	+ ·00003	+ ·00006	+ ·00006	+ ·00006	+ ·00006	+ ·00005	+ ·00004	+ ·00004	+ ·0
						Winter Means.						
− ·00006	− ·00003	·00000	+ ·00002	+ ·00003	+ ·00002	+ ·00002	+ ·00002	+ ·00002	+ ·00002	+ ·00002	+ ·00001	+ ·0
						Annual Means.						
− ·00010	− ·00007	− ·00003	+ ·00001	+ ·00003	+ ·00004	+ ·00004	+ ·00004	+ ·00004	+ ·00003	+ ·00003	+ ·00002	+ ·0

· reading is above the mean

Table VII.—Hourly Means of the Inclination, calculated from the Horizont

Hours	Preceding noon.	Mid.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
		67° +					Winter.						
1900. onths.	′	′	′	′	′	′	′	′	′	′	′	′	′
an....	13·5	13·1	13·2	13·1	13·1	13·0	12·9	12·8	12·7	12·9	13·2	13·6	13·
eb.....	13·3	12·8	12·7	12·7	12·6	12·6	12·5	12·4	12·5	12·6	12·8	13·0	13·
arch..	13·4	12·9	12·9	12·9	12·9	12·9	12·8	13·0	13·0	13·2	13·7	14·0	14·1
ct.....	12·2	11·2	11·3	11·2	11·2	11·1	10·9	10·9	11·1	11·5	12·2	12·5	12·
ov. ...	10·8	10·6	10·5	10·6	10·5	10·5	10·5	10·5	10·6	10·8	11·1	11·2	11·1
ec.....	10·1	10·0	10·0	10·0	10·0	10·0	10·0	10·0	9·9	9·9	9·9	9·8	10·
eans..	12·2	11·8	11·8	11·8	11·7	11·7	11·6	11·6	11·6	11·8	12·1	12·4	12·
							Summer.						
	′	′	′	′	′	′	′	′	′	′	′	′	′
pril...	13·6	12·7	12·7	12·7	12·7	12·6	12·7	12·7	12·6	12·9	13·3	13·8	13·
ay....	13·4	12·5	12·5	12·7	12·6	12·7	12·9	13·2	13·4	13·6	13·7	13·3	13·1
une ...	11·9	11·4	11·4	11·5	11·5	11·4	11·4	11·7	12·0	12·3	12·7	13·0	12·
uly....	11·7	10·7	11·0	11·0	11·1	11·1	11·1	11·3	11·6	11·9	12·3	12·4	12·1
ug. ...	10·8	10·2	10·2	10·3	10·2	10·4	10·5	10·7	11·1	11·6	11·8	11·5	11·
ept. ...	11·6	11·2	11·3	11·4	11·4	11·4	11·5	11·7	12·0	12·3	12·6	12·6	12·
eans..	12·2	11·5	11·5	11·6	11·6	11·6	11·7	11·9	12·1	12·4	12·7	12·8	12·

Table VIII.—Diurnal Inequality of th

ours	Mid.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
						Summer Means.						
	′	′	′	′	′	′	′	′	′	′	′	′
	−0·3	−0·2	−0·1	−0·2	−0·1	−0·1	+0·1	+0·4	+0·7	+1·0	+1·0	+0·8
						Winter Means.						
	′	′	′	′	′	′	′	′	′	′	′	′
	0·0	−0·1	0·0	−0·1	−0·1	−0·2	−0·2	−0·2	0·0	+0·3	+0·5	+0·6
						Annual Means.						
	′	′	′	′	′	′	′	′	′	′	′	′
	−0·2	−0·1	−0·1	−0·1	−0·1	−0·1	0·0	+0·1	+0·4	+0·7	+0·8	+0·7

NOTE.—When th

and Vertical Forces (Tables III and V). (The Mean for the Year = 67° 11′·8.)

Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mid.	Succeedin noon.
						Winter.							
′	′	′	′	′	′	′	′	′	′	′	′	′	
13·5	13·2	13·1	13·2	13·1	13·2	13·1	13·1	13·0	13·0	12·9	13·0	12·9	13·1
13·1	12·9	12·9	12·9	12·9	12·7	12·7	12·6	12·5	12·5	12·6	12·5	12·5	12·7
13·6	13·1	12·9	12·9	12·8	12·8	12·7	12·6	12·5	12·6	12·6	12·5	12·5	13·2
12·2	11·8	11·5	11·4	11·4	11·3	11·2	11·1	11·1	11·2	11·1	11·1	11·1	11·7
11·0	10·8	10·8	10·7	10·7	10·6	10·5	10·5	10·5	10·5	10·6	10·6	10·6	11·1
10·1	10·0	10·1	10·0	10·0	9·9	9·9	9·9	10·0	10·0	10·1	10·1	10·1	10·8
12·3	12·0	11·9	11·9	11·8	11·7	11·7	11·6	11·6	11·6	11·7	11·6	11·6	12·0
						Summer.							
′	′	′	′	′	′	′	′	′	′	′	′	′	′
13·1	12·8	12·5	12·4	12·4	12·6	12·5	12·4	12·3	12·4	12·4	12·4	12·4	13·0
12·7	12·7	12·7	12·8	12·8	12·6	12·1	11·9	12·0	12·0	12·1	12·0	12·0	12·9
12·5	11·8	11·5	11·4	11·5	11·4	11·2	11·3	11·3	11·4	11·6	11·6	11·6	12·7
11·7	11·3	11·2	11·1	11·0	11·2	11·1	10·9	10·9	10·9	10·9	11·0	10·9	11·5
10·2	9·8	10·0	10·0	10·2	10·4	10·3	10·0	10·1	10·0	10·0	10·0	9·9	10·2
11·5	11·3	11·4	11·5	11·6	11·6	11·4	11·1	11·2	11·3	11·4	11·2	11·2	11·0
12·0	11·6	11·6	11·5	11·6	11·6	11·4	11·3	11·3	11·3	11·4	11·4	11·3	11·9

Inclination as derived from Table VII.

Noon	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mi
						Summer Means.						
′	′	′	′	′	′	′	′	′	′	′	′	′
+0·2	−0·1	−0·2	−0·2	−0·2	−0·1	−0·3	−0·5	−0·4	−0·4	−0·3	−0·4	−0·
						Winter Means.						
′	′	′	′	′	′	′	′	′	′	′	′	′
+0·4	+0·2	+0·1	0 0	0·0	−0·1	−0·1	−0·1	−0·2	−0·2	−0·2	−0·2	−0
						Annual Means.						
′	′	′	′	′	′	′	′	′	′	′	′	′
+0·3	0·0	−0·1	−0·1	−0·1	−0·1	−0·2	−0·3	−0·3	−0·3	−0·3	−0·3	−0

the reading is above the mean.

2 I 2

APPENDIX IA.

MEAN VALUES, for the years specified, of the Magnetic Elements at Observatori whose Publications are received at the National Physical Laboratory

Place.	Latitude.	Longitude.	Year.	Declination.	Inclination.	Horizontal Force. C.G.S. Units.	Vertical Force C.G.S. Units.
Pawlowsk	59° 41′ N.	30° 29′ E.	1898	0° 30′·3 E.	70° 39′·7 N.	·16522	·47077
Katharinenburg	56 49 N.	60 38 E.	1898	9 55·6 E.	70 40·2 N.	·17802	·50752
Kasan	55 47 N.	49 8 E.	1894	7 39·7 E.	68 37·5 N.	·18572	·47451
			1895	7 43·8 E.	68 35·5 N.	·18580	·47390
			1896	7 47·1 E.	68 33·7 N.	·18605	·47381
			1897	7 54·8 E.	68 34·8 N.	·18616	·4745
Copenhagen ...	55 41 N.	12 34 E.	1899	10 15·8 W.	68 40 N.	·17490	·4478
Stonyhurst	53 51 N.	2 28 W.	1899	18 17·7 W.	68 51·8 N.	·17273	·44677
			1900	18 10·9 W.	68 50·3 N.	·17312	·44720
Hamburg......	53 34 N.	10 3 E.	1896	11 36·7 W.	67 38·8 N.	·18061	·43921
Wilhelmshaven	53 32 N.	8 9 E.	1899	12 31·0 W.	67 45·0 N.	·18072	·44173
Potsdam	52 23 N.	13 4 E.	1899	10 0·7 W.	66 33·3 N.	·18818	·43392
Irkutsk........	52 16 N.	104 16 E.	1898	2 2·6 E.	70 13·2 N.	·20137	·55991
de Bilt(Utrecht)	52 5 N.	5 11 E.	1898	13 59·1 W.	—	·18487	—
Kew..........	51 28 N.	0 19 W.	1900	16 52·7 W.	67 11·8 N.	·18428	·43831
Greenwich.....	51 28 N.	0 0	1899	16 34·2 W.	67 10·2 N.	·18419	·43754
			1900	16 29·0 W.	67 8·5 N.	·18450	·43764
Uccle (Brussels)	50 48 N.	4 21 E.	1899	14 18·3 W.	66 13·2 N.	·18938	·42975
			1900	14 13·6 W.	66 9·8 N.	·18952	·42896
Falmouth	50 9 N.	5 5 W.	1899	18 32·7 W.	66 48·7 N.	·18663	·43569
Prague	50 5 N.	14 25 E.	1899	9 11·9 W.	—	·19926	—
St. Helier (Jersey).........	49 12 N.	2 5 W.	1900	16 59·7 W.	65 45·5 N.	—	—
Parc St. Maur (Paris)	48 49 N.	2 29 E.	1897	14 58·6 W.	64 59 6 N.	·19717	·42270
Vienna........	48 15 N.	16 21 E.	1898	8 24·1 W.	—	·20797	—
O'Gyalla(Pesth)	47 53 N.	18 12 E.	1900	7 28·8 W.	—	·21153	—
Odessa........	46 26 N.	30 46 E.	1898	4 41·5 W.	62 30·5 N.	·22033	·42341
Pola*.........	44 52 N.	15 51 E.	1899	9 25·7 W.	—	·22135	·38900
Nice	43 43 N.	7 16 E.	1899	12 4·0 W.	60 11·7 N.	·22390	·39087
Toronto.......	43 40 N.	79 30 W.	1897	4 53·0 W.	—	·16650	—
Perpignan	42 42 N.	2 53 E.	1897	13 51·3 W.	60 3·5 N.	·22440	·38959
Tiflis	41 43 N.	44 48 E.	1897	1 59·0 E.	55 48·3 N.	·25664	·37770
Capodimonte (Naples) ..	40 52 N.	14 15 E.	1898	9 22·6 W.	—	—	—
			1899	9 15·8 W.	—	—	—
			1900	9 10·2 W.	—	—	—
Madrid	40 25 N.	3 40 W.	1897	15 56·9 W.	—	—	—
Coimbra.......	40 12 N.	8 25 W.	1899	17 24·2 W.	59 28·9 N.	·22724	·38549
Washington ..	38 55 N.	77 4 W.	1894	3 39·9 W.	70 34·3 N.	·19979	·56646
Lisbon........	38 43 N.	9 9 W.	1900	17 18·0 W.	57 54·8 N.	·23516	·37484
Tokio.........	35 41 N.	139 45 E.	1897	4 29·9 W.	49 2·8 N.	·29816	·34356

* The vertical force is mean from months June to December only.

APPENDIX IA—*continued.*

Place.	Latitude.	Longitude.	Year.	Declination.	Inclination.	Horizontal Force. C.G.S. Units.	Vert Fo C.G Uni
	° ′	° ′		° ′	° ′		
Zi-ka-wei	31 12 N.	121 26 E.	1897	2 18·5 W.	45 53·0 N.	·32799	·33
			1898	2 19·0 W.	45 48·7 N.	·32778	·33
Havana	23 8 N.	82 25 W.	1898	3 10·8 E.	52 30·7 N.	·31166	40
Hong Kong....	22 18 N.	114 10 E.	1899	0 21·1 E.	31 29·4 N.	·36676	·22
Tacubaya......	19 24 N.	99 12 E.	1895	7 45·6 E.	44 22·2 N.	·33428	·32
Colaba (Bombay)	18 54 N.	72 49 E.	1897	0 31·3 E.	20 59·1 N.	·37463	·14
Manila........	14 35 N.	120 58 E.	1898	0 51·4 E.	16 28·7 N.	·37952	·11
Batavia	6 11 S.	106 49 E.	1898	1 14·9 E.	29 47·4 S.	·36752	·21
Dar-es-salem* ..	6 49 S.	39 18 E.	1896	8 41·6 W.	36 50·8 S.	·29004	·21
			1897	8 29·9 W.	36 53·3 S.	·29009	·21
			1898	8 18·1 W.	36 56·8 S.	·28966	·21
Mauritius	20 6 S.	57 33 E.	1898	9 39·2 W.	54 22·4 S.	·23873	·33
Rio de Janeiro†	22 55 S.	43 11 W.	1899	7 45·9 W.	13 16·0 S.	·2505	·05
Melbourne.....	37 50 S.	144 58 E.	1898	8 20·1 E.	67 22·4 S.	·23364	·56

* Data for 1896 and 1897 are from absolute observations only. For 1898 use was made o available magnetograph records.

† Data from first three and last three months of year only.

APPENDIX II.—Table I.

Mean Monthly Results of Temperature and Pressure. Kew Observatory.
1900.

Months.	Thermometer.								Barometer.*					Mean vapour-tension.
	Mean.	Means of—			Absolute Extremes.				Mean.	Absolute Extremes.				
		Max.	Min.	Max. and Min.	Max.	Date.	Min.	Date.		Max.	Date.	Min.	Date.	
1900.	°	°	°	°	°	d. h.	°	d. h.	ins.	ins.	d. h.	ins.	d. h.	in.
Jan.….	40·4	44·9	35·4	40·2	53·0	24 2 P.M.	27·9	14 8 A.M.	29·934	30·483	11 11 A.M.	29·231	3 2 P.M.	·216
Feb. …	38·4	43·2	33·4	38·3	56·7	26 3 ,,	19·0	9 8 ,,	29·573	30·124	14 10 P.M.	28·526	19 11 ,,	·199
March..	39·4	45·1	34·6	39·9	56·0	12 3 ,,	24·9	18 6 ,,	30·013	30·672	13 11 ,,	29·215	19 6 A.M.	·182
April…	47·6	55·7	39·2	47·5	73·4	21 4 & 5 P.M.	27·9	2 5 ,,	29·991	30·586	19 10 A.M.	29·244	4 2 ,,	·239
May …	52·0	59·6	44·2	51·9	69·3	6 5 P.M.	37·2	16 4 ,, 20 4 ,,	29·980	30·356	30 0·23 A.M.	29·469	3 NOON	·279
June…	59·8	68·3	52·1	60·2	86·5	11 3 & 4 P.M.	46·1	5 3 ,,	29·937	30·258	1 0·5 A.M.	29·451	25 11 A.M.	·366
July …	66·9	76·9	57·5	67·2	89·4	16 2 ,, 19 4 ,, 20 1 ,,	45·2	8 4 ,,	30·008	30·283	8 NOON	29·616	2 4 P.M.	434
Aug.…	61·0	69·0	53·8	61·4	81·3	18 4 ,,	46·3	31 5 ,,	29·961	30·417	30 10 A.M.	29·240	6 6 ,,	·394
Sept.…	57·7	67·5	49·2	58·3	79·4	16 2 ,,	41·9	4 6 ,,	30·136	30·553	12 10 ,,	29·594	27 11 ,,	365
Oct.….	50·7	57·2	43·9	50·6	70·1	8 3 ,,	36·6	16 7 ,,	29·984	30·597	22 11 ,,	29·281	26 3 ,,	·307
Nov. …	46·4	50·7	41·7	46·2	59·9	1 NOON & 1 ,,	27·3	11 8 ,,	29·747	30·381	18 10 P.M.	29·119	29 5 A.M.	·278
Dec. …	45·8	49·8	40·7	45·3	56·1	5 9 ,,	31·0	24 5 ,,	29·930	30·548	16 7 ,,	28·919	31 2 ,,	·269
Yearly Means	50·5	57·3	43·8	50·6	..	….	..	….	29·933	..	….	..	..	·294

* Reduced to 32° at M.S.L.

This table has been compiled at the Meteorological Office from values intended for publication in the volume of "Hourly Means" for 1900.

Meteorological Observations.—Table II.

Kew Observatory.

Months.	Mean amount of cloud (0=clear, 10=over-cast).	Rainfall.*			Weather. Number of days on which were registered						Wind.† Number of days on which it was									
		Total.	Maxi-mum.	Date.	Rain. ‡	Snow.	Hail.	Thun-der-storms.	Clear sky.	Over-cast sky.	Gales.§	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.‖
1900.		ins.	ins.																	
January	7·6	2·920	0·550	6	19	2	1	0	2	20	0	5	1	1	1	5	5	8	5	3
February	7·6	3·175	0·550	2	18	4	0	0	2	17	4	6	5	3	2	4	5	2	1	5
March	7·5	0·935	0·375	18	8	2	0	0	2	19	0	10	6	3	2	1	1	3	5	2
April	6·1	0·925	0·320	3	14	0	1	0	5	11	2	3	3	3	1	2	6	9	3	5
May	6·8	1·065	0·235	22	11	0	0	0	1	14	1	6	6	2	1	3	8	2	3	1
June	7·0	2·020	0·350	24	12	0	0	2	3	15	0	5	1	1	1	3	10	7	2	2
July	5·2	1·360	0·510	27	7	0	0	3	7	7	0	2	1	2	1	3	11	5	6	5
August	6·0	2·915	0·440	3	15	0	2	2	6	9	1	4	5	2	..	7	6	4	3	5
September...	5·3	0·670	0·310	27	7	0	0	0	6	7	0	4	2	3	..	2	6	9	4	9
October	6·5	1·660	0·475	29	16	0	0	0	1	10	0	5	..	1	..	1	13	7	4	5
November ...	7·8	1·680	0·280	24	17	0	0	0	2	21	0	6	3	2	2	4	9	3	1	2
December ...	7·9	2·540	0·580	30	18	0	0	0	0	19	3	2	..	1	1	9	14	4	..	3
Totals and means.	6·8	21·865	..	..	162	8	4	7	37	169	11	58	33	24	12	44	94	63	37	47

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* Measured at 10 A.M. daily by gauge 1·75 feet above ground.

† As registered by the anemograph.

‡ The number of rainy days are those on which 0·01 inch rain or melted snow was recorded.

§ In a "gale" the mean wind velocity has exceeded 35 miles an hour in at least one hour of the twenty-four.

‖ In a "calm" the mean wind velocity for the twenty-four hours has not exceeded 5 miles an hour.

Meteorological Observations.–

Kew Observatory.

Months.	Bright Sunshine.				Maximum temperature in sun's rays. (Black bulb *in vacuo.*)			Minimum temperature on the ground.			Horizontal movement of the air.*		
	Total number of hours recorded.	Mean percentage of possible sunshine.	Greatest daily record.	Date.	Mean.	Highest	Date. †	Mean.	Lowest.	Date. ‡	Average hourly velocity.	Greatest hourly velocity.	Date.
1900.	h. m.		h. m.		deg.	deg.		deg.	deg.		miles.	miles.	
January	46 12	18	5 36	18	66	86	17	29	14	13	11·4	31	28
February	54 18	20	8 24	21	72	99	18	28	6	8	12·6	41	13
March	81 24	22	9 18	20	84	107	20	27	10	18	10·4	30	23
April	173 0	42	12 12	18	106	125	22	29	14	2	10·5	37	13
May	175 0	36	12 42	2	113	130	5 28	36	22	16	11·1	35	3
June	181 36	37	15 6	10	124	139	11	46	36	27	11·0	26	4 10
July	291 6	59	15 0	11	134	153	16	49	33	8	8·5	31	27
August	186 0	41	13 36	13	118	136	19	48	38	5	10·3	35	3
September	178 6	47	10 54	11	118	128	9 22	39	31	6	7·3	28	27
October	134 18	40	9 54	8	99	121	2	37	25	16 21	10·0	32	6
November	46 36	18	7 24	10	75	101	1	35	19	11	10·5	32	15
December	36 48	15	6 0	21	65	83	4 21	35	21	22	13·5	45	28
Totals and Means	1584 24	33	..	..	98	..	..	..	36	..	10·6	..	..

* As indicated by a Robinson's anemograph, 70 feet above the general surface of the ground, the original factor 3 being used.

† Read at 10 A.M., and entered to previous day. ‡ Read at 10 A.M., and entered to same day.

APPENDIX III.—Table I.

Register of principal Seismograph Disturbances. 1900.

No. in Kew register.	Date.		Commencement of P.T.'s.*	Duration of P.T.'s.*	First maximum.	Second maximum.	Maximum amplitude.		Tota durati of dist ance
							mm.	Secs. of arc.	
			h. m.	m.	h. m.	h. m.			h. m
200	Jan.	5	19 21·6	40·2	20 7·9	20 11·5	1·0	0·85	1 4
207	,,	17	6 37·0	8·2	6 48·8	6 50·6	0·6	0·50	0 3
209	,,	20	6 46·2	10·3	7 24·6	7 29·5	15·0	12·60	3 1
226	May	11	17 35·3	9·9	18 20·6	—	0·6	0·53	1 3
230	,,	16	20 23·7	10·6	21 1·8	21 3·8	1·2	0·92	1 5
237	June	21	20 47·3	26·3	21 40·9	21 45·4	2·5	1·73	3 4
244	July	29	7 18·5	13·5	8 37·2	8 39·3	0·9	0·63	3 1
247	Aug.	28	11 8·0	5·2	11 13·8	11 20·2	1·3	0·92	0 4
253	Oct.	7	21 31·2	29·4	22 10·0	22 12·0	1·4	1·05	2 2
254	,,	9	12 34·7	13·5	13 8·4	13 18·6	8·0	6·00	4
256	,,	29	9 21·5	8·7	9 43·2	9 44·1	12·6	9·45	6 3
257	Nov.	5	8 13·2	19·2	8 40·0	—	0·9	0·68	1 1
258	,,	9	16 30·2	23·0	16 55·0	17 0·8	1·2	0·90	1
259	,,	9	18 38·5	9·0	18 53·1	—	0·7	0·52	0 5
262	,,	24	8 8·7	9·6	8 47·8	—	2·5	1·87	2
265	Dec.	18	23 37·0	21·8	24 7·7	—	1·5	0·87	1
266	,,	25	5 16·4	9·8	5 27·4	5 55·1 6 6·7	3·5	2·03	3

* P.T.'s = preliminary tremors. The times recorded are G.M.T.; midnight = 0 or 24 h
The figures given above are obtained from the photographic records of a Milne Horiz
Pendulum; they represent E—W displacements.

APPENDIX IV.—Table I.

RESULTS OF WATCH TRIALS. Performance of the 51 Watches which obtained the highest number of marks during the year.

Watch deposited by	Number of watch.	Escapement, balance spring, &c.	Mean daily rate.					Mean variation of daily rate. ±	Mean change of rate for 1° F.	Difference between extreme gaining and losing rates.	Marks awarded for			Total Marks.
			Pendant up.	Pendant right.	Pendant left.	Dial up.	Dial down.				Daily variation of rate.	Change of rate with change of position.	Temperature compensation.	
											0—40	0—40	0—20	0—100.
			secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.				
Fridlander, Coventry	25582	S.r., g.b., s.o., "Karrusel"	+3·8	+3·5	+3·4	+4·6	+3·4	0·2	0·06	3·5	35·8	38·4	15·9	90·1
" "	25594	S.r., g.b., s.o., "Karrusel"	+1·8	+1·4	+2·3	+1·8	+3·0	0·4	0·01	3·5	32·0	38·0	19·3	89·3
Baume & Co., London	103031	G.b., s.o., "Tourbillon" chronometer	−1·6	−1·8	−1·0	+0·4	−1·4	0·3	0·03	4·5	33·4	37·5	17·8	88·7
H. Golay, London	155	S.r., g.b., s.o., "Karrusel"	−2·8	−1·5	−2·2	−2·0	−1·2	0·4	0·03	3·5	32·1	38·1	18·0	88·2
W. Matthews, Coventry	97835	S.r., g.b., s.o., "Karrusel"	+1·3	+1·3	+1·5	+0·6	+2·9	0·3	0·07	6·0	34·8	37·7	15·1	87·6
H. Golay, London	156	S.r., g.b., s.o., "Karrusel"	−1·5	−1·0	−2·1	−0·5	−1·0	0·4	0·04	4·5	31·7	38·1	17·5	87·3
S. Yeomans, Coventry	76686	S.r., g.b., s.o., "Karrusel"	+0·0	+0·1	+0·5	+0·7	+0·5	0·3	0·09	5·5	33·7	39·0	14·3	87·0
Fridlander, Coventry	25564	S.r., g.b., s.o., "Karrusel"	−0·4	−1·3	−0·5	+0·3	+0·4	0·3	0·07	5·0	33·8	37·9	15·2	86·9
J. White & Son, Coventry	36643	S.r., g.b., s.o.	+3·8	+2·5	+1·5	+3·5	+2·8	0·3	0·05	4·2	32·1	37·3	16·4	86·8
Fridlander, Coventry	25591	S.r., g.b., s.o., "Karrusel"	−0·5	−0·8	−0·6	−2·0	+2·0	0·3	0·06	8·0	33·1	36·2	16·3	86·6
Chas. Frodsham & Co., London	08753	D.r., fusee, s.o., "Tourbillon" lever	+3·2	+3·0	+2·8	+0·5	+1·8	0·3	0·05	5·2	33·3	36·4	16·4	86·1
Fridlander, Coventry	25584 472902	S.r., g.b., s.o., "Karrusel"	−0·2	+0·5	+0·2	+0·1	+1·6	0·4	0·07	4·5	32·3	38·1	15·6	86·0
Ehrhardt, Ltd., Birmingham	272902	S.r., g.b., s.o.	+0·5	+1·8	+1·2	+1·4	+3·6	0·5	0·03	4·7	30·9	36·8	18·1	85·8
W. Matthews, Coventry	37459	S.r., g.b., s.o., "Karrusel"	−0·1	−0·1	+0·1	+2·1	+2·2	0·4	0·03	4·3	31·5	35·8	18·3	85·6
G. E. Sims, London	04823	S.r., g.b., s.o., "Karrusel"	+0·3	−0·1	−0·4	+1·3	+2·1	0·3	0·06	5·2	33·1	36·5	15·9	85·5
S. Yeomans, Coventry	76648	S.r., g.b., s.o., "Karrusel"	−1·7	−1·3	−1·1	−0·7	+0·3	0·4	0·07	5·2	32·7	37·8	15·0	85·5
H. Golay, London	150	S.r., g.b., s.o., "Karrusel"	−0·4	+0·4	+1·6	+0·2	−0·4	0·4	0·06	5·5	31·5	37·7	16·3	85·5
S. Yeomans, Coventry	76650	S.r., g.b., s.o., "Karrusel"	−0·6	−0·3	−0·1	+3·4	−0·9	0·3	0·05	5·5	33·6	35·0	16·8	85·4
Fridlander, Coventry	25505	S.r., g.b., s.o., "Karrusel"	−4·4	−3·9	−3·9	−1·1	−4·8	0·4	0·05	6·5	32·6	36·0	16·8	85·4
Matthews, Coventry	97767	S.r., g.b., s.o., "Karrusel"	−0·5	−0·8	−0·2	+0·8	+1·4	0·4	0·05	3·7	32·2	36·9	16·3	85·4
H. Golay, London	167	S.r., g.b., s.o., "Karrusel"	−1·5	−1·1	−1·7	+0·3	−0·6	0·4	0·05	3·8	31·3	37·4	16·7	85·4
Fridlander, Coventry	25602	S.r., g.b., s.o., "Karrusel"	+0·6	+1·1	+2·8	−0·1	+3·4	0·4	0·03	6·2	32·0	35·1	18·2	85·3
Chas. Frodsham, London	0·617	D.r., fusee, s.o., "Tourbillon" lever	+2·5	+2·7	+2·3	+4·5	+3·1	0·4	0·06	3·7	31·3	37·5	16·0	84·8
Wright & Craighead, London	8208	S.r., g.b., s.o., "Karrusel"	+4·8	+4·5	+4·4	+5·9	+4·6	0·4	0·08	4·7	31·7	38·3	14·6	84·6
J. White & Son, Coventry	36305	D.r., g.b., s.o.	+4·8	+5·2	+4·8	+3·7	+3·7	0·4	0·06	6·7	31·2	37·6	15·7	84·5
Montandon-Robert, Geneva	1096	D.r., g.b., s.o., minute repeater	−2·1	−4·6	−1·5	−0·6	−2·0	0·4	0·07	5·5	33·2	36·1	15·1	84·4

Table I—*continued.*

Watch deposited by	Number of watch.	Escapement, balance spring, &c.	Mean daily rate.					Mean variation of daily rate. ±	Mean change of rate for 1° F.	Difference between extreme gaining and losing rates.	Marks awarded for			Total Marks.
			Pendant up.	Pendant right.	Pendant left.	Dial up.	Dial down.				Daily variation of rate.	Change of rate with change of position.	Temperature compensation.	
											0—40	0—40	0—20	0—100.
			secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.				
Fridlander, Coventry	25592	S.r., g.b., s.o., "Karrusel"	−0·2	−0·1	+0·7	+1·7	−0·2	0·3	0·11	6·0	34·3	37·3	12·8	84·3
Ehrhardt, Ltd., Birmingham	284560	S.r. g.b., s.o.	+1·2	+0·8	+0·6	+0·2	+3·4	0·4	0·06	7·7	31·5	36·6	16·2	84·3
Montandon-Robert, Geneva	1111	D.r., g.b., s.o.	−2·6	−1·4	−4·2	−2·6	−3·8	0·5	0·05	4·7	30·8	36·5	17·0	84·3
Smith & Son, London	191–277	S.r g.b., s.o., "Karrusel"	−0·9	+0·5	+0·7	+2·3	+0·6	0·5	0·05	4·5	30·4	37·2	16·5	84·1
S. Yeomans, Coventry	76684	S.r., g.b , s.o., "Karrusel"	+0·2	+0·7	+0·7	+3·0	+0·9	0·4	0·09	5·7	32·9	37·0	14·1	84·0
T. J. Jackson, Coventry	83582	S.r., g.b., s.o.	+5·1	+4·1	+1·6	+5·4	+7·2	0·4	0·02	7·2	31·2	34·1	18·6	83·9
Stauffer & Co., London	181318	D.r g.b., s.o., chronograph	−0·8	−4·5	−3·2	−0·2	−2·3	0·5	0·03	5·7	31·0	34·6	18·3	83·9
Fridlander, Coventry	25587	S.r., g.b., s.o., "Karrusel"	+2·3	+1·8	+1·8	−1·8	+0·9	0·4	0·06	7·5	32·3	35·3	16·1	83·7
W. Matthews, Coventry	97261	S.r. g.b., s.o., "Karrusel"	+4·9	+3·7	+4·3	+2·1	+2·9	0·5	0·03	6·5	29·1	36·5	17·9	83·5
Smith & Son, London	172–351 14887	S.r., g.b., s.o.	+5·0	+3·2	+4·1	+1·5	+0·1	0·4	0·03	8·5	31·9	33·6	17·9	83·4
Fridlander, Coventry	52764	D.r., g.b., s.o.	−1·0	+0·1	−1·6	−0·4	−2·8	0·4	0·08	5·2	32·1	36·6	11·5	83·2
J. White & Son, Coventry	35103	S.r., g.b., s.o.	+1·4	+3·6	+1·4	+3·5	+6·0	0·4	0·03	5·8	31·2	34·2	17·8	83·2
Matthews, Coventry	97766	S.r. g.b., s.o., "Karrusel"	+2·0	+4·4	+5·0	+2·4	+3·1	0·4	0·08	7·5	32·6	35·8	14·7	83·1
Usher & Cole, London	29854	S.r., g.b., s.o., "Karrusel"	+0·6	+0·8	+0·7	+1·6	+2·1	0·4	0·10	5·7	32·1	37·7	13·3	83·1
J. White & Son, Coventry	36906	D.r g.b., s.o.	+1·5	+0·1	+2·0	−1·4	+3·2	0·5	0·03	7·7	30·9	34·5	17·7	83·1
S. Yeomans, Coventry	76664	S.r., g.b., s.o., "Karrusel"	+1·3	+1·7	+1·5	+0·4	+2·2	0·5	0·09	7·0	30·5	38·1	14·4	83·0
Baume & Co., London	12986	S.r., g.b., s.o., "Karrusel"	−2·1	−2·2	−2·2	−0·4	+1·1	0·5	0·05	5·7	30·9	35·0	17·0	82·9
J. White & Son, Coventry	34929	D.r g b., s.o.	+1·3	+5·5	+2·7	+1·3	+3·6	0·5	0·04	7·2	30·7	34·6	17·6	82·9
R. Milne, Sale	1263	S.r., g.b., s.o., "Karrusel"	−0·5	−0·4	+0·2	−1·0	−2·4	0·5	0·07	5·5	30·2	37·1	15·4	82·7
Williamson, Ltd., London	56019	S.r g.b., s.o., "Karrusel"	+2·6	+1·9	+2·6	+2·7	+4·6	0·5	0·06	6·8	29·5	37·2	16·0	82·7
" " "	56020	S.r g b., s.o., "Karrusel"	−0·0	+0·3	−0·1	+2·8	+3·0	0·4	0·06	4·5	31·9	34·5	16·1	82·5
H. Golay, London	157	S.r. g.b., s.o., "Karrusel"	−3·5	−2·6	−2·7	−0·1	−1·8	0·4	0·07	5·0	31·1	36·1	15·3	82·5
Ehrhardt, Ltd., Birmingham	272896	S. g b., s.o.	+2·5	−1·8	−1·3	+1·1	−2·0	0·5	0·01	7·7	30·2	33·2	19·1	82·5
" " "	272897	S.r., g.b., s.o.	+5·4	+2·0	+2·5	+1·3	+1·2	0·6	0·02	7·0	28·2	35·3	18·7	82·2
R. Gardner, London	52009	S.r., g.b., s.o., "Karrusel"	−0·2	−1·1	−1·2	+0·9	−1·4	0·6	0·03	4·5	27·2	37·0	18·0	82·2

In the above List, the following abbreviations are used, viz.:—s.r. for single roller; d.r. for double roller; g.b. for going barrel; s.o. for single overcoil; d.o. for double overcoil; + for gaining rate; − for losing rate.

Table II.

Highest Marks obtained by Complicated Watches during the year.

Description of watch.	Number.	Deposited by	Marks awarded for			Total marks.
			Variation.	Position.	Temperature.	
			0—40	0—40	0—20	0—100.
Minute and split seconds chronograph, repeater, and perpetual calendar, with phases of the moon	150-100	S. Smith and Son, London	30·3	29·6	7·8	67·7
Minute and split seconds chronograph and minute repeater	1900-5	S. Smith and Son, London	31·4	34·1	16·5	82·0
Minute chronograph and minute repeater (not split seconds)	29828	Usher and Cole, London	30·9	26·9	12·7	70·5
Minute and split seconds chronograph	181318	Stauffer, Son, and Co., London	31·0	34·6	18·3	83·9
" " "	140-80	S. Smith and Son, "	28·4	32·2	18·3	78·9
" " "	2429	H. Golay, "	27·8	33·0	15·7	76·5
" " "	181324	Stauffer, Son and Co., "	30·7	31·4	13·1	75·2
Minute and seconds chronograph	28166	Usher and Cole, London	30·9	34·2	15·3	80·4
" " "	2345	H. Golay, "	28·5	33·5	16·5	78·5
" " "	2316	" "	29·3	30·8	17·8	77·9
" " " (non-magnetic)	260529	Baume and Co. "	28·1	34·7	14·0	76·8
Minute repeater	1096	Montandon-Robert, Geneva	33·2	36·1	15·1	84·4
" "	1900-3	S. Smith and Son, London	33·8	37·4	10·9	82·1
" "	1958	H. Golay, "	30·3	35·4	14·4	80·1
" " (and clock)	1154	Montandon-Robert, Geneva	30·5	32·3	16·7	79·5

Table II—*continued.*

Description of watch.	Number.	Deposited by	Marks awarded for			Total marks.
			Variation.	Position.	Temperature.	
			0–40	0–40	0–20	0–100.
"Non-magnetic"	190–364 25581	S. Smith and Son, London....	29·8	36·6	14·1	80·5
"	191–231	" "	31·8	34·8	13·9	80·5
"	191–228	" "	26·0	35·3	16·3	77·6
"	191–373 25590	" "	30·5	32·7	12·8	76·0

"The Stability of a Spherical Nebula." By J. H. Jeans, B.A., Scholar of Trinity College, and Isaac Newton Student in the University of Cambridge. Communicated by Professor G. H. Darwin, F.R.S. Received June 15,—Read June 20, 1901.

(Abstract.)

It is usual to take as the theoretical basis of the nebular hypothesis the established fact that the equilibrium of a rotating mass of liquid becomes unstable as soon as the rotation exceeds a certain critical value. The present paper attempts to examine whether it is justifiable to argue by analogy from the case of a liquid to that of a gaseous nebula, and it is found that, on the whole, this question must be answered in the negative. The paper is written with especial reference to a paper by Professor G. H. Darwin,* in which it is shown that a swarm of meteorites may, with certain limitations, be treated as a mass of gas. The result obtained for a gaseous nebula can accordingly be at once transferred to the case of a meteoric swarm.

It appears that the main difference between the stability of a liquid and that of a gas, lies in the difference of the parts played by gravitation in the two cases. In the case of a liquid, gravitation is the factor which supplies the forces of restitution; in the case of a gas these forces are provided by the elasticity of the gas, while the influence of gravitation, for some vibrations at least, tends towards instability.

It is shown, in the first place, that the principal vibrations of any spherically symmetrical nebula can be classified into vibrations of orders 0, 1, 2, ... ∞, where a vibration of order n is such that the radial displacement and the cubical dilatation at any point are each proportional to the same surface-harmonic S_n of order n.

The case of a nebula which extends to infinity is then examined, and it is shown that the stability depends solely upon the value of a function as defined by

$$u_\infty = \operatorname*{L^t}_{r=\infty} \frac{2\pi\rho r^2}{\kappa},$$

where ρ, κ are the density and elasticity of the gas at a distance r from the centre. Vibrations of zero order are of zero frequency; vibrations of order n (other than zero) become unstable as soon as u_∞ exceeds the value

$$u_\infty = \tfrac{1}{2}n(n+1).$$

Hence instability enters first through a vibration of order $n = 1$, and the nebula becomes unstable as soon as the value of u_∞ exceeds unity.

It is found that for a non-rotating nebula in which the gas equations

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* 'Phil. Trans.,' A, vol. 180, p. 1.

are satisfied at every point, $u_\infty = 1$. Hence the stability or instability of an actual nebula may be regarded as determined by the sign of the algebraical sum of a number of corrections. The signs of these corrections are as follows:—

(i.) Rotation, however small, tends to instability.

(ii.) If the nebula is in process of cooling, the configuration at any instant will not be strictly an equilibrium configuration; the values of some quantities will lag behind their equilibrium values, and this "lag" tends to instability.

(iii.) Viscosity does not influence the question of stability or instability.

(iv.) A correction is required by the fact that the assumed gas equations cannot remain true for densities below a certain critical value. This can be seen to supply a factor which tends towards stability.

We conclude that a nebula may become unstable for values of the rotation, which are quite small in comparison with those required in the case of a rotating fluid.

The instability first enters through a vibration of frequency $p = 0$, the configuration at this instant corresponding to what Poincaré describes as a "point of bifurcation." The subsequent motion consists at first of a condensation of matter about one radius of the nebula, and a rarefaction about the opposite radius. In the later stages there is superimposed upon this a condensation about the axis formed by these two radii, and a rarefaction in the neighbourhood of the corresponding equator. This motion, it will be seen, strongly suggests the ultimate separation of the nebula into two nebulæ of unequal size, or, in other words, the ejection of a satellite.

The influence of rotation in effecting instability will increase as the temperature decreases, and we can imagine the same nebula becoming unstable time after time as it cools, stability being regained each time after the ejection of a satellite.

If the rotation of the primary is large, the planes of the orbits of the satellites will be almost entirely determined by the direction of the axis of rotation; for smaller values of the rotation other factors may come into play, so that there is theoretically no limit to the obliquity of the planes of the satellites. For instance, if a slowly rotating nebula, when near to the critical state of neutral equilibrium, is penetrated by a meteorite of sufficient size, the result will be the ejection of a satellite, of which the plane will almost entirely depend on the path of the disturbing meteorite. The same effect may be caused by the attraction of a distant mass, the plane of the satellite depending mainly upon the position or path of this mass.

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"The Spectrum of η Argus." By Sir David Gill, K.C.B., LLD., F.R.S., H.M. Astronomer at the Cape. Received May 24,—Read June 6, 1901.

[Plate 4.]

The star η Argus, as is well known, was for a short time almost the brightest star in the heavens. Between 1677 and 1870 its light fluctuated between magnitude 0 and 6·8, and, since the latter date has gradually faded from 6¾ to 7¾—its magnitude at the present day.

Soon after the McClean telescope was mounted, and by way of testing its performance, a plate was taken, with the object-glass prism of 8¼° refracting angle in front of the object glass, of the area of the sky surrounding η Argus.

As this plate showed that η Argus had a very remarkable bright-line spectrum, an attempt was made to obtain a spectrograph with the slit spectroscope, together with a comparison spectrum. Within the past few weeks I have been engaged in measuring some of these experimental spectrograms—a work that other occupations had until now prevented me from undertaking.

As the reductions of the measures show that the spectrum of η Argus closely resembles that of the Nova Aurigæ, it seems to be of considerable interest, in view of the appearance of Anderson's new star in Perseus, to publish the present results, although in many respects they are not so complete as might otherwise be desirable. Thus I have no doubt that, by sacrificing the definition near Hγ and by a longer focal setting and longer exposure, one could get a considerable extension of the spectrum in both directions with the objective prism, and, with the slit-spectroscope, obtain a good determination of the velocity of the star in the line of sight by a much shorter exposure and with direct comparison of the brightest star-line with Hβ. These further points may, however, remain for future investigation.

The plate taken with the slit spectroscope is shown in fig. 1 (Plate 4). It was exposed as follows:—

1899.	April 14	Exposure	165 minutes.
	,, 15	,,	10 ,,
	,, 16	,,	150 ,,
	,, 17	,,	45 ,,
	Total.................		6 h. 10 m.

The comparison spectrum of iron was obtained from a single brilliant spark between iron terminals connected with a powerful coil and battery of Leyden jars immediately before the first day's exposure.

Eleven selected iron lines were carefully measured with the Toepfer micrometer. A least-square solution with Hartmann's formula gave

$$\lambda = \overset{(\lambda_0)}{2180 \cdot 30} - \frac{\overset{(C)}{181854 \cdot 2}}{n - \underset{(n_0)}{128 \cdot 8971}}$$

of which the residuals respectively were

λ.	Resid.	λ.	Resid.
4063·72......	−0·03	4404·79......	−0·15
4171·82......	−0·02	4476·34......	0·15
4118·90......	0·18	4529·1	0·30
4143·85......	−0·16	4872·25......	0·35
4260·61......	−0·06	4957·50......	−0·18
4325·88......	−0·10		

In determining the wave-lengths of the lines in the spectrum of η Argus the above formula was not used, as the representation did not seem sufficiently exact nor could the whole spectrum be conveniently measured at once.

The attached table shows the subdivisions of observation and computation. The above value of λ_0 was retained in the computations, but n_0 and C were determined separately for each block. The means of the micrometer readings are corrected for the carefully determined errors of the screw.

It will be noted that we get for the wave-lengths of the hydrogen lines the following results:—

	Observed.	Known.	K − O.
H_β	4863·38	4861·49	−1·89
H_γ	4343·71	4340·66	−3·05
H	4105·08	4101·85	−3·23

As there is no symmetry between the time of exposure of the plate to the iron flash and to the star-spectrum, we cannot suppose this displacement to be necessarily due to motion of the star; it is more probably due to change of temperature, &c., in the spectroscope. The wave-lengths given in the separate column are corrected for displacement so as to bring out the wave-lengths of the hydrogen and other lines at their true values.

The wave-lengths of the corresponding bright lines in the spectrum of Nova Aurigæ as observed at the Lick Observatory or Potsdam,* are given in the adjoining column, and the agreement is very remarkable.

The photograph with the object-glass prism was taken in 1899, January 14, with an exposure of one hour. The star was trailed to and fro for 0·5 mm., the guiding being done by a neighbouring star viewed in the guiding telescope. The original negative is enlarged 5 diameters in the plate sent (fig. 2, Plate 4).

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* Scheiner's (Frost) 'Astronomical Spectroscopy,' p. 287.

The wave-lengths given in the object-glass prism table were deriv
from careful measures which were converted into wave-lengths l
Hartmann's formula and the known wave-length of the hydrogen line

The wave-lengths resulting from the object-glass prism are natural
far less reliable than those from the slit spectroscope.

From the very exact agreement between the spectrum of η Arg
and that of the Nova Aurigæ, it appears that whatever the causes
the origin of the Nova in Auriga, very similar causes have probab
produced the historical changes in the brightness of η Argus.

Table.

Spectrum of η Argus. Measures from slit spectrograph.						Corresponding bright lines in spectrum of Nova Aurigæ.	η Argus (objective prism	
Comparison. Micrometer. R.	Spectrum. Fe.	Spectrum of η Argus.			λ Corected for displacement.	P = Potsdam. L = Lick. λ	λ	Int
		Micrometer.	λ	Int.				
63·4193	4957·68	...	...	...	...	...	5018·2	2
		62·6624	4925·9	6	4924·2	P 4923	4924·5	4
		61·1187	4863·38 Hβ	40	4861·49	P 4862 Hβ	4861·49	40
		59·8889	4815·6	2	4813·5	...	4811·6	1
54·6904	4630·90	57·5872	4730·5	2	4828·2	...	4727·0	3 b
54·6896	4630·90	...	...	...	...	...	4665·8	3 v. l
54·4117	4622·00	54·6871	4630·9	4	4628·5	P 4628	4627·6	8
		54·4070	4621·7	2	4619·3	...	—	—
		53·2965	4585·9	7	4583·4	P 4583	4583·4	7
		52·8596	4572·1	3	4569·6	L 4570	—	—
		52·4900	4560·5	6	4558·0	P 4557	—	—
		52·2008	4551·5	7	4549·0	L 4549	4552·2	—
		51·6428	4534·1	4	4531·8	P 4530	—	—
		51·2971	4523·9	5	4521·3	P 4520	4518·8	v. v.
		51·0199	4515·6	2	4513·0	—	—	—
		50·7851	4508·6	2	4506·0	—	—	—
		50·5527	4501·7	1	4499·1	—	—	—
		50·2151	4491·7	4	4489·1	L 4490	4487·7	5 v.
		49·6058	4474·0	1	4471·3	$\frac{L+P}{2}$ 4472	4472·4	—
		49·4519	4469·5	1	4466·8	—	—	—
		49·1225	4460·1	2	4457·4	—	—	—
		48·9977	4456·5	2	4453·9	—	—	—
		48·7287	4448·9	2	4446·2	P 4445	—	—
		48·5516	4444·0	2	4441·3	—	4441·6	—
47·5260	4415·33	47·5599	4416·3	10	4413·6	P 4417 ?	4414·0	—
47·1436	4404·94	...	...	...	...	...	...	10
47·1424	4404·94	...	...	...	...	...	4395·8	3
46·3547	4383·72	45·4700	4360·7	9	4357·5	...	4360·3	1
44·1345	4325·98	45·1883	4353·3	6	4350·2	L 4355	4354·5	20
43·4232	4308·02	44·8215	4343·71 Hγ	10	4340·66	L 4340 Hγ	4340·66	20
43·1062	4299·44	...	...	...	...	...	4300·9	4
42·9005	4294·32	42·6890	4289·1	9	4286·1	...	4286·0	10
42·4178	4282·54	42·2246	4277·7	3	4274·7	...	4275·3	3
41·9777	4271·68	—	—	—	—	—	—	—
41·5002	4260·67	—	—	—	—	—	—	—
41·0769	4250·65	40·8929	4245·8	7	4242·7	...	4242·4	7
40·0791	4227·65	40·4445	4235·3	5	4232·2	...	4232·2	7
39·7487	4219·52	—	—	—	—	—	—	—
38·3117	4144·01	...	...	...	...	P 4176	4174·8	6 br
35·1127	4118·72	...	...	...	...	L 4166 P 4158	4164·4	—
32·7827	4071·84	34·5930	4108·2	Suspected	4105·0	—	—	—
32·3631	4063·75	34·4388	4105·08 Hδ	3	4101·85	L & P Hδ	4101·85	8
—	—	—	—	—	—	—	4087·0	1

br = broad ; v. br. = very broad.

Fig. 1.

Fig. 2.

CROONIAN LECTURE.—"Studies in Visual Sensation." By C. LLOYD MORGAN, F.R.S., Principal of University College, Bristol. Lecture delivered March 21, 1901,—MS. received March 25, 1901.

Peculiar difficulties are encountered when any attempt is made to express the relative values of sensations in quantitative terms which shall make some approach to exactness. No doubt we commonly deal with the less and the more of sensation; we say that a surface appears duller or brighter; but on what scale shall we determine with any precision how much the less, or by what amount the more? What is to be our unit of sensation in terms of which we can reckon our gains and our losses? At first sight it may seem reasonable to assume that the unit of sensation is that which corresponds to some definite and constant amount of physical stimulus or physiological excitation. And unquestionably we seem justified in asserting that under constant conditions, physical and physiological, a given amount of stimulus produces an amount of sensation which is constant in quantity. If it be not so the relation of stimulus to sensation is not a subject that is open to scientific investigation. But apart from the fact that there is some variation of sensitiveness among different individuals, and even in the same observer at different times, there are many familiar facts which show that the physical measurement of luminosity does not accord with the estimates we make of the brightness of the illuminated surface. If a sheet of white paper be illuminated by a standard candle at a given distance it appears of a given brightness; if now the distance of the candle be doubled, the physical luminosity is reduced to one-fourth. But it looks a good deal more than one-quarter as bright. Its brightness may not be even halved. Again, the physical luminosity of coloured paper, as measured by Sir Wm. Abney's methods, does not give values which satisfy sensation. A blue with luminosity 9, as compared with white paper reckoned as 100, appears to have a brightness nearly half-way between black and white; a red with luminosity 18 does not certainly appear twice as bright as the blue. Furthermore, it is well known that a series of equal increments of stimulus does not produce a similar series of equal increments in sensation.

This may readily be illustrated by means of a rotating disc. If a disc be prepared with equal sectors of black and white, the effect on the eye, when rotation is sufficiently rapid completely to extinguish flicker, is that of a uniform grey. But it is a grey so light as to be not far removed from white. We may assume that the physical luminosity of the surface is, since the sectors are equal, the arithmetical mean between that of the white and that of the black employed.

But the brightness or sensation-luminosity is certainly far removed from the arithmetical mean between that due to white and that produced by black. The fact is, perhaps, even more clearly brought out if we divide a disc into eleven concentric areas of equal width, of which the inner is all white and the outer all black, while the intervening areas have sectors giving a series of 10 per cent. increments of white. On setting such a disc in rotation a series of concentric grey rings is obtained. Now if the equal increments of stimulus produced equal increments of sensation, the ten steps leading from black to white should appear to be of equal value. But they appear to be of very unequal values. While the step from black to the darkest grey involves a large stride in sensation, seemingly almost half-way towards the white, that from white to the lightest grey is of no great amount. Nor is this difference materially altered by reversing the order of the rings. With steps proceeding from inner black to outer white their inequality for sensation is just as obvious.

No doubt in reaching this conclusion we are dependent on the exercise of comparison and judgment. We must compare the value of the steps from ring to ring in order that we may perceive their inequality. But the inequality is not a property of the perception but of the visual sensations which are perceived to be separated by unequal intervals. We cannot investigate sensations at all without passing judgment upon them. It is fatal, however, to clear thinking to confuse the act of judgment with the sensory data on which such judgment is passed.

It is noteworthy that the rings afforded by such a disc when in rapid rotation are not uniform in shade. Apart from the differences of luminosity for sensation between ring and ring, the shade of grey within any selected ring is not the same throughout its width. There is the same percentage of white stimulus throughout its breadth; but there is not the same brightness for the eye between its limiting boundaries. When the ring adjoins its lighter neighbour it appears distinctly darker than it does on that side which is in juxtaposition to its darker neighbour. This is unquestionably due to the effects of contrast, through the subjective influence of which each ring is differentiated in sensation, though there is no corresponding differentiation in the exciting stimulus. It is noteworthy, too, that this contrast effect is more marked in the darker rings than it is in the lighter rings. We have here a disturbing element, for which we must be prepared to make the necessary allowance. For the present, however, we may assume that, though introducing a factor which somewhat distracts the judgment, the disturbance is not sufficient to invalidate the conclusion that equal, or approximately equal, increments of stimulus produce increments of brightness which differ widely in value.

We may next endeavour to ascertain whether we cannot by experimental work obtain a series of rings which do afford approximately equal steps from black to white—of which any intervening ring appears to be of an intensity or shade which is the arithmetical mean between its neighbours on either side. This may be done by means of slit discs on Maxwell's method, giving sectors which slide over each other so as to alter the relative proportions of the white and black. First a mid-grey may be found, which appears to give a half-way sensation between black and white; then other greys, which appear to be arithmetical means between the mid-grey and black on the one hand, and on the other hand between the mid-grey and white. Thus by a series of careful adjustments rings may be obtained which enable the eye to pass from black to white by steps which are of approximately equal value for sensation.

It is not, however, easy to judge of the exact equality of the sensation increments. It is not easy, for example, to say what shade of grey stands just midway between black and white; and with four steps, even when one judges them to be approximately equal, one feels that there is equality with a subtle difference. The step from black to dark grey may be substantially similar in value to that from light grey to white; but it is not the same; and there is the disturbing element of contrast causing the rings to lack uniformity of shade. One feels that the method of rings giving equal sensation increments can only give a first approximation to a scale of sensation. For what they are worth, however, let us consider the results.

Admitting that we have reached a first approximation towards an evenly graded series of sensations, we have at least advanced a stage towards the establishment of an arbitrary unit of sensation. We have obtained a scale or ladder from black to white. How shall we deal with it? Let us term our black the zero of an arbitrary scale, and our white 100 per cent. We must realise, however, that our zero, which we term black, is simply a datum level from which to reckon. That which I employ is a dull black surface paper coated with black enamel. This gives a bright reflecting surface; but it is not difficult so to arrange matters that the scanty light reflected to the eye from its surface is derived from black velvet or cloth hung in a dark corner. Still it is not, and it makes no pretence to be, absolute black. Let us assume that it is a very dark grey, and let that be our zero of stimulus and also our zero of sensation. So too at the other end of the scale. Our white paper affords an arbitrarily selected luminosity under given conditions of illumination, and we call it 100 per cent. of stimulus, corresponding to 100 per cent. of sensation. We have thus a percentage scale—I repeat again a purely arbitrary percentage scale—for both stimulus and sensation, by means of which we can bring them into relation to each other within the assigned limits.

Let us now compare the results we have so far obtained, stating

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them in the terms afforded by the arbitrary scales. The percentages are as follows:—

Sensation	0	25	50	75	100
Stimulus............	0	6·5	20	47	100

Stated in this form, while the sensations are in arithmetical progression there is at first sight no very definite series in the stimuli. But if we express the results in a somewhat different form the stimuli fall into an orderly sequence. The following figures give the *increments* of sensation and of stimulus:—

Sensation	0	+ 25	+ 25	+ 25	+ 25	= 100
Stimulus	0	+ 6·5	+ 13·5	+ 27	+ 53	= 100

It is clear that the stimulus increments are here nearly in geometrical progression. And if we may base a purely provisional and empirical generalisation on so slender an experimental foundation, we may say that equal increments of sensation require increments of stimulus in geometrical progression.

Such being the preliminary results obtained from a series of approximately equal sensation steps, we may now, on the basis of our provisional generalisation, interpolate other points between those obtained by observation, and through them sweep a smoothed curve. And having done so, we can translate the curve on to a disc which shall give a continuous geometrical increase of stimulus from our zero black to our 100 per cent. of white. And this on rapid rotation should afford a smooth passage from black to white in sensation. There ought to be a perfectly even and uniform ascending slope of sensation from our zero black through progressively lightening shades of grey to our limit of 100 per cent. of white. Our mid-grey should lie just in the middle between the extremes. When the disc so prepared is set in rapid rotation, however, though there is a gentle shading from white into black, this shading is not uniform. There is a lack of balance. The mid-grey does not appear to be just half-way between black on the one hand and white on the other hand. It lies too near the black, and the shading is therefore too rapid from this mid-grey into black, not rapid enough in the opposite direction towards white. The appearance is not that of a uniform slope of sensation, but rather that of a gentle convex curve, the surface appearing slightly spherical.

It may here be noted in passing that we have to be on our guard against the misleading effects of a so-called optical illusion. In our rotating disc we have to judge the position of the mid-grey, which should lie equidistant from the black and the white. But in a disc or a sector thereof there is a tendency to misjudge the distance, from the centre, of a circle which bisects the radii. The inequality of the areas tends to confuse the judgment as to distance, and the position where

the mid-grey should fall is apt to be placed too far from the centre. The position of the mid-grey is also apt to be misjudged according as we are shading from inner white to outer black or *vice versâ*. In practice I endeavour to avoid these disturbing effects, first by constructing discs to shade both ways and taking the mean results, and, secondly, by dealing with a reflected image of a portion of the disc, from centre to circumference, in a slip mirror, 140 mm. long by 25 mm. wide, the edges of which may be graduated. It is easier to judge of the accuracy of shading in such a band than in a complete disc. Making all allowances, however, for misjudgment of position in the mid-point, the smoothed curve drawn through the points experimentally determined by the method of graded rings does not shade satisfactorily.

Before attempting to indicate the probable cause of this discrepancy, it will be convenient to draw attention to the further experimental work which it suggests. If the smoothed curve we have so far obtained does not afford to the eye satisfactory shading, it obviously remains to determine what curve does give results in sensation which appeal to the judgment as approximately accurate. The shading of the disc which expresses the curve passing through 20 per cent. of white stimulus as the mid-point is so far satisfactory as to suggest that the curve is right in principle but faulty in its application. And a great number of experiments, which need not here be described, convinced me that the introduction of + and − variations at different parts of such a curve, so as to alter its character, only serve to make matters worse and not better. It seems, therefore, that what requires alteration is the position of the mid-point of the curve, or in other words the value of the first of the series of smoothed steps, and that of the factor required to give a geometrical progression of stimulus increments.

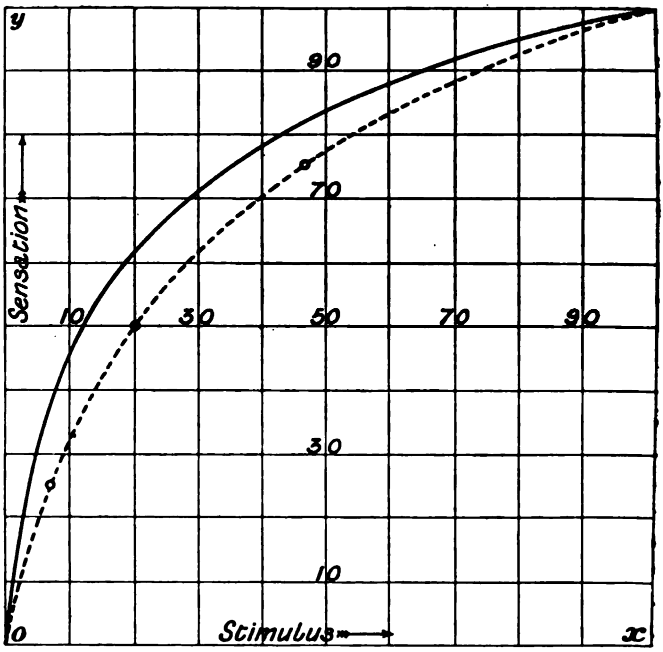
It is easy to construct a curve on the same principle which shall pass through any desired mid-point, and to translate it into the answering curve on a disc. It being obvious that the required mid-point is less than 20 per cent., a series of discs were constructed in which the value of the mid-point ranged from 20 per cent. down to 10 per cent. By using these, I found that the mid-point for continuous shading of white into black lies between 10 per cent. and 15 per cent.; and by further experimental work, I found that 12 per cent. gives the best result for my eye under the conditions of daylight illumination which I employ. The accompanying figure shows the curve representing the relation of stimulus to sensation which is deduced from it. The firm line shows the curve passing through 12 per cent. as mid-point, the dotted line that passing through the points determined by means of the graded disc with grey rings.

It here naturally suggests itself that the data obtained for the graded ring disc were erroneous, and that the discrepancy is due to

[redacted]

faulty observation. This can now be readily put to the test of further experiment. A ring disc can be constructed on the basis of the new curve. But this on rotation affords steps which are of very distinctly unequal value to the eye.

FIG. 1.



There is therefore a real discrepancy for sensation between the results obtained by the method of continuous shading, and those obtained by the method of graded steps. May it not be due to those effects of contrast to which attention has already been drawn? To test the validity of this suggestion attempts were made to get rid of the effects of contrast within each ring, and in doing so, to obtain a rough quantitative measure of these effects. We have seen that each ring appears too light on that side which adjoins a darker neighbour, too dark on the other border where it is in contact with a lighter neighbour. Either by increasing the amount of white stimulus on its darker side, or by decreasing that amount on its lighter side, the ring may be made to appear of uniform shade throughout. It was found that approximately the same proportional amount of white must be added at one border or subtracted at the other border to produce this result.

Taking the step disc, which gives fairly equal sensation increments, it was found that the three grey rings required very unequal amounts of proportional reduction in order to render them of uniform shade to the eye. As the mean of three sets of observations, the dark grey ring required 50 per cent. reduction of the white at its outer border; the mid-grey ring 40 per cent.; the light-grey ring 25 per cent. These figures give only a rough and preliminary approximation to a quantitative estimate in terms of physical stimulation of the effects of contrast under certain conditions of illumination and for speeds of rotation sufficiently rapid completely to get rid of any flicker effect. If the illumination be materially reduced or if flicker occur, the contrast effects within the rings reappear. In other words, with reduced illumination or with that flicker effect which has recently been studied by Professor Sherrington,[*] a large proportional amount of reduction is required.

The quantitative estimate of contrast and its physiological bearing, cannot here be further discussed. The markedly different effects in the several rings is sufficient to suggest that we have here a sufficient cause for the discrepancy between results obtained by the method of ring grading and those reached through continuous shading. For the present, however, I am not prepared to do more than suggest that the curve for continuous shading affords a more trustworthy scale for comparing the relative values of stimulus and sensation than is afforded by graded rings which do not appear of uniform shades of grey throughout their width. I provisionally accept therefore the curve through 12 per cent. mid-point as a basis for further experimental work.

I must here confess that in a previous paper[†] I gave far too high a percentage for the mid-point. But the black I then used was not nearly so deep, the white was not quite so brilliant; I failed to make due allowance for the so-called optical illusions before mentioned; and, the worst error as I now see, I used ring grading as a check on continuous shading, not realising that the effects of contrast vitiated the results in the manner in which I have just attempted to indicate.

I may now pass on to consider another fact which shows the importance of conducting observations in visual sensation under approximately uniform conditions of illumination. Suppose that with a given illumination we have obtained even shading or fairly equal steps on a ring disc, and suppose that the illumination be then materially diminished. The one disc no longer gives even shading; the other no longer gives rings with equal sensation steps. Delbœuf[‡] drew attention to this fact for discs with grey rings, and accounted for it by a somewhat far-fetched hypothesis of physiological tension. No such

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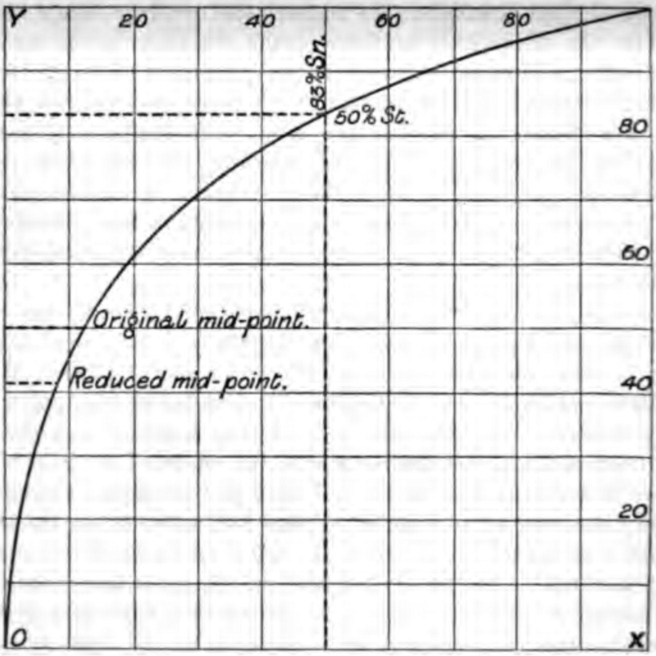
[*] 'Journal of Physiology,' vol. 21, p. 33 (1897).

[†] 'Psychological Review,' May 1900, p. 217 (vol. 7).

[‡] 'Examen Critique de la Loi Psychophysique,' 1883, pp. 147-48.

hypothesis is, however, needed. The fact is a necessary corollary from the nature of the curve which brings stimulus and sensation into relation with each other. This may best be illustrated by taking a somewhat extreme case, and dealing only with the value of mid-grey. Let us suppose that 12 per cent. of white stimulus gives, under a given illumination, a sensation of approximately 50 per cent. on the arbitrary scale—that is to say, a sensation half-way between black and white. And let us further suppose that the illumination is reduced to one-half. What will be the effects in sensation? It might at first sight be supposed that since the full-white was reduced by half, and the 12 per cent. for mid-grey also reduced by half, the sensations underwent a similar reduction. But further consideration shows that the two scales (that for stimulus and that for sensation) being unequally reduced, the position of the mid-point for sensation is necessarily shifted.

FIG. 2.



Reference to fig. 2 shows that 50 per cent. stimulus affords 83 per cent. sensation, and that 6 per cent. stimulus affords 36 per cent. sensation. But 36 per cent. sensation is not the mid-point between 0 per cent. and 83 per cent. The mid-sensation will be 41·5 per cent., and this requires 8 per cent. of stimulus. Hence, for the given reduction illumination an additional 2 per cent. of stimulus is required afford a mid-sensation between the black and the reduced value of the white. It is here assumed that the reduced illumination makes so small a difference in the black as to be inappreciable and practically negligible.

Fortunately for experimental work a *slight* reduction of the illumination makes but little difference in the mid-point for sensation. A reduction of the physical luminosity of the white paper by 15 per cent. only reduces the sensation it affords by 4 per cent., and the additional stimulus to be added to give the new mid-point is only 0·74 per cent.

It may be pointed out that the general fact of the alteration of sensation values by changes in the illumination is quite familiar. An ill-lit engraving not only looks duller, but the relative intensities of the shading are not preserved. And the fact would probably be more noticeable were it not that we are daily accustomed to changes of illumination of the same scene as the sun declines and sinks below the horizon.

I shall return presently to the question of illumination so as to bring these facts into relation with the results of the further experimental work to be ere long described.

If the provisional scale represented by the graphic curve gives an approximation to the relative values of stimulus and sensation, that is to say, of physical luminosity and apparent brightness to the eye, we may use it to interpret the facts which I mentioned at the outset with regard to the physical illumination of a surface of white paper and its apparent brightness. Let us suppose that with standard illumination the luminosity of the surface is 64, the corresponding value for sensation in terms of brightness is 89. If now the physical luminosity is reduced to one-fourth, it will have the value 64 ÷ 4 = 16, the corresponding value of which is, for sensation, 56. One-quarter the illumination thus affords about two-thirds the brightness, which is pretty well in accordance with the testimony of sensation. The 9 per cent. luminosity of blue gives a sensation-luminosity or brightness of 44 per cent., and the 18 per cent. luminosity of red a brightness of 59 per cent. These again accord very fairly with the verdict of the eye.

Having now obtained a fairly even shading from white into black, colours were next dealt with. Coloured papers were employed, and no attempt was made to obtain colours with any approach to spectral purity. Continuous shading will alone be considered for comparison with that of black into white. The curves for five colours on black were experimentally determined and plotted. The early work was purely empirical. Plus and minus alterations at different parts of the extent of each curve were introduced until the eye was satisfied that there was an approximately even shading from black into the colour under investigation. But when it was found that in each case for equal increments of sensation increments of colour stimulus in geometrical progression were required, further work was based on the assumption that this empirical generalisation is trustworthy. For convenience of plotting an arbitrary percentage scale was used in each case, so that the curves merely represent the percentages of red, blue, or other stimulus which give equal increments of colour sensation between black and the unmodified colour reckoned as 100. The curves being constructed on similar principles, they are sufficiently indicated by reference to their mid-points, that is, to the stimulus which affords 50 per cent. of colour sensation. The following table gives the results for five colours :—

	Mid-point.	
Light yellow on black	13·5 per cent.	of yellow stimulus.
Orange on black	18·0 „	of orange „
Light blue on black	19·0 „	of light blue stimulus.
Red on black	23·0 „	of red stimulus.
Full blue on black	28·0 „	of blue stimulus.

Two cases were also taken so as to afford the even sensational shading of white into colour. The results obtained were as follows :—

	Mid-point.	
White on full blue	25 per cent.	of white.
„ red	30 „	of red.

And three cases were taken so as to obtain even shading from one colour into another—for example, red into blue through intervening tints of purple—with the following results :—

	Mid-point.	
Orange on full blue	36 per cent.	of orange.
Yellow on light blue	40 „	of yellow.
Red on full blue	44 „	of red.

The fact that in all these ten sets of experimental results, a curve is obtained based on the principle that equal increments of sensation require increments of stimulus in geometrical progression, materially broadens the empirical generalisation based on the observation work for the shading of white into black.

Can we not, however, bring the results yet further into line and express them all as portions of a single curve exhibiting the relation of visual stimulus to visual sensation ?

It is well known—largely through the valuable work of Sir Wm. Abney—that the luminosity of any colour may be measured by matching it with a grey.* I have thus determined the luminosity of my coloured papers in terms of greys produced by sectors of the black

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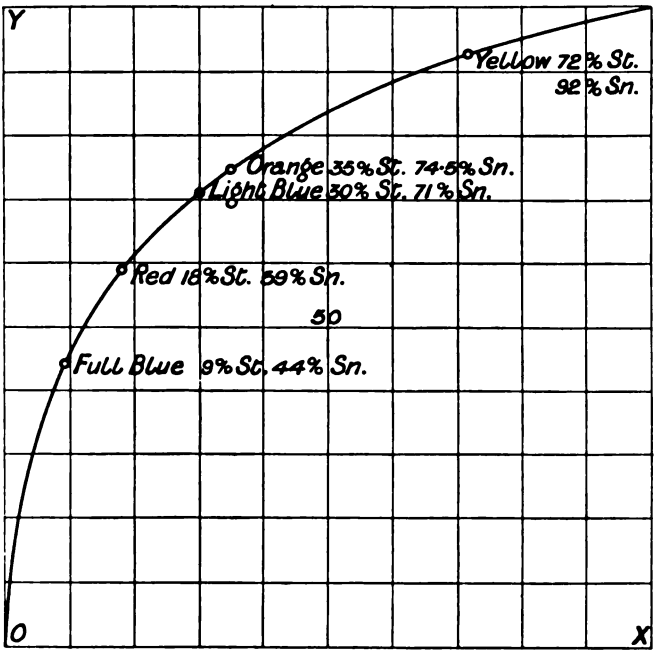
* See Abney, 'Roy. Soc. Proc.,' vol. 67, No. 436, p. 118.

and white employed for continuous shading. In other words, their physical luminosity was assigned in terms of the arbitrary scale. The approximate means of forty observations are given in each case, the variations from the mean ranging from + – 1 per cent. for full blue to + – 3 per cent. for yellow. The following table gives these approximate means—the brightness or sensation luminosity being taken from the black-white curve through 12 per cent. mid-point, which affords our scale of sensation.

	Physical luminosity.	Sensation luminosity.
Full blue	9 per cent. white	44·0 per cent.
Red	18 „ „	59·0 „
Light blue	30 „ „	71·0 „
Orange	35 „ „	74·5 „
Yellow	72 „ „	92·0 „

The values so determined are indicated on the accompanying graphic representation of the black-white curve.

FIG. 3.

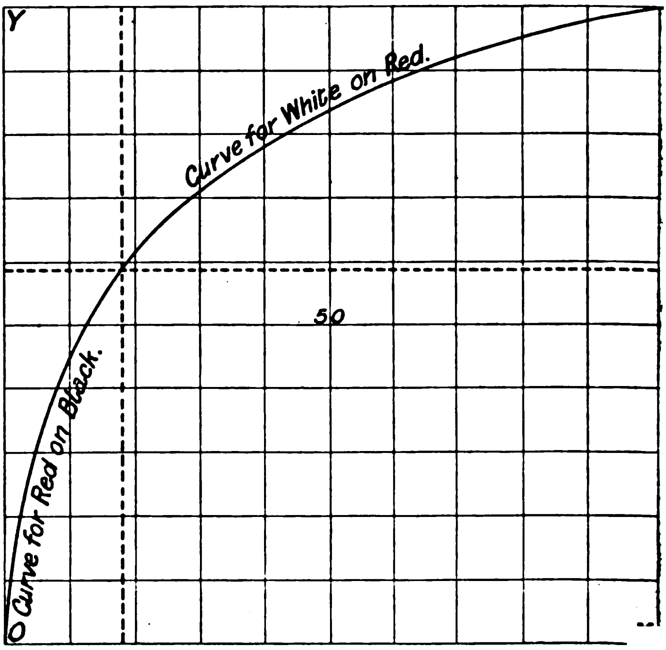


It is now an easy matter to compare the portions of the curve limited by any determined luminosities, with the whole curves obtained by directly experimental methods. That portion of the curve, for example, which lies between black and the luminosity point for red may be compared with the curve for red on black, and similarly the remaining portion of the curve with that for white on red. We have to deal with the parts of the graph blocked off by dotted lines in fig. 4. For convenience of comparison these are in the following table converted into mid-point percentages.

Mid-point Percentages.

	Luminosity method.	Method of shading.
Yellow on black	13·8	13·5
Orange on black	18·6	18·0
Light blue on black	19·7	19·0
Red on black	23·6	23·0
Full blue on black	29·5	28·0
White on full blue	24·7	25·0
White on red	30·6	30·0
Orange on full blue.........	35·4	36·0
Yellow on light blue	39·1	40·0
Red on full blue	43·0	44·0

FIG. 4.



If these results be accepted as giving a sufficiently close agreement it follows, first, that for colour shading the percentages of stimulus required are dependent on the physical luminosity of the colours employed, and secondly that all the data obtained by the method of shading can be plotted on a single curve which exhibits the relation of stimulus to sensation in visual impressions. It also follows that if the intensity of illumination of a disc for white-black shading be so reduced as to lower its luminosity to that, say, of orange under full illumination, the mid-point value will be the same as that for orange on black. I am instituting experiments to test the accuracy of this result; but they are at present incomplete.

Incomplete too are experiments on the method of least perceivable difference.

I find that under certain conditions of illumination and at a given distance from the eye, the amount of white necessary to give a just observable grey ring on a black disc is approximately 0·1 per cent., while under the same conditions the amount of black necessary to give a just observable grey ring on a white disc is approximately 1·1 per cent. I believe, though I cannot assert with confidence, that the least perceivable amounts of white on an intervening series of greys are such as to give a geometrical series. But I find this method of least perceivable increments of sensation—lying though it does at the very basis of so much psychophysical work in the past—far from easy of application, since the required increments are small, and since it is difficult to say what is just perceivable. The extremes I have quoted indicate a geometrical series of 240 stages, with a mid-point of nearly 23 per cent. of white—which is nearer the results with the ring discs than those obtained by continuous shading.

I have also attempted to check the foregoing luminosity determinations by finding the least perceivable amount of coloured paper on a black disc. On the assumption that the amount required is inversely proportional to the luminosity, the results obtained are not very different from those above given. But since I do not regard these results as comparable in accuracy to those obtained on Sir Wm. Abney's method, I do not think it necessary to quote them here.

I have now described the experimental work on which a purely arbitrary scale of visual sensation in relation to the exciting stimuli is based. It is mainly founded on an appeal to my own eye, which is fairly normal with regard to colour sensation. Unquestionably it depends on the personal equation. But I have now only to determine the luminosities of any coloured surfaces, and I can by reference to the scale construct a disc which shall give without further experimental work an even shading of the one into the other. For example, I had not experimentally determined the mid-point for the shading of light blue and orange. By calculation the mid-point should be 48·9 per

cent. A disc with 49 per cent. was constructed and shaded quite satisfactorily. At the same time all I venture to claim is that the general principle is correct. For other eyes the mid-point of the black-white scale may differ somewhat from the 12 per cent. which for me gives the best results. For them the luminosities of the colours may be slightly or even markedly different. But I believe that if the luminosities be determined on their scale it will be found that for them, too, equal increments of sensation are due to increments of stimulus in geometrical progression.

I have not so far adequately correlated my own results with those obtained by previous observers. I regard the investigation as still incomplete, and think that this important part of the work should be reserved as an appendix to follow the presentation of independent observations. A few words may be added in conclusion, however, on the relation which the empirical scale of sensation may hold to an absolute scale based on certain assumptions.

It will be remembered that for purposes of comparison with the black-white curve colour luminosities were determined and recorded in terms of the arbitrary scales. Sir Wm. Abney's determinations are in reference to an absolute zero, his black having a value of about 3·3. Let us assume that the absolute zero of stimulation lies a little less than 2 per cent., or more exactly 1·87474, below the arbitrary zero of my curve, and let this amount be added to the stimuli throughout the scale, so that the white becomes 101·87474, the mid-point 13·87474, and so on. On this assumption the arbitrary scale becomes, so far as stimulus is concerned, an absolute scale. And on this absolute scale of stimulus, the sensations, + some undetermined constant, form an arithmetical series, while the stimuli which are in relation to them form a geometrical series. In other words, the addition of this constant to the summed increments of stimulus at any stage of the scale causes these summed increments to fall into line as the terms of a geometrical progression. The stimulus value of our mid-point on the absolute scale is the geometrical mean between the values of our extremes on the same scale. *On this assumption*, therefore, and *between these limits*, Weber's Law and Fechner's expression of it hold good.

Fechner's logarithmic law, however, involves other assumptions. It involves the assumption that some unit of stimulus 1, gives sensation 0, and that below this threshold of sensation there range an indefinite series of sensations or quasi-sensations of negative sign. And, pushed to its logical conclusion, it further assumes that the logarithmic law holds good throughout this negative series.

Now it is clear that no studies in sensation can throw light on what lies below the threshold of sensation. But physiological research may afford data for the continuation of the curve into the subliminal region.

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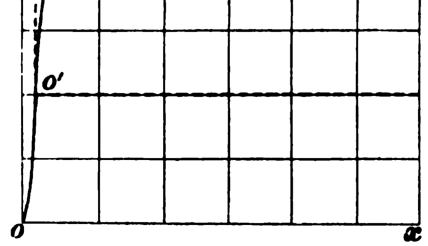
The valuable and important researches of Dr. Augustus Waller,* on retinal stimulation and electrical response, seem to indicate that near its lower limit the curve becomes sigmoidal. The stimulus has to overcome a certain amount of physiological inertia before the normal sweep of the curve is established.

For a time I believed that I had obtained evidence of such a sigmoidal flexure near the origin of the curve in my experimental work on shading. But further observation led me to the conclusion that if it exist within the limits of my curve, the method of investigation is not sufficiently delicate to establish its influence.

Apart, however, from the experimental evidence which Dr. Waller adduces in support of the sigmoidal curve, and apart from the general considerations which he suggests in favour of such a change of sign, some such assumption seems to be well-nigh necessary if we are to attempt to give a complete curve, which near the threshold of sensation does not land us in the maze of difficulties arising from the asymptotic character of a wholly logarithmic curve. There is nothing therefore extravagant in the assumption that the origin of the completed sigmoidal curve should be placed in round numbers 20 per cent. below the arbitrary zero of sensation, and that this amount should be added to the terms of the sensation series on the arbitrary scale in order to convert it into an absolute scale of physiological response. This is indicated in fig. 5, which represents the hypothetical continuation of

FIG. 5.



the curve, on the assumption of sigmoidal curvature, beyond the limits of sensory observation. The part of the graph blocked off by dotted lines shows the lower part of the empirical curve, the absolute zero

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* See 'Brain,' vol. 23, Part 1, p. 30 (1900).

of stimulus being placed in round numbers 2 per cent. below the arbitrary zero, that of physiological response in round numbers 20 per cent. below the arbitrary point of origin (0′) of the empirical curve.

At the same time this 20 per cent. estimate is little better than a guess. I am of opinion that the time for an absolute scale is not yet, and that an empirical generalisation in close touch with observation and experiment, such as that on which my own curve is based, is more likely to be helpful as a guide to further investigation than a wider law involving assumptions the validity of which is doubtful.

"The Yellow Colouring Matters accompanying Chlorophyll and their Spectroscopic Relations. Part II." By C. A. SCHUNCK.

Communicated by Dr. E. SCHUNCK, F.R.S. Received June 5,—Read June 20, 1901.

[PLATES 5, 6.]

In the former investigation* the yellow colouring matters, generally known as the xanthophyll group, which accompany chlorophyll in the healthy green leaves, and which are extracted along with it by means of alcohol, were separated from the chlorophyll by treating the alcoholic extracts with an excess of animal charcoal in the cold, by which means the chlorophyll is absorbed by the charcoal, leaving the yellow colouring matters in the alcohol. On investigating this crude yellow solution it became evident that more than one colouring matter was present, and I now give the results of the experiments I have made in the endeavour to further isolate the constituents of this group by means of carbon bisulphide, which method was adopted by Sorby† in his investigation of the different colouring matters present in plants. The crude alcoholic extracts of the accompanying yellow colouring matters, which I will for the future term the xanthophylls, can be obtained either by the above method or by boiling the chlorophyll extracts for three or four hours with caustic potash or soda (10 grammes to 1 litre of solution), allowing to stand, and shaking up with ether, which takes up the xanthophylls unaltered, whereas the chlorophyll is changed to an alkali compound of alka-chlorophyll, which is insoluble in ether, but soluble in water; the ethereal solution is then evaporated, and the residue dissolved in alcohol. From either method of preparation the same results are obtained.

These crude yellow alcoholic solutions of the xanthophylls show, as a general rule, four distinctive absorption bands in the violet and ultra-violet situated between the lines F and L (Plate 5, C, 2), any indication of

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* 'Roy. Soc. Proc.,' vol. 65, p. 177.

† 'Roy. Soc. Proc.,' vol. 21, p. 456.

[redacted]

a band in the red being due to a trace of chlorophyll that has not been removed, but in some instances depending upon the particular plant experimented with, and the same plant at different seasons, The fourth and most refrangible band is extremely faint, if not absent (Plate 6, F, 1). This variation of the spectrum I failed to observe in my former experiments, and its significance will be apparent later on. As pointed out in my former investigation,* in some instances only the first two or three bands are visible, the rest of the violet and ultra-violet being obscured by a yellow colouring matter producing general absorption, but no bands, which, according to Sorby, belongs to his Lichnoxanthine group, and corresponds to the so-called xanthophyll of Tschirch. In such cases a separation can be effected by agitating with ether, and the addition of water, the colouring matter causing the obscuration remaining in the watery alcoholic solution. In every case the extent of the ultra-violet visible varies, depending, as before, upon the particular plant experimented upon and the same plant at different seasons.

Most of the present experiments were made with alcoholic extracts obtained from *Ficus Carica* and *Ficus Repens*, both of which give a very excellent chlorophyll spectrum, pointing to the presence of very little acid in the juices of the leaf, and, as the presence of acid affects the xanthophylls, it is of importance to prevent complications to experiment with a plant that is more or less free from acid in its juices, a delicate indication of which is the condition of the chlorophyll spectrum of the alcoholic extract, whether normal or not, for the least trace of acid will cause the fourth chlorophyll band to become pronounced instead of appearing very faint. The observations of the absorption spectra were effected as before by means of photography, quartz lenses and an Iceland spar prism being used, and the source of light was a Welsbach incandescent gas mantle of 60-candle power.

The method of procedure was to agitate the crude alcoholic solution of the xanthophylls from which the chlorophyll had been removed by one of the above means with successive equal volumes of CS_2 until no more colouring matter was taken up by the CS_2, each volume of CS_2 being equal to about half the volume of the crude solution experimented upon. By this means we have the colouring matters capable of being taken up by CS_2 divided into several CS_2 portions or fractions (which varied from six to twelve according to the concentration of the crude solution) according to their relative solubility, leaving in the alcohol those colouring matters which are more soluble in it than in CS_2.

On examining first the alcoholic portion from which the dissolved CS_2 had been evaporated by gentle heat, it is found to be a paler yellow than the crude solution and to give four absorption bands in

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* 'Roy. Soc. Proc.,' vol. 65, p. 181.

the violet and ultra-violet, the first two and least refrangible of which are slightly but distinctly shifted towards the violet compared to the first two bands in the crude solution, while the other two occupy approximately the same positions (Plate 5, A, 3); but it is only in a few instances they are plainly visible on the photographic plate, usually they are more or less obscured, only the first band being distinct and well defined (Plate 6, F, 2). The obscuration is no doubt due to the yellow colouring matter before mentioned, the greater quantity of which remains in the alcohol after the CS_2 fractionation, being more soluble in the former than in the latter. Its presence in a considerable quantity tends further to obscure the bands, and it can then be detected at once by the alcoholic solution after fractionation, being more of a straw colour than the usual pale yellow. This spectrum is not stable, for, after standing a few days the least refrangible band fades and finally disappears, and, after a further lapse of time, the other three bands, more especially the third and fourth, became intensified and well defined, the rest of the ultra-violet being obscured (Plate 6, F, 4); but in some cases when there is very little obscuration present, an additional band is discernible in the ultra-violet (Plate 5, A, 4). This change, however, only takes place, as a rule, after fractionation, as the crude solution can be kept a considerable time without any change taking place, pointing to the capability of one colouring matter in protecting a less stable one in a mixture. The same change, however, can be effected at once by adding a very small quantity of HCl to the alcoholic portion, when the colour of the solution immediately becomes a paler yellow, but in a few hours all the bands disappear and the solution becomes a peacock-blue colour which, in a day or two, likewise fades leaving the solution finally colourless. This blue coloration is a characteristic of the colouring matter left in the alcohol after fractionation. By agitating the alcoholic portion with ether and adding water till a separation takes place, the ether takes up the greater quantity of the colouring matter, and, on spontaneous evaporation, an amorphous lemon-yellow substance is deposited which also gives this same spectrum. The last of the CS_2 fractions when taken into alcohol in some cases likewise give this spectrum.

The question whether the normal spectrum of the alcoholic portion represents a single colouring matter I have been unable to decide definitely by spectroscopic means, but I think the above facts tend to prove that on standing or by the action of HCl a definite colouring matter is formed therefrom giving the above changed spectrum, and from it, by the further action of acid, a blue colouring matter is produced. I also think the experiments tend to show that this colouring matter does not pre-exist in the leaf, but is formed subsequently, either spontaneously or by the action of the acid juices during or after the ocess of extraction, which is supported by the fact that from extracts of such leaves as ivy and Virginia creeper that contain much acid in their juices, as evidenced by the condition of their chlorophyll spectrum, the alcoholic portion exhibits this changed spectrum, but if means be taken during extraction to neutralise the acid the normal spectrum is obtained.

Sorby considers* that the alcoholic portion, in addition to his lichnoxanthine, contains two colouring matters which he terms xanthophyll and yellow xanthophyll, and that the action of acid on the *latter* produces the colouring matter giving the above changed spectrum and afterwards the blue coloration.

The CS_2 fractions were evaporated at a gentle heat to dryness, and taken up with alcohol and examined successively. In the first one or two fractions the ultra-violet is visible to a considerable extent, the spectrum consisting of three pronounced well-defined bands, which are slightly shifted, more especially the first towards the red end as compared to the first three bands in the crude solution, the fourth band being absent. The subsequent fractions one by one transmit less and less of the ultra-violet, the three bands are gradually shifted little by little towards the violet in succeeding fractions, the first band gradually becomes fainter, while a fourth band more refrangible than the other three, makes its appearance and becomes intenser as we pass from fraction to fraction, and it will be found that one of the latter fractions corresponds in its spectrum to that of the crude solution (Plate 5, B, 1–5). Lastly the final fractions as a rule exhibit the spectrum produced by acid on the alcoholic portion, the colouring matter to which it is due appearing to be more soluble in CS_2 than in alcohol. The greater part of the colouring matter is found in the first two or three fractions, which are coloured a rich yellow, the succeeding fractions becoming paler and paler until the final fractions are almost colourless, and in order to exhibit their spectra have to be greatly concentrated.

The interpretation of this series of spectra is, I believe, that the crude solution is a mixture of chrysophyll and the colouring matters or matter remaining in the alcohol after fractionation, together with the colouring matter formed from the latter by the action of acid. For on comparing the spectrum of the first fractions with that of chrysophyll they are identical, save that the bands in the former are very slightly shifted towards the violet (Plate 5, D, 1–2); these first fractions also transmit the ultra-violet to a considerably greater extent than does the crude solution, which, together with the three pronounced bands, is a characteristic of chrysophyll; and further, if we mix chrysophyll and the colouring matter remaining in the alcohol after fractionation together, in proper proportions, the spectrum obtained is identical with that of the crude solution (Plate 6, E, 2 and 3). Likewise, I believe,

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* 'Roy. Soc. Proc.,' vol. 21, p. 459.

the various fractions contain these same colouring matters in different proportions, depending upon their relative solubility in CS_2 and alcohol, which is borne out by the slight differences in their spectra, as we pass in rotation from the first to the last fraction. Chrysophyll, as is well known, is always found deposited in the from of sparkling red crystals from the crude chlorophyll extracts when concentrated sufficiently on standing, but in one case only have I been able to obtain the crystals from a crude solution of the xanthophylls after removing the chlorophyll, though I have made many attempts. The failure in this respect may perhaps be accounted for by the very great difficulty there always is in even re-crystallising this substance.

That the bands are not quite in identical positions is admissible, for one cannot obtain a complete separation by a method that depends upon the relative solubility of its constituents in two solvents, so that we should expect to find in the first fractions a little of the other colouring matters (which tend to produce the shifting of the bands), together with the greater portion of the chrysophyll.

From the above results it is, I think, evident that chrysophyll pre-exists, and is not formed spontaneously from one of the colouring matters of the leaf as has been held by some observers, and that it is one if not the chief constituent of the xanthophyll group of yellow colouring matters, accompanying chlorophyll in the healthy green leaf. Chrysophyll evidently corresponds to the orange xanthophyll of Sorby,* which he states is one of the most universally distributed of all vegetable colouring matters, occurring in greater or less quantity in all classes of plants, including fungi.

The action of acid upon the spectrum of chrysophyll, the first CS_2 fractions, the alcoholic portion and the crude solution of the xanthophylls is instructive when compared together, and tends further to confirm the above view taken of the constitution of the crude solution. If a small quantity of HCl be added to each, the effect upon the chrysophyll spectrum and that of the first CS_2 fractions is to cause the bands to fade and the solutions to become gradually colourless (Plate 6, G, 1 and 2). In the crude solution the effect is to cause the first band to become fainter and the fourth darker, even though it be extremely faint, as I have pointed out is the case in some crude solutions. The bands then after a short time fade, but the solution assumes a green colour before becoming colourless (Plate 6, G, 3 and 4).

Lastly, in the alcoholic portion, as before stated, the effect of the acid is to remove the first band, and to clear up the spectrum, the three remaining bands becoming intensified, especially the third and fourth. The bands then fade and the solution assumes a peacock-blue colour, which also after a short time fades, leaving the solution colourless (Plate 6, G, 5). Thus the effect of acid in causing the first band to fade

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* 'Roy. Soc. Proc.,' vol. 21, p. 457.

and the fourth to intensify in the crude solution, together with its effect upon the alcoholic portion and chrysophyll, is in accordance with the view that it is a mixture of the two. I also think the action of acid upon the spectrum of the alcoholic portion explains the origin of the fourth band in the crude solution and its appearance in the later CS_2 fractions, and conclude that it is due to the colouring matter giving the changed spectrum, and formed from the alcoholic portion, either spontaneously or by the action of the acid juices during or after extraction, and that its variability in intensity depends upon the amount of this colouring matter formed. If there be but little acid present, or if means be taken to neutralise it during extraction, then the band will appear, but faint, and in some cases perhaps absent. The green colour assumed by the crude solution is no doubt due to the formation of the peacock-blue colouring matter, which, mixed with the yellow chrysophyll, causes the solution to appear green.

From the above experiments I was evidently in the wrong in the former investigation in considering that the four-banded spectrum exhibited by the crude solution of the xanthophylls represented a single colouring matter, to which I restricted the name Xanthophyll, and think now the right interpretation is that this spectrum is due to a mixture of colouring matters, the chief constituent of which I have been led to believe from the above facts is Chrysophyll, the only member so far of the accompanying yellow colouring matters, I believe, that is obtainable in a crystalline form.

EXPLANATION OF PLATES.

(The solvent in every case is Alcohol.)

PLATE 5.

Xanthophylls obtained from an extract of ***Ficus Repens*** in the month of February:—

A. (1) The first CS_2 fraction.
    (2) The thirteenth and final fraction.
    (3) The alcoholic portion, showing in this experiment four distinct bands.
    (4) The above + HCl, in this experiment showing a distinct fourth band.

B. Some of the CS_2 fractions in alcohol:—
    (1) The first; (2) the second; (3) the fifth; (4) the seventh; (5) the ninth.

C. (1) The first CS_2 fraction.
    (2) The crude solution of the xanthophylls.
    (3) A *mixture* of the first CS_2 fraction and the alcoholic portion.
    (4) The alcoholic portion.

D. Comparison of—
    (1) The first CS_2 fraction.
    (2) Chrysophyll.
    (3) The crude solution of the xanthophylls in which the fourth band in this instance is faint.

PLATE 6.

E. Xanthophylls obtained from an extract of *Ficus Repens* in the month of May:—

- (1) Chrysophyll obtained from the crude solution of the xanthophylls.
- (2) Crude solution of the xanthophylls.
- (3) A mixture of chrysophyll and the alcoholic portion.
- (4 and 5) The alcoholic portion of different strengths, showing a slight obscuration.

F. Xanthophylls obtained from an extract of *Ficus Repens* in the month of December:—

- (1) Crude solution of the xanthophylls; a case in which the fourth band is almost, if not, absent.
- (2 and 3) The alcoholic portion of different strengths. This is the usual appearance of this spectrum, showing the bands more or less obscured.
- (4) The alcoholic portion after standing a little time, the spectrum being the same as that produced immediately by the action of HCl.

G. The action of HCl on the xanthophylls:—

- (1) The first CS_2 fraction.
- (2) The first CS_2 fraction + HCl.
- (3) Crude solution of the xanthophylls.
- (4) Crude solution of the xanthophylls + HCl.
- (5) Alcoholic portion (F – 2) + HCl.

"On Skin Currents.—Part I. The Frog's Skin." By AUGUSTUS D. WALLER, M.D., F.R.S. Received May 29,—Read June 6, 1901.

The principal object of the following observations was to investigate in the case of skin an electrical reaction by which it is in general possible to determine whether an animal or vegetable tissue is alive or dead.*

A side issue raised in connection with the general inquiry was whether or no the test is applicable to the human body; this obviously led to a detailed study of skin effects upon man and upon animals.

In the case of the frog, previous observations on skin currents are numerous and conflicting; but in so far as my present theme is concerned, the results have come out with the utmost regularity and quite clear of any suspicion of physical fallacy. In the case of man, the question has proved to be less simple, and although it is easy to distinguish between an assuredly living and an assuredly dead piece of skin, it is far from easy in doubtful cases to make sure that the skin is completely dead. The difficulty is caused by polarisation currents

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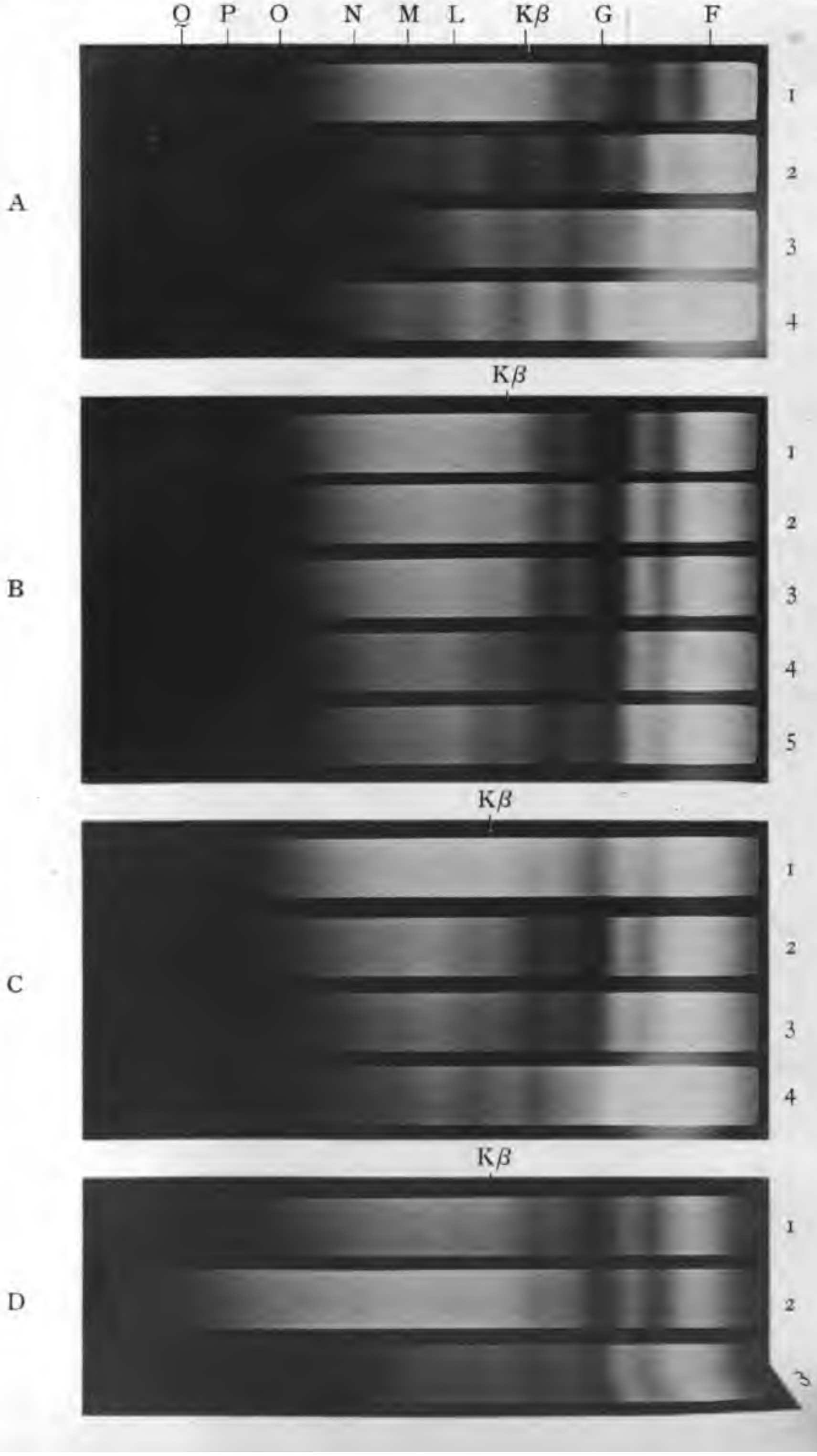
* 'Roy. Soc. Proc.,' vol. 68, p. 79. References to previous papers are given *there—p. 92.*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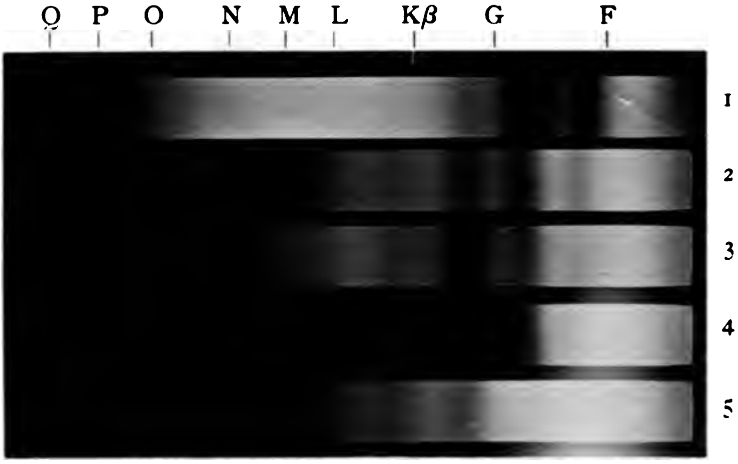

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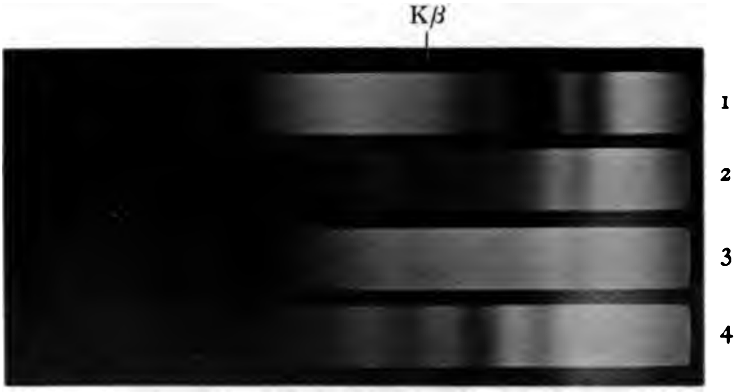

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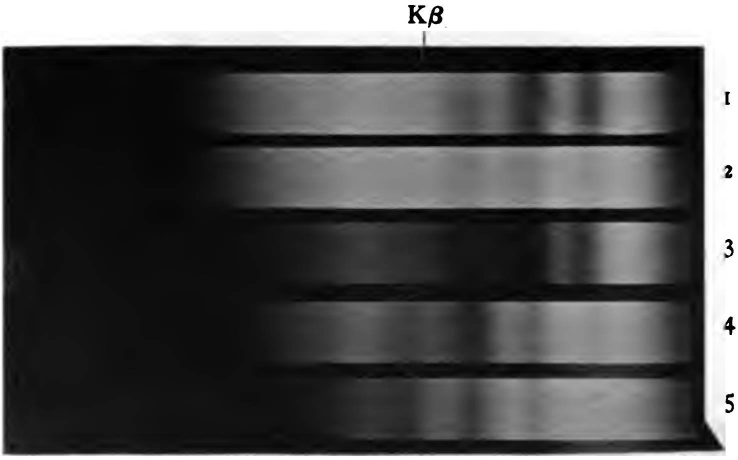

with or against a reaction of low E.M.F., and is not eluded as easily as might have been anticipated by the use of alternating currents. Thus, *e.g.*, while it is easy to assure oneself that a healthy skin may survive for at least a week, one may not feel assured that it is absolutely dead at that time; and in the case of skin obtained from the post-mortem room 24 hours after death, while one may be quite sure that a given skin is still alive, one may not be so sure that another skin is completely dead.

For these reasons I have preferred in the present communication to describe only the very clear and easily demonstrated results of direct excitation of the frog's skin. And in connection with those clear and regular results, I take the opportunity of describing the more variable and debateable results of the indirect excitation of the same skin through nervous channels.

METHOD.—The method by direct excitation is as has been previously described and figured in the case of a vegetable tissue,* a piece of frog's skin laid on a perforated glass or ebonite plate in place of the seed between the unpolarisable electrodes, which serve for the exciting

current and subsequently for the excited current. For the purposes of the description to follow, the skin is to be pictured as if with its superior or external surface A directed upwards, in which case a current from the internal surface B to the external surface A, or an "outgoing" current is ascending or positive, and an "ingoing" current from A to B descending or negative. Excitation was made by single induction shocks, by series of alternating induction shocks, and by condenser discharges. The direction of exciting currents was always determined, the effects of polarisation were tested for, the electrodes in particular being always examined for polarisation, "anomalous" or positive, as well as ordinary or negative.

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* *A. D. W.*, *loc. cit.*, p. 82, fig. 1.

To obtain the effects of indirect excitation two kinds of nerve-skin preparation were used—(1) That of Roeber* and of Engelmann,† consisting of the sciatic nerve, knee, and skin of leg; (2) that of Hermann,‡ consisting of spinal column and skin of back.

In the case of indirect excitation, the response was observed during and after excitation. In the case of direct excitation, the accidental skin-current was exactly compensated, and the skin was excited while the galvanometer was short-circuited; the galvanometer was put into circuit between 1 and 2 seconds after excitation.

RESULTS.—1. The normal current is negative (ingoing). It regularly increases during the first 15 to 30 minutes after the skin is put upon the electrodes. The ordinary value of its E.M.F. is from 0·01 to 0·10 volt, *e.g.*—

Time.	Voltage of current.
0 min.	– 0·0010
10 „	– 0·0080
20 „	– 0·0265
30 „	– 0·0330

A lively skin gives greater current than a poor skin. Nevertheless, the former may, at the outset, exhibit a small current by reason of a positive (outgoing) effect due to manipulation. The latter gradually subsides, and negative current therefore gradually augments.

2. The normal response to direct excitation is positive (outgoing). The excitation may be mechanical or electrical, by a condenser discharge or by an induction shock, in a positive or in a negative direction.

The response is greater and smaller with stronger and weaker excitation. The initial positive frequently gives place to a subsequent negative phase, or a positive interrupted by a negative phase may be witnessed. In such cases comparatively weak excitations were used. With strong excitation the positive response is very persistent, and there is a marked "deflection-remainder."

The positive response to negative excitation generally exceeds the positive response to positive excitation.

Tetanising currents of alternated direction give positive response.

The response to a single break shock exceeds that to the corresponding make shock with the ordinary arrangement of an induction coil.

The response exhibits the phenomena of summation and of fatigue.

It is abolished at temperatures above + 45° or below – 6° and by mercuric chloride.

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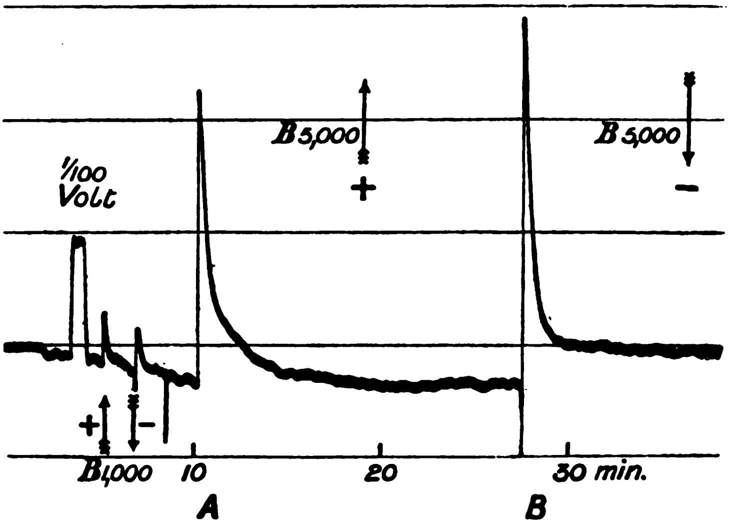
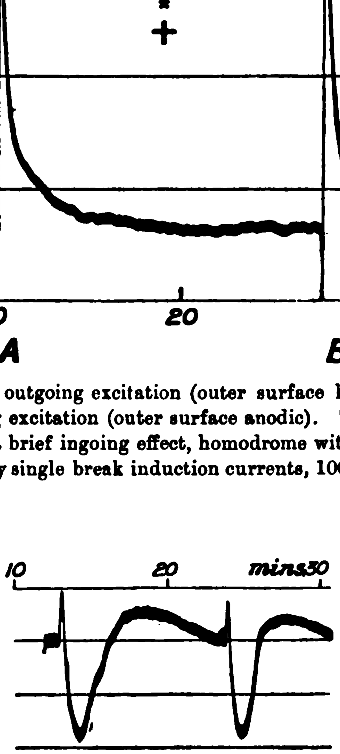
* Roeber, 'Du Bois-Reymond's Archiv,' p. 635. 1869.

† Engelmann, 'Pflüger's Archiv,' vol. 6, p. 127. 1872.

‡ Hermann, 'Pflüger's Archiv,' vol. 17, p. 292. 1878.



A, outgoing response to outgoing excitation (outer surface kathodic); **B**, outgoing response to ingoing excitation (outer surface anodic). The outgoing response, B, is proceded by a brief ingoing effect, homodrome with the exciting current. The excitation is by single break induction currents, 1000 +, 1000 −, 5000 +, 5000 −.



Polyphasic effect of direct excitation. Out—in—out. Response of this type is infrequent. The usual effect (or after-effect) is a strong or predominant outgoing effect, as shown in preceding figure.

Influence of Raised Temperature upon Direct Response of Frog's Skin.

Time.	Temp.	Tetan. 1000 +.	Tetan. 1000 −.
0 mins.	20°	+ 0·0200	+ 0·0230
40 "	30°	+ 0·0260	+ 0·0230
50 "	40°	+ 0·0020	+ 0·0005
55 "	45°	+ trace	− trace

Influence of Lowered Temperature upon Direct Response of Frog's Skin.

Time.	Temp.	Normal current.	Tetan. 1000+.	Tetan. 1000−.
0 mins.	18°	−0·03	+0·0142	+0·0083
	10°		+0·0125	+0·0085
	0°	−0·01	+0·0075	+0·0085
30 ,,	−2°		+0·0042	+0·0060
	−4°		+0·0028	+0·0035
	−6°		[spontaneous	+0·0035]
60 ,,	−6°	−0·00	+0·0015	−0·0010*
	−6°		−0·0005	+0·0005

* To single break shocks 10,000 + and 10,000 −. There was no response to 1000 + and −.

Note.—At −6° there was a sudden positive deflection, of electromotive source and not due to any sudden alteration of resistance, presumably indicative of excitation at the instant of congelation.

The signs + and − as regards tetanisation by alternating induction currents, refer to the direction of the break shock. Thus 1000 + signifies 1000 units of Berne scale, break shock outgoing (and make shock ingoing) through the skin.

With a dead skin, the deflections due to polarisation are in the direction of the break current, presumably by reason of superior polarisation by makes over breaks. (*Cf.* 'Proc. Physiol. Soc.,' November 12, 1898.)

With skin in this state, strong single shocks give rise to the ordinary polarisation counter currents.

Some Data regarding Magnitudes of Effects of Direct Electrical Excitation of Frog's Skin.

(Interval between Excitation and Galvanometer Closure = 2 Secs.)

Excitation.		Response.
1. Break induction current....	100 +	+ 0·0050 vol
	100 −	+ 0·0010 „
	1000 +	+ 0·0550 „
	1000 −	+ 0·0850 „
	10,000 +	+ 0·0700 „
	10,000 −	+ 0·0900 „
2. Break „ „	1000 +	+ 0·0380 „
	1000 −	+ 0·0420 „
	5000 +	+ 0·0260 „
	5000 −	+ 0·0320 „
3. Make „ „	1000 +	+ 0·0045 „
	1000 −	+ 0·0015 „
Break „ „ ...	1000 +	+ 0·0140 „
	1000 −	+ 0·0160 „
4. Make „ „	500 +	nil
	500 −	nil
Break „ „	500 +	+ 0·0035 „
	500 −	+ 0·0135 „
Make „ „	1000 +	+ 0·0150 „
	1000 −	+ 0·0065 „
Break „ „	1000 +	+ 0·0370 „
	1000 −	+ 0·0500 „
5. Condenser discharge	8 volts 1 mF. + (= 640 ergs)	+ 0·0100 „
	„ „ −	+ 0·0100 „
	8 volts 0·1 mF. + (= 64 ergs)	+ 0·0015 „
	„ „ − „	+ 0·0008 „

N.B.—The + sign signifies outgoing direction, the − sign ingoing direction.

3. The electrical response to indirect excitation of the nerve of a nerve-skin preparation is of three types—

I. Positive or outgoing.

II. Mixed { (*a.*) Positive interrupted by negative.
 (*b.*) Negative followed by positive.

III. Negative or ingoing.

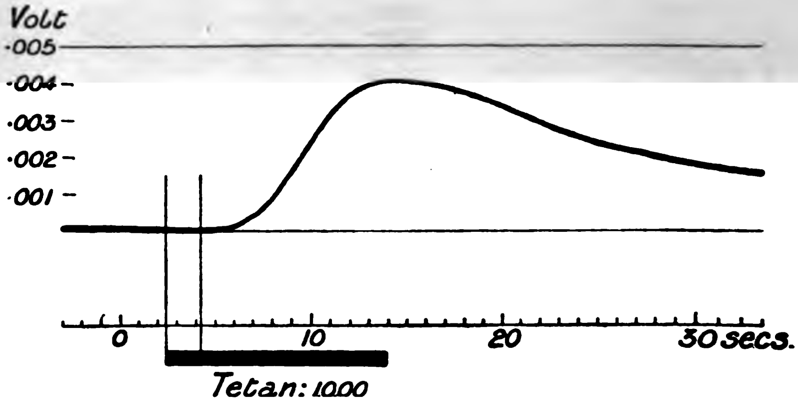
I have in no one instance witnessed the three types upon the same preparation, and may not therefore definitely say that they form three progressive stages. Nevertheless, I regard a positive response of type I as being the most normal, it having presented itself with the best preparations; and type III as the most enduring, it having exhibited least decline in consequence of repeated stimulation.

have seen a response, positive at first, give place to a negative effect; and in the case of a mixed response of type II, I have seen a decreasing positive phase with an increasing negative phase. The entire series of responses is strongly suggestive of the theory that each effect is an algebraic sum of two opposite effects.

The positive effect by indirect excitation through nerve is less enduring than the negative effect. A second is always much smaller than a first positive effect.

Skin giving a mixed or a negative effect by indirect excitation has nearly always given a pure positive effect in response to direct excitation of whatever direction.

4. The interval of time between excitation of nerve and electrical response of skin is about 2 seconds.



Electrical response of skin of frog's leg to tetanic excitation of the sciatic nerve. (N.B.—The response is ingoing, *i.e.*, "Hermann's variation.")

5. The electrical conductivity of the skin is greatly augmented by direct excitation. This point is not in itself very remarkable since the alteration might be simply due to electrolysis. But the physiological origin of the change is indicated by the fact that dead skin similarly excited exhibits little or no change and by the fact that

6. The electrical conductivity of skin is greatly augmented by indirect excitation through nerve.

[redacted]

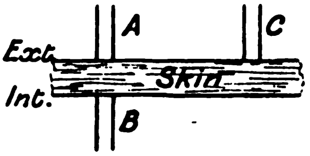
Influence of Excitation of Nerve upon Electrical Resistance of the Skin.

Exp.	Resistance before excitation.	Resistance after excitation.
1	2500 ohms	1000 ohms
2	2800 "	1400 "
3	2500 "	1500 "
4	4300 "	2400 "
5	3000 "	3000 "
6	4000 "	1300 "
7	3900 "	1200 "

Note.—In all except the 5th experiment, excitation of the nerve gave a large positive response. In the 5th experiment, there was no response and no diminution of resistance.

7. Atropine injected into the dorsal lymph sac has not in my hands abolished the electrical response of the skin produced by excitation of nerve. But by direct application to the skin the effect of such excitation has been promptly abolished. There has at such time been no perceptible alteration of the positive response to direct excitation in either direction. Such direct positive response has been promptly abolished by pencilling the external surface of the skin with a solution of mercuric chloride. In several instances the skin, before ceasing to respond altogether, has manifested a small negative response to both directions of excitation. The reaction is rapidly abolished by $HgCl_2$ solution of decimolecular strength, more gradually but completely abolished by $HgCl_2 \frac{M}{100}$ = (2·7 per 1000). Prolonged (½ hour) soakage of the skin in a freshly made 1 per cent. solution of atropine sulphate has produced diminution of the direct response—not much more marked, however, than may sometimes be observed after soakage in normal saline.

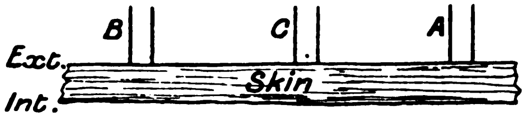
8. The electrical response of the skin to direct electrical excitation is at or near its external surface. This fact is indicated by the result of pencilling with mercuric chloride solution, and conclusively demonstrated by the following experiments:—



Excitation of the skin through A and B, subsequent lead-off to galvanometer *A and C*. A large after-effect is witnessed, from A to C through the galvanometer, whatever had been the direction of the exciting current—*i.e.*, with A previously anodic or previously kathodic. On repeating the experiment, with lead-off through B and C there is little or no effect. The results are independent of the position of C, which may be transferred to the lower surface without altering them. The inefficacious combination B C is at once rendered efficacious by transferring B to the upper surface. (It is of course understood that any accidental current between A and C and B and C is compensated before each excitation.)

The experiment may be further varied in several ways, of which the most obvious is that in which all three electrodes are external or internal.

With external exciting electrodes A and B and subsequent effects led off from A C and B C, the direction of deflections indicates current in the skin from C to A and from C to B, *i.e.*, outgoing in A and B respectively, for both directions of excitation A to B or B to A. With internal exciting electrodes and the same (moderately strong) excitation there is little or no effect between C and A, or C and B, or even A and B.



Conclusion.—The two facts that I consider to be of principal importance as regards the further study of skin-phenomena are—

1. That the normal current of the unexcited skin is ingoing.
2. That the normal response of the excited skin is outgoing.

The hypothesis or figment in accordance with which these facts may be understood, or at least remembered, can be expressed as follows:—In a passive mass of living (animal) matter acted upon by its environment, there must be greater chemical change at any external point of its surface than at any internal point of its mass, and therefore an ingoing current. In an active mass of living (animal) matter giving out energy to the environment, chemical change must be greater within the mass than at the surface, and therefore an outgoing current. In the passive state any point of the surface is electro-positive to any point of the interior; in the active state internal points become less electronegative or actually electropositive in relation to the external surface.

BIBLIOGRAPHICAL NOTE.

Normal Current, or Current of Rest.—Du Bois-Reymond,* in connection with his investigation of muscle currents, was the first to definitely

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* 'Thierische Elektricität,' 1854-57, passim.

[redacted]

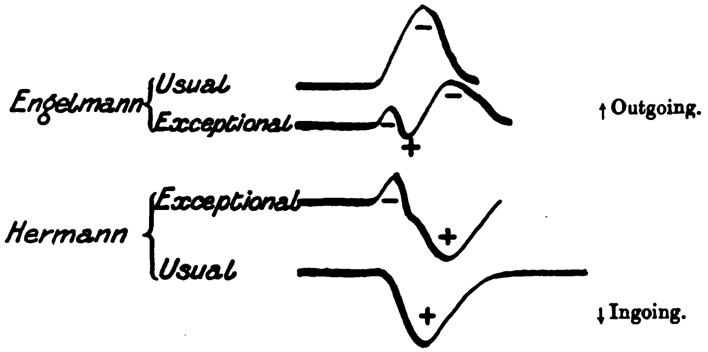
state that the normal current of the frog's skin is directed from without inwards. All subsequent observers have confirmed this point.

Indirect Excitation.—Roeber,[*] acting upon a suggestion of Rosenthal, was the first to make nerve-skin preparations of the sciatic nerve and skin of the leg, and to show that excitation of the sciatic nerve gave rise to an electromotive variation of the skin. He observed in the great majority of instances "a negative variation of the gland currents in consequence of non-electrical as well as of electrical excitation of the sciatic nerve." He mentions as an exceptional phenomenon, p. 644, a positive variation of the normal current.

Engelmann,[†] using the same method, comes to a similar conclusion, viz., that the usual effect of indirect excitation is negative variation of an ingoing current. He gives measurements of the effect (p. 130), from which may be gathered that a good response in his hands had the value 0·025 Daniell. The latent period is given as being from ½ to 4 seconds. He describes the course of the variation as being very usually triphasic (− + −), which in the terminology used in the present communication reads + − +.

He considers that skin currents are "myogenic," the effects of the muscular investment of skin glands. He studies with particular care the influence upon the currents of variations in moisture of the skin, (imbibition and concentration currents).

Hermann[‡] contradicts Engelmann's theory, and, to a certain extent his statement of fact as regards the action current. He gives the usual and principal effect as being a positive variation of the normal current.



He states, however, that such positive variation is sometimes preceded by a negative effect, and that, in rare cases, a pure positive effect is

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[*] Du Bois-Reymond, 'Archiv,' 1869, p. 633.

[†] 'Pflüger's Archiv,' vol. 6, p. 97, 1872.

[‡] 'Pflüger's Archiv,' vol. 17, p. 291, 1878.

observable. The opposition between Engelmann's and Hermann's statements is therefore not absolute enough to justify the statement that Engelmann's variation is negative and Hermann's positive. The difference of statement is one of degree only, Engelmann having been more prominently impressed by the outgoing phase, Hermann by the ingoing phase. Hermann considers that the chief (ingoing) phase is due to glandular activity, while the preliminary outgoing phase is due to a short circuiting, *viâ* gland ducts, of an epithelial current of action attributable to keratinisation.

Bach and Oehler,[*] under Hermann's guidance, observed that superficial cauterisation of the skin with saturated solution of $HgCl_2$ abolishes the normal current, and leaves the action current intact. Hermann's view is that normal current depends upon epithelial investment as well as upon glandular epithelium, whereas action currents through nerve stimulation depend upon glands.

Bayliss and Bradford,[†] employing Hermann's nerve-skin preparation, found Hermann's variation (ingoing) during January, Engelmann's variation (outgoing) during March. Their attention was particularly attracted during the last three months of the year to a triphasic character of variation − + − (or, according to the terminology of the present communication, + − +).

Direct Excitation of the Skin.—The first mention of definite direct excitation of the skin is to be found in Engelmann's paper of 1872.[‡]

Strong induction shocks were passed through the electrodes applied to opposite surfaces of the skin.

Compensation of its current was previously established, the galvanometer was cut out of circuit during excitation, and the effect upon the skin was observed immediately afterwards. The direction of excitation was not distinguished.

Biedermann[§] approaches the question from the general standpoint of Hering's theory of opposite movements, dissimilation and assimilation, employs more particularly the frog's tongue, finds that during direct tetanisation (tongue and galvanometer in series) the response of the living tongue may be either positive or negative according to circumstances, the principal of these being temperature and moisture.

Bohlen,[||] under Biedermann's guidance, studied the gastric mucosa, *i.e.*, one epithelial layer in place of two, as in the case of the tongue, and obtained results confirmatory of Biedermann's.

Reid[¶] and Reid and Tolput,[**] using the skin of the eel, found that

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[*] 'Pflüger's Archiv, vol. 22, p. 30, 1880.

[†] 'Jour. of Physiology,' vol. 7, p, 217, 1886.

[‡] 'Pflüger's Archiv,' vol. 6, p. 136.

[§] 'Pflüger's Archiv,' vol. 54, p. 209, 1893.

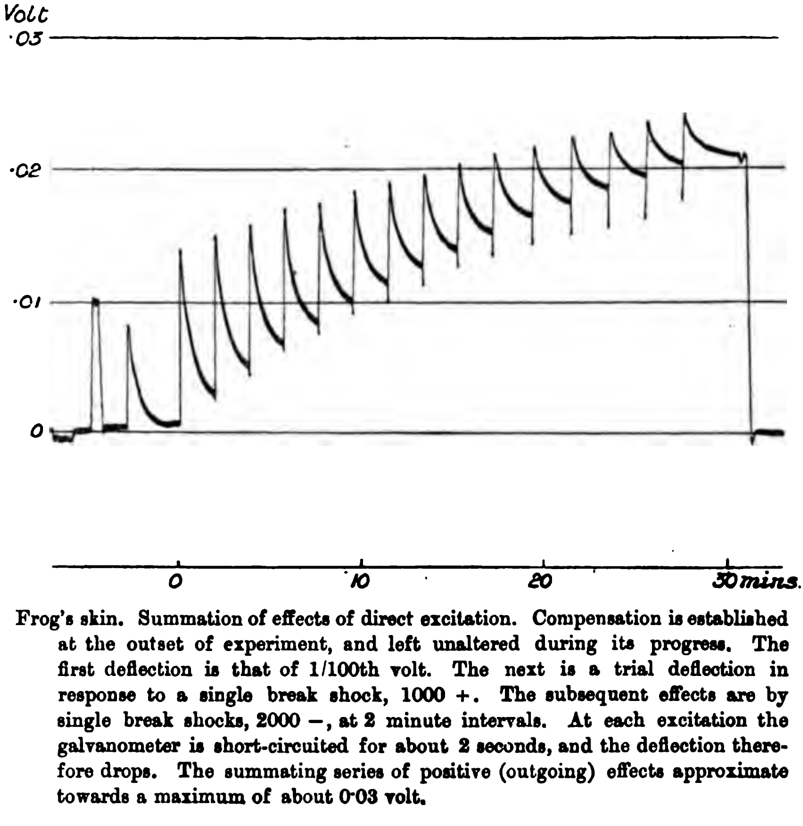
[||] 'Pfluger's Archiv,' vol. 57, p. 97, 1894.

[¶] 'Phil. Trans.,' B, 1893, p. 359.

[**] 'Jour. of Physiology,' vol. 16, p. 217, 1894.

mechanical excitation and electrical excitation by induction shocks in either direction caused ingoing effects, occasionally preceded by outgoing effects.

Waller* finds that the normal and regular response of the frog's skin to any sort of disturbance—mechanical, chemical, or electrical—consists in a positive (outgoing) current.



Frog's skin. Summation of effects of direct excitation. Compensation is established at the outset of experiment, and left unaltered during its progress. The first deflection is that of 1/100th volt. The next is a trial deflection in response to a single break shock, 1000 +. The subsequent effects are by single break shocks, 2000 −, at 2 minute intervals. At each excitation the galvanometer is short-circuited for about 2 seconds, and the deflection therefore drops. The summating series of positive (outgoing) effects approximate towards a maximum of about 0·03 volt.

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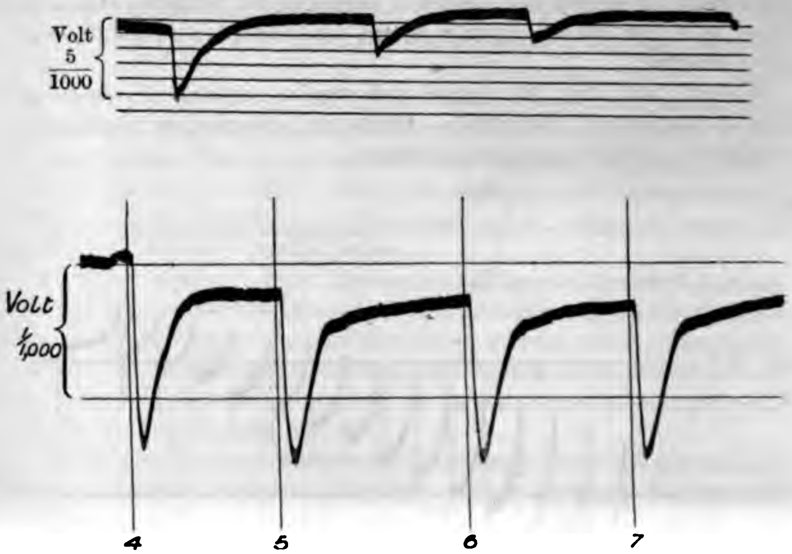
* 'Proc. Physiol. Soc.,' 1900.



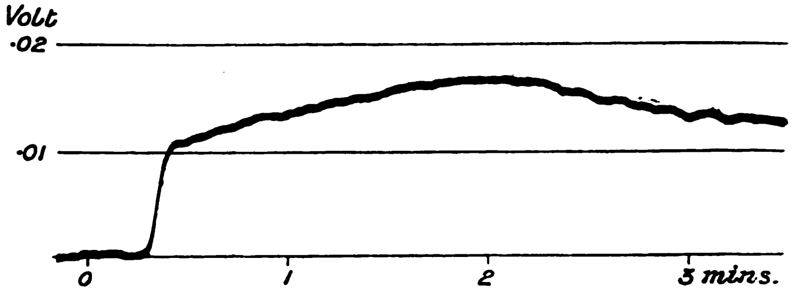
Frog atropinised by repeated injections into the dorsal lymph-sac of a 1 per cent. fresh solution of atropine sulphate.

1st nerve-skin preparation put up 2 hours later. Initial skin-current = − 0·0030 volt. Tetanisation of sciatic nerve by Berne coil at 1000 units for 15 seconds at intervals of 10 minutes. Series of ingoing effects.

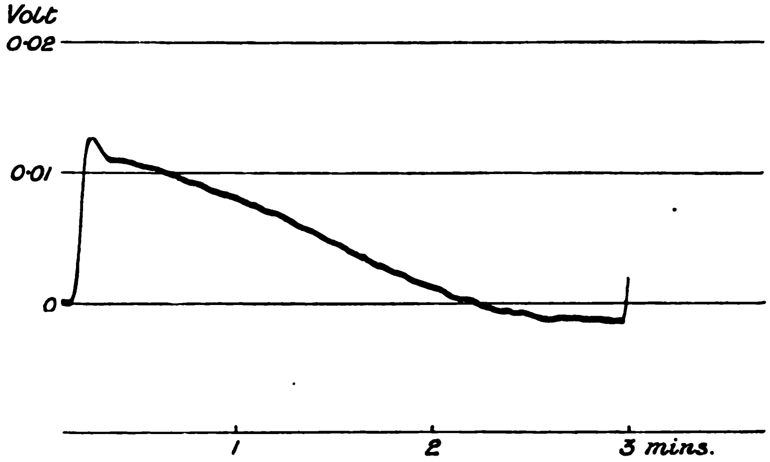
Time…………	0	10	20	30	40	50	60 min.
Effects.	− 0·0040,	0·0020,	0·0015,	0·0013,	0·0011,	0·0011,	0·0010 volt.

In the first three responses of the upper line the galvanometer was shunted; in the next four responses of the lower line the galvanometer was unshunted.

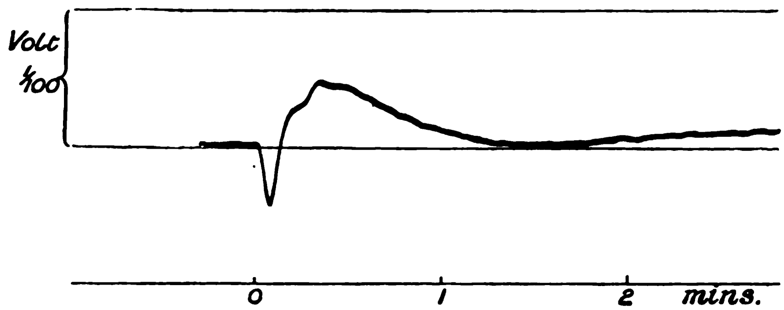
Response of Frog's Skin to Indirect Excitation.



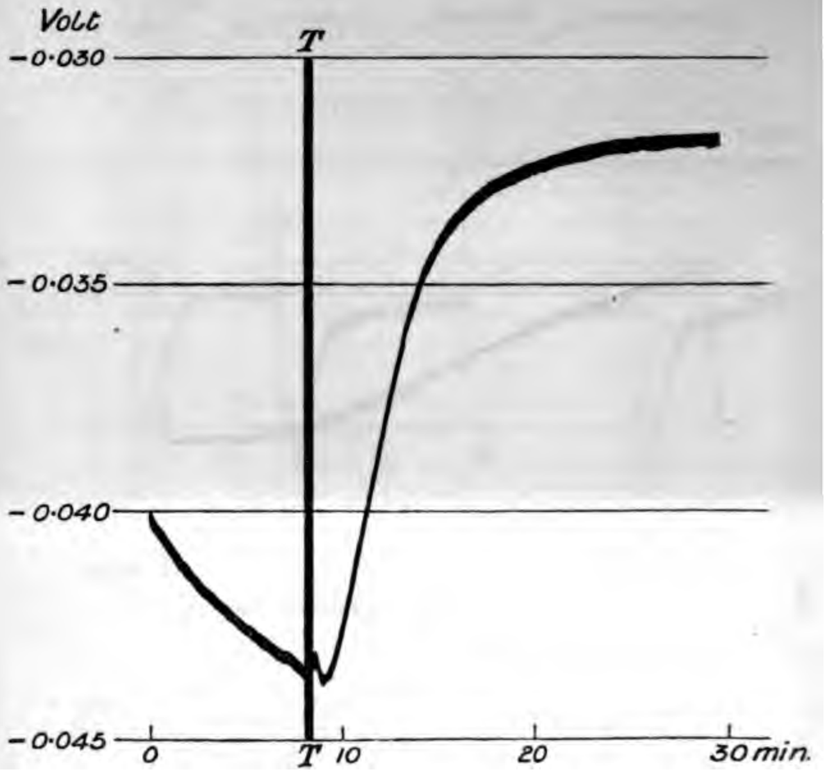
Type I.—Outgoing or positive response.



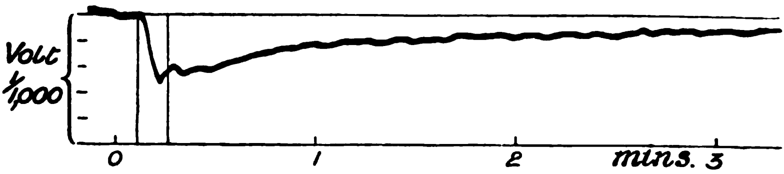
Type I.—Outgoing or positive response.



Type II.—Mixed response.



Type II.



Type III.—Ingoing or negative response.

[redacted]

"Virulence of Desiccated Tubercular Sputum." By HAROLD SWITHINBANK. Communicated by Sir JAMES CRICHTON BROWNE, F.R.S. Received May 31,—Read June 20, 1901.

In the spring of 1900 two plots of a superficial area of 44 sq. feet each were carefully partitioned off in the experiment house with close mesh-wire netting, and laid down with closely cropped lawn turf, which quickly grew into an even sward.

On the 16th day of May following, the grass of these two plots having been cut as short as possible (not exceeding a length from the ground surface of one-quarter to one-half of an inch), the two plots were watered evenly with 4 gallons of water, in which had been incorporated 3 pints of disintegrated tubercular sputum from the Brompton Consumption Hospital, 2 gallons being distributed over the grass of each plot by means of an ordinary watering can with a rose spout.

The plots were then left for fourteen days under the following conditions, being designated respectively as Plot "T A" and Plot "T B," that is to say:—

Plot "T A" was exposed during the whole of the fourteen days to all climatic influences, including the direct rays of the sun between the hours of 10 A.M. and 6 P.M. The weather was exceptionally dry and fine.

Plot "T B" was for the same period exposed to the same conditions as the above, with the exception of the sun's rays, from which it was carefully shielded.

On the 30th May the following animals were turned down to feed upon the two plots:—

Plot "A."	Plot "B."
Two rabbits.	Three rabbits.
Three guinea-pigs.	Three guinea-pigs.

These animals were marked as follows:—

Rabbit T 2.	Both fore-paws red.	Rabbit T 1.	Right fore-paw red.
Rabbit T 3.	Left fore-paw red.	Rabbit T 4.	Red nose.
Guinea-pig T 6.	Right hind-paw red.	Rabbit T 5.	Blue nose.
Guinea-pig T 7.	Right hind-paw blue.	Guinea-pig T 9.	Right fore-paw red.
Guinea-pig T 8.	Left hind-paw blue.	Guinea-pig T 10.	Both fore-paws red.
		Guinea-pig T 11.	Right fore-paw blue.

The short grass on the plots was quickly eaten down, when the ground became completely bare and, owing to drought and the scratching of the rabbits, covered with a layer of fine dust. The animals were then fed upon moistened bran, contained in dishes, and greenstuff thrown upon the ground.

The two tables marked "A" and "B" respectively, and attached hereto, show the general effect of the treatment upon each individual animal. Fuller details of the *post-mortem* results were given on separate sheets.

Plot "A."

Animal.	No.	Distinctive mark.	Killed or died.	Summary of *post-mortem* results.
Rabbit	T 2	Two fore-paws red	Killed after 6 weeks, 21.7.1900	Tuberculous. Disease chiefly confined to respiratory system. Abundant tubercle in lung structure. Bacilli found in abundance.
Rabbit	T 3	Left fore-paw red	Died after 10 weeks, 13.8.1900	Tuberculous. Infection limited almost entirely to respiratory organs. Lungs crowded with tubercle—("an exaggerated form of miliary tubercle." G.T.B.). Bacilli found in abundance.
Guinea-pig	T 6	Right hind-paw red	Died after 12 days, 11.6.1900	Exact cause of death unknown—apparently over-feeding. Too early to show sign of tubercle.
Guinea-pig	T 7	Right hind-paw blue	Died after 14 weeks, 4.9.1900	Generalised tuberculosis. Specially marked in respiratory system and liver. Lungs crowded with tubercular deposit. Liver enormously enlarged, the anterior portion of lobes consolidated and caseous. Bacilli found in abundance.
Guinea-pig	T 8	Left hind-paw blue	Killed after 15 weeks, 13.9.1900	Generalised tuberculosis. Lungs one mass of tuberculous areas, calcareous and caseating. Pharyngeal glands enlarged and calcareous. Pleura covered with tuberculous patches. Spleen ditto. Caseating nodule on pyloric orifice. Occasional nodules on peritoneum and mesentery, but not so marked. Lymphatic glands of splenic omentum enormously enlarged and caseous.

"Plot B."

Animal.	No.	Distinctive marks.	Killed or died.	Summary of *post-mortem* results.
Rabbit	T 1	Right fore-paw red	Died after 25 days. 23.6.1900	Generalised tuberculosis. Specially marked in respiratory system. Lungs crowded with tuberculous areas, distributed equally through the organ.
Rabbit	T 4	Red nose ...	Killed. 4.10.1900	Tuberculous. Abundant tubercle in lung structure. Glands of fauces much enlarged and tuberculous. Bacilli found in abundance.
Rabbit	T 5	Blue nose ..	Killed. 4.10.1900	Tuberculous. Lungs crowded with miliary tubercles. Kidneys much enlarged, and covered with tuberculous nodules. Bacilli found in abundance.
Guinea-pig	T 9	Right fore-paw red..	Killed. 4.10.1900	Tuberculous. Disease not marked, and confined wholly to rare tubercles in lung structure. Bacilli found, but in small numbers.
Guinea-pig	T 10	Both fore-paws red	Killed. 4.10.1900	Non-tuberculous. Organs all healthy.
Guinea-pig	T 11	Righ fore-paw blue	Killed. 4.10.1900	Non-tuberculous. All organs healthy with exception of lungs. These much congested and patchy, but no perceptible tubercle. No bacilli found.

From the above it will be seen that, eliminating one guinea-pig which died at an early stage of the experiment from other causes, 80 per cent. of the experimental animals were found at death to be suffering from tuberculosis in a very marked degree, and although in most cases this was generalised, yet in all it was the respiratory system in which the disease was most marked. The state of many of these was described by Sir George Brown (to whom I am very greatly indebted for the kind and unfailing aid he has given me in checking and supervising the results of every *post-mortem*) as extraordinary, and the specimens preserved will show to what an extent these organs were affected.

Two animals alone remained unaffected, and these were found quite *free from tubercle* when killed at the end of five months from the date of the commencement of the experiment. I can only attribute this immunity to a very high degree of natural resistance which at times is met with in all experimental animals, and which we are compelled to allow for.

Eighteen animals were born during the course of the experiment, at intervals of 4, 5, 9, and 13 weeks, all of whose parents subsequently were found to be tuberculous. These were killed and examined at intervals, and in not one of them was there evidence of tuberculosis. It would therefore be not unreasonable to suppose that, although desiccation for a period of fourteen days proved insufficient to destroy, under these conditions, the virulence of the sputum, yet this was accomplished at some point between this and four weeks. What this point is, a further experiment on similar lines when sufficient sunlight is available, will be necessary to elucidate. I propose to carry this out in the early summer of next year.

"Effect of Exposure to Liquid Air upon the Vitality and Virulence of the Bacillus Tuberculosis."

By H. SWITHINBANK. Communicated by Sir JAMES CRICHTON BROWNE, F.R.S.

Received June 11,—Read June 20, 1901.

A series of experiments carried out early in the year 1900 with the object of testing the effect of the temperature of liquid air upon the vitality and virulence of the bacillus tuberculosis produced results which, although in complete accord as far as the question of vitality was concerned with those arrived at by Professor Macfadyen in the carefully planned experiments reported to the Royal Society on the 1st February and the 5th April, 1900, raised some doubt in my mind as to whether the abnormally low temperature, continued for a lengthened period, might not have some modifying effect upon the virulence of the organism. I decided therefore, in the month of January of this year, to put the question to the test of an experiment which I hoped would be conclusive.

The questions to be solved appeared to me to be—

1. Whether exposure for varying periods to the temperature of liquid air had any effect upon the vitality of the bacillus tuberculosis.
2. Whether such exposure in any way modified its virulence.
3. Whether time was a factor in the question.
4. Whether, as is the case at the higher end of the thermometric scale, successive alternations of temperature had any special effect.
5. Whether actual contact* with liquid air, if obtainable, produced any special results.

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* The word "contact" is used throughout, but it is doubtful whether actual

The experiments, which were carried out in duplicate, lasted over a period of five months, and I am greatly indebted to Dr. Debrand, of the Pasteur Institute, not only for his general supervision of the experimental animals, but also for his kindness in making the autopsy of one complete series as a control.

A special strain of tubercle, isolated from a human cervical gland, was used for the purpose of inoculations. Sub-cultures of this were made upon potato, and the *raclage* from these was used throughout the whole series of experiments. This was enclosed in specially made tubes, and submitted to the influence of liquid air as follows* :—

Tubes A. Six hours continuous exposure to liquid air, without contact.

Tubes B. Twelve hours' exposure, without contact.

Tubes C. Twenty-four hours' exposure, without contact.

Tubes D. Twenty-four hours' exposure *with contact*, the tubes remaining filled with liquid air during the whole period.

Tubes E. Forty-eight hours' exposure, without contact.

Tubes F. One hundred and forty-four hours' exposure, without contact.

Tubes G. One week's exposure, without contact.

Tubes H. Six weeks' exposure, without contact.

Tubes K. Six weeks' exposure *with contact*, the tubes remaining filled with liquid air during the whole period.

To test the question of successive alternations of temperature:—

Tubes L. Six alternate exposures of one hour each during twelve hours to the temperature of liquid air and that of 15° C.

Tubes M. Three alternate exposures as above, followed by six hours continuous exposure to liquid air.

Tubes O. Controls.

The effect of the above treatment, judged by the result of the subcutaneous inoculation of the guinea-pig with an emulsion made from the contents of one of each series of the above tubes, will be shown by the following table. Thirty animals in all were inoculated, and ½ c.c. of the emulsion was used in each case.

The question of vitality was tested by making sub-cultures from the tubes after exposure. With the exception of those tubes exposed to alternations of temperature, no difficulty was found in obtaining a luxuriant growth.

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contact is possible. Given that a cell contains a large proportion of water, it is questionable whether the admission of liquid air to the tube containing the organisms would not give rise to the immediate formation around each individual cell of a thin coating of ice which would effectually protect the cell contents from any specific action the liquid air might possibly have upon them.

* The temperature of liquid air may be taken at −193° C., the actual temperature to which the organisms were exposed as −186° C.

Results of Subcutaneous Inoculation into the Guinea-pig of $\frac{1}{2}$ c.c. of an Emulsion in Broth of Contents of Tubes treated as above.

Tubes.	Treatment.	Animal died or killed.	After	Precis of *post-mortem* results.
A.	Six hours without contact	killed	100 days	Tubercular. Deep inguinal glands much enlarged and caseous. Liver enormously enlarged and studded with well-marked tubercles. Spleen much enlarged and crowded with tubercle. Peri-bronchial glands enlarged and calcareous. Mesenteric glands enlarged, and in some cases caseating. Tubercle bacilli found.
B.	Twelve hours without contact	killed	100 days	Tubercular. Glands of left inguinal region much enlarged and filled with caseous matter. Liver congested and permeated throughout with minute tubercles. Spleen ditto. Rare tubercles in lung structure. Peri-bronchial glands enlarged, hard, and in some cases caseating. Tubercle bacilli found.
C.	Twenty-four hours without contact	died	95 days	Tubercular. Deep inguinal glands enormously enlarged and caseous. Liver hypertrophied and full of tubercle. Spleen enormously enlarged and crowded with tubercles. Lungs a mass of minute tubercles. Tubercle bacilli found.
D.	Twenty-four hours *with contact*	killed	100 days	Tubercular. In left inguinal region an enlarged gland the size of a pea, hard and filled with caseous matter. Retro-peritoneal glands enlarged and caseous. Liver studded with tubercles. Gland at hilus of liver the size of small haricot and filled with cheesy pus. Spleen of normal size, but studded with minute tubercles. Peri-bronchial glands enlarged. Lungs studded with minute tubercles. Tubercle bacilli found.
E.	Forty-eight hours without contact	killed	100 days	Tubercular. Subcutaneous abscess at seat of inoculation. Inguinal glands slightly enlarged. Liver congested, patchy, and crowded with tubercle. Spleen permeated with minute tubercles. Caseating nodule on hilus of liver. Lungs covered with tuberculous patches. Large caseating nodule on superior surface of thorax. Peri-bronchial glands enlarged and caseating. Tubercle bacilli found.
F.	144 hours	died	78 days	Tubercular. Inguinal glands enormously enlarged and caseating. Liver

Tubes.	Treatment.	Animal died or killed.	After	Precis of *post-mortem* results.
				studded throughout with innumerable tubercles. Spleen enormous, and crammed with tubercle bacilli. Lungs one mass of tubercle.
G.	One week without contact	died	97 days	Tubercular. Much emaciated. Group of hard calcareous glands in right inguinal region. Ditto in left. Retro-peritoneal glands enlarged, hard, and calcareous. Liver studded with minute tubercles. Lungs a mass of miliary tubercle. Peri-bronchial glands much enlarged. Mesenteric glands enlarged and caseating. Tubercle bacilli found.
H.	Forty-two days without contact	died	94 days	Tubercular.* Inguinal glands enlarged, hard and calcareous. Retro-peritoneal glands ditto. Liver much enlarged and markedly tuberculous. Spleen enormously enlarged and crowded with tubercles the size of a millet seed. Lungs crowded with tubercles ranging in size from that of a small pin's head to that of a mustard seed. In sub-maxillary region a group of six enlarged glands the size of a haricot, together with several smaller ones, all hard and calcareous. Mesenteric glands enlarged, but not so seriously affected as other organs. Tubercle bacilli found.
K.	Forty-two days *with contact*	killed	94 days	Tubercular.* At seat of inoculation a large caseating nodule the size of a haricot. Liver enormously enlarged, friable, and permeated throughout with minute tubercles. Spleen much enlarged and crammed with minute tubercles. Lungs crowded with tubercles ranging in size from that of a millet seed to that of a grain of rice. Peri-bronchial glands enlarged and caseating. Mesenteric glands but slightly affected. Tubercle bacilli found.
L.	Alternate exposure as above to room temperature and extreme cold	killed	100 days	Animal very well nourished and in excellent condition. A small calcareous nodule at seat of inoculation. Spleen slightly enlarged. A few minute tubercles in lung structure, but rare. Peri-bronchial glands slightly enlarged. Tubercle bacilli found, but with difficulty.

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* The emulsion used for inoculation of these two animals was of much greater density than that employed in other cases.

[redacted]

Tubes.	Treatment.	Animal died or killed.	After	Precis of *post-mortem* results.
M.	Alternate exposure as above to room temperature and extreme cold	killed	100 days	No evidence of tubercle found in animal of English series. In that of French series a few minute tubercles were found in lung structure.

The control animals (inoculated from Tubes O) died after a period of 42, 54, 56, and 63 days, respectively, the autopsy of these showing marked tuberculosis, affecting almost every organ of the body. The series of animals, of which the autopsy was made at the Pasteur Institute, gave results in every way corroborative of those detailed above.

It should be noted: 1. That the control animals succumbed to the disease at a much earlier date than those inoculated with the exposed material, seven of these latter being still living on the 100th day from the commencement of the experiment. The sole exception to this is guinea-pig 13 G, inoculated with material exposed for one week, which died on the thirty-third day.

2. That the time of exposure appeared to make no difference, the animals inoculated with material exposed for forty-two days showing at death tuberculous lesions as pronounced as those in which the material was exposed for the shortest period.

3. That no difference could be traced in the virulence of the material exposed to contact with liquid air.

4. That in animals inoculated with material which had been subjected to alternate exposures, it was difficult to find evidence of tubercle. It was only after very careful search that some small tuberculous lesions could be discovered.

To sum up the results of the experiment, it would appear then—

1. That simple exposure to the temperature of liquid air has little or no effect upon the bacillus tuberculosis as far as vitality is concerned.

2. That its virulence is to some degree modified, but not destroyed, by such exposure, even if it be continued for a lengthened period.

3. That length of exposure is not a factor in the question.

4. That actual immersion in liquid air has no special effect upon the organism, nor does it produce results in any way differing from simple exposure to the temperature obtained by it.

5. That successive alternations of extreme cold and normal tem-

perature have a decidedly destructive effect upon the vitality and virulence of the organism.

I am very greatly indebted to Professor Dewar, F.R.S., not only for a constant supply of liquid air, but also for many valuable suggestions given me during the course of the experiment, and my cordial thanks are due to Dr. Roux and the officials of the Pasteur Institute for the facilities given me at that Institution for carrying out the necessary inoculations.

"On the Behaviour of Oxy-hæmoglobin, Carbonic-oxide-hæmoglobin, Methæmoglobin, and certain of their Derivatives, in the Magnetic Field, with a Preliminary Note on the Electrolysis of the Hæmoglobin Compounds." By Arthur Gamgee, M.D., F.R.S., Emeritus Professor of Physiology in the Owens College, Victoria University. Received and Read, June 20, 1901.

1. *The Observations of Faraday and Plücker on the Diamagnetic Properties of the Blood.*

In the course of his investigations on magnetism and diamagnetism, read before the Royal Society in the year 1845, Faraday* found that, notwithstanding the iron which its colouring matter contains, the blood is a diamagnetic liquid. "I was much impressed," he remarked, "by the fact that blood was not magnetic, nor any of the specimens tried of red muscular fibre of beef or mutton. This was the more striking, because, as will be seen hereafter, iron is *always* and in almost all states magnetic. But in respect to this point it may be observed that the ordinary magnetic property of matter and this new property are in their efforts opposed to each other; and that when this property is strong it may overcome a very slight degree of ordinary magnetic force, just as also a certain amount of magnetic property may oppose and effectually hide the presence of this force." † Faraday further found the blood to behave like all the constituent tissues of animal bodies which he investigated, and was led to state that "if a man could be suspended with sufficient delicacy, after the manner of Dufay, and placed in the magnetic field, he would point equatorially;

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* "On New Magnetic Actions and on the Magnetic Condition of all Matter," 'Phil. Trans.,' 1846, *part* 1.

† *Faraday's* 'Experimental Researches in Electricity,' vol. 3 (1845), p. 38, *para. 2285.*

[redacted]

for all the substances of which he is formed, including the blood, possess this property." *

De la Rive and Brunner,† later, suspending a bound-up frog between the poles of an electro-magnet, observed it to assume an equatorial position, thus realising Faraday's prediction that a complex animal organism must be diamagnetic in accordance with the properties of its constituent tissues and of the water which enters so largely into their composition.

Shortly after the publication of Faraday's researches on diamagnetism, Professor Plücker,‡ of Bonn, in a well-known paper, which appeared in 1848, after describing the characteristic behaviour of magnetic and diamagnetic liquids contained in watch-glasses placed upon and between the poles of powerful electro-magnets, gave the results of his observations on the diamagnetic properties of the blood. He not only confirmed, by experimenting on the blood of the frog, of man, and of the ox, the accuracy of Faraday's statements, but, by employing the microscope in his observations, he was able to show that the blood corpuscles are more strongly diamagnetic than the liquid in which they float.§

2. *Objects of the Present Investigation.*

At a time when all facts bearing on the physical properties and the chemical relations and structure of the blood-colouring matter are rightly claiming the attention of many of the leading workers in physiological chemistry, it appeared to me very desirable to examine the magnetic properties of the crystalline blood-colouring matter itself, in the condition of utmost available purity, and, whatever the results might be, to extend the inquiry to its leading iron-containing derivatives.

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* Faraday's 'Experimental Researches in Electricity,' vol. 3, p. 36 (2281).

† De la Rive and Brunner's researches are only known to me at second hand from the account given of them in Valentin's 'Grundriss der Physiologie' (4 Auflage, 1855, p. 507), where an engraving is reproduced in which a bound-up frog is shown placed between the poles of an electro-magnet.

‡ Plücker, 'Experimentelle Untersuchungen über die Wirkung der Magnete auf gasförmige und tropfbare Flüssigkeiten.' Refer to the heading "Über das magnetische und diamagnetische Verhalten der tropfbarflüssigen Körper," in 'Poggendorff's Annalen der Physik und Chemie,' vol. 73, 1848, p. 575, para. 49.

§ In 1874, Dr. R. C. Shettle, in a paper read before the Royal Society ('Roy. Soc. Proc.,' vol. 23, 1875, pp. 116–120), gave the results of experiments which had led him to the conclusion that arterial blood is paramagnetic as compared with venous blood, which is diamagnetic, the assumed difference in magnetic behaviour being explained by the author as due to the paramagnetic properties of *the oxygen* absorbed by venous blood. In reference to these statements, the only *observation* which I have to make, on the basis of my own work, is that they are *entirely* erroneous.

[redacted]

Although Faraday had shown that the blood is diamagnetic, and Plücker that the blood corpuscles are more decidedly diamagnetic than the liquid in which they float, it was yet conceivable, though improbable, that the iron-containing hæmoglobin would prove to be a feebly magnetic body, of which the true magnetic behaviour was concealed by the substances with which it is associated in the blood corpuscles. Whether hæmoglobin proved to be magnetic or diamagnetic, it obviously would be of great interest to examine the magnetic properties of the iron-containing substances which the blood-colouring matter yields when it is decomposed by acids in the presence of oxygen, and in the event of a difference between the magnetic behaviour of the mother-substance and its derivatives, to push the inquiry in a direction likely to lead to the discovery of the cause of the discrepancy. In pursuance of such an object I have been led to inquire whether the pure blood-colouring matter in aqueous solution is an electrolyte, and having discovered that it is one, to examine the results of its electrolysis. On this part of my inquiry the statements which I have to make in this paper are strictly preliminary, and, except in the first most interesting particular that oxy-hæmoglobin and CO-hæmoglobin separate in the first instance unchanged from their aqueous solutions when these are subjected to very feeble currents, are to be considered as liable to correction by future more extended work.

3. *The Electro-magnet employed in the present Research.*

The electro-magnet employed was constructed by Ladd many years ago, and is sufficiently powerful to be employed for observations on the rotation of the plane of polarisation of light. I had it fitted with an accurately closing glass case and with adequate arrangements for the proper suspension of the bodies under examination. I am not possessed of instruments which would enable me to determine directly the strength of the magnetic field employed in my several sets of experiments. The Rev. F. J. Jervis-Smith, F.R.S., Millard Lecturer in Experimental Mechanics in the University of Oxford, to whom I had the pleasure of showing my experiments, had the great kindness to make careful measurements of the coils, and has practically reconstructed an electro-magnet similar in dimensions to mine, with the same windings, and of which the iron core derived from a similar instrument, made by Ladd, was probably identical in properties to that in my electro-magnet. Using Professor Rowland's method for determining the field, he obtained the following results :—

Intensity of the earth's horizontal magnetic component at Oxford = 0·18.

Distance between faces of pole pieces, 3 cm.

Current in Amperes.	Magnetic Field in C.G.S. units.
2·4	516
3·3	700
4·2	870

Probably it is safe as an approximate estimate to assume that my field was about 1000 C.G.S. units with a current of 5 amperes.

All the fundamental experiments on the magnetic properties of oxy-hæmoglobin, CO-hæmoglobin, and methæmoglobin were made by suspending cakes of the dried crystalline bodies by means of one or a few fibres of silk between the poles, thus avoiding the disturbing influence of glass tubes, however feebly magnetic. In the case of hæmin the substance was similarly examined, in the first instance, by suspending as far as possible rectangular cakes formed by the aggregation of microscopic crystals. In the case of hæmatin, the substance, being in an amorphous pulverulent condition, was necessarily examined in glass tubes, but its intensely magnetic properties prevented in its case, as in that of hæmin, any difficulties arising from the very feebly magnetic properties of the glass tube containing it.

4. *Oxy-hæmoglobin a strongly Diamagnetic Body.*

The oxy-hæmoglobin employed in the present research was prepared by myself during the past winter from the blood of the horse by employing substantially the method of Hoppe-Seyler. In some cases the blood corpuscles were separated from the defibrinated blood by long continued centrifugalising; generally, however, the defibrinated blood was mixed with ten times its volume of a mixture made by diluting 10 volumes of saturated NaCl solution with 90 volumes of distilled water, and the corpuscles were then separated by means of the centrifuge.

In either case, the magma of corpuscles was treated with a small quantity of distilled water and pure ether, and the mixture having been thoroughly agitated in a stoppered separating funnel, the aqueous solution of the blood-colouring matter was separated and filtered into flasks surrounded with ice, and subsequently treated with one-fourth of its volume of pure absolute alcohol at a temperature of − 5° C., and the mixture placed in an ice chamber for twenty-four or thirty-six hours. The oxy-hæmoglobin which crystallised was separated from its mother-liquor by means of the centrifuge. The crystalline mass was repeatedly washed with distilled water at 0° C., and the washed crystals treated with distilled water at 30° C.; the saturated solution was rapidly centrifugalised, rapidly filtered into flasks surrounded by ice and salt, and the hæmoglobin caused to crystallise by the addition of absolute alcohol under the prolonged influence of cold. After being crystallised three times, the oxy-hæmoglobin was collected on filters, and the moist mass of microscopic crystals drained. The pasty crystalline mass was dried *in vacuo* over sulphuric acid at a temperature which never exceeded 5° C.

Behaviour in the Magnetic Field.—An irregular mass of three times crystallised oxy-hæmoglobin dried *in vacuo*, weighing 1·088 grammes, and measuring 18 mm. in length, 13 mm. in depth, and 13 mm. in breadth, was suspended by a couple of fibres of unspun silk between the poles of the magnet, the distance between these being 20 mm.; the mass was made to rest in the axial position before the current was passed through the coils.

Three cells of an accumulator were employed; on closing the key the mass of hæmoglobin instantly assumed the equatorial position. The experiment was repeated with masses of hæmoglobin prepared at various times, and recrystallised from one to three times, and weighing from 0·5 to 2 grammes, and invariably they were found to be powerfully diamagnetic.

A specimen of oxy-hæmoglobin of the horse, kindly prepared for me under the direction of Professor Hofmeister in the Chemico-Physiological Laboratory of the University of Strasburg, by the ammonium-sulphate method, and which had been five times crystallised, proved to be as powerfully diamagnetic as the oxy-hæmoglobin prepared by myself by Hoppe-Seyler's method.

5. *Carbonic-oxide-hæmoglobin is, like Oxy-hæmoglobin, strongly Diamagnetic.*

Mode of Preparation.—The carbonic oxide-hæmoglobin employed was prepared by saturating a concentrated solution of twice crystallised oxy-hæmoglobin with pure CO, and then crystallising the CO compound by the addition of absolute alcohol and exposure to a temperature of − 5°—10° C.

Behaviour in the Magnetic Field.—A nearly rectangular prismatic mass of CO-hæmoglobin which had been dried *in vacuo*, and which weighed 0·642 gramme, and of which the length was 17 mm., the breadth 6·5 mm., and the depth 13 mm., was brought into the axial position between the poles of the electro-magnet, the distance between these being 18 mm. On passing the current from three cells of an accumulator through the coils of the electro-magnet the mass instantly assumed the equatorial position. The experiment was repeated with *different specimens* of CO-hæmoglobin, and invariably with the same *result.*

[redacted]

In the absence of all data as to the diamagnetic moment of either Oxy- or CO-hæmoglobin, it is impossible to state whether these bodies differ in any degree in respect to their behaviour in the magnetic field. Working carefully but merely qualitatively, it would appear, however, that their behaviour in the magnetic field is identical.

6. *Methæmoglobin is, like Oxy-hæmoglobin, strongly Diamagnetic.*

The substance was prepared by adding to a saturated solution of twice crystallised oxy-hæmoglobin of the horse a few drops of solution of ferricyanide of potassium until the characteristic change in colour and in the spectrum indicated the complete conversion into methæmoglobin. The solution was cooled to − 5° C., treated with one-fourth of its volume of absolute alcohol at − 10° C., and the mixture placed in ice and salt for a period of thirty-six hours. The crystalline methæmoglobin which separated was then washed with repeated quantities of ice-cold water, collected on a filter, drained, and dried *in vacuo* at a temperature not exceeding 5° C. Experiments with lumps of this substance varying in weight between 0·3 and 1·0 gramme showed it to be apparently as diamagnetic as oxy-hæmoglobin.

7. *Hæmatin and Acethæmin (Hæmin) intensely Magnetic Substances.*

Preliminary Remarks.

The more recent analysis of Jaquet, Zinoffsky, and Hüfner have led to the conclusion that, at any rate in the horse, the dog, the ox, and the hen, there exists a remarkable constancy in the proportion of the iron which exists in hæmoglobin (0·335 per cent.).* If it be assumed that 1 molecule of hæmoglobin contains 1 atom of iron, the molecular weight of the hæmoglobin of the dog, the horse, the ox, and the hen would be 16,669, a result which concords admirably with the volume of oxygen and carbonic oxide which can enter into combination with hæmoglobin on the assumption (first of all advanced by Lothar Meyer) that 1 molecule of hæmoglobin can combine either with 1 molecule of oxygen or of carbonic oxide. The empirical formula for the hæmoglobin of the dog calculated by Jaquet from his analyses is probably very near the truth, namely, $C_{758}H_{1203}N_{195}S_3FeO_{218}$.

Why should hæmoglobin possess so enormously high a molecular weight? The question suggested itself to Bunge, who has furnished us with a reason which is eminently suggestive: "The enormous size of the hæmoglobin molecule," says this writer, "finds a teleological explanation, if we consider that iron is eight times as heavy as water.

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* For a discussion of all the more recent analysis of hæmoglobin, see my ticle on "Hæmoglobin" in Schäfer's 'Text-book of Physiology,' p. 189, et seq.

[redacted]

A compound of iron, which would float easily along with the blood current through the vessels, could only be secured by the iron being taken up by so large an organic molecule."

When oxy-hæmoglobin is subjected to the action of acids and alkalies it splits up with great ease into a coloured iron-containing body and into an albuminous body (or mixture of such bodies). The former, to which the name of Hæmatin has been given, is a derivative of the molecular group existing in the blood-colouring matter, upon which its colour, its spectroscopic characters, and its physiological properties doubtless depend, *though it is a derivative which is unquestionably a product of oxidation, and in no sense represents the real hæmochromogen.* According to Hoppe-Seyler, the empirical formula of hæmatin is $C_{34}H_{35}O_5N_4Fe$, whilst according to Nencki its composition is represented by the formula $C_{32}H_{32}O_4N_4Fe$.

When the decomposition of oxy-hæmoglobin is effected by glacial acetic acid in the presence of alkaline chlorides, a perfectly crystalline substance separates, which has been hitherto known under the name of *hæmin*, but which we shall now, following the suggestion of Nencki, term *acethæmin.* This body was looked upon by Hoppe-Seyler as a hydrochloride of hæmatin; the recent researches of Nencki and Zaleski have shown that acethæmin contains 8·59 of iron, and possesses a composition represented by the formula $C_{34}H_{33}O_4N_4ClFe$; it contains an acetyl group, and both the acetyl and chlorine in it are linked to the iron. When this body is dissolved in weak solutions of sodium hydrate in the cold, the chlorine and acetyl are separated, and on neutralisation with acids, hæmatin of composition $C_{32}H_{32}O_4N_4Fe$ is obtained. It is with these two coloured iron-containing decomposition products of hæmoglobin, hæmatin and acethæmin, that my observations have been carried out. Before referring to these in detail, I wish again to insist that these oxidation-products in no sense represent the unaltered iron-containing group to which the blood-colouring matter owes its physiological properties. As Hoppe-Seyler showed, when hæmoglobin is decomposed by acids and alkalies *in the absence of all traces of oxygen*, hæmatin is never formed, but a colouring matter which possesses the same spectrum as that which had previously been described by Stokes as that of reduced hæmatin.

This substance Hoppe-Seyler called hæmochromogen, and he expressed the opinion that it constitutes the veritable coloured radical upon which the physiological properties of hæmoglobin depend. The experimental facts advanced by Hoppe-Seyler have always appeared to me absolutely inadequate to warrant this hypothesis, which, however, is most suggestive, and demands a thorough and a new investigation.

A. *Magnetic Properties of Acethæmin.*

The acethæmin employed in the present research was prepared by me from ox's blood by the method of Schalfijew. Some of the specimens were purified by recrystallisation from glacial acetic acid, others by dissolving in a chloroformic solution of pure quinine, and subsequently adding to the filtrate hot glacial acetic acid, saturated with NaCl.*

My first observations were made with a block of agglomerated hæmin crystals weighing 0·6455 gramme, and measuring 26 mm. in greatest length, 18 mm. in height, and 6 mm. in thickness: this block was suspended by two fibres of silk, so as to occupy the equatorial position in reference to the pole pieces of the magnet. The distance between the poles being 30 mm., on passing a current from three accumulator cells through the coils, the mass instantly assumed the axial position, and was strongly attracted to the nearest pole, the suspending silk fibres being sensibly deflected from their original vertical position. Even when the poles of the electro-magnet were 40 mm. apart, the mass instantly set in an axial position when the current was passed. The observations were repeated with numerous specimens of hæmin, and always with similar results.

B. *Magnetic Properties of Hæmatin.*

The hæmatin employed in these researches was prepared by dissolving recrystallised and perfectly pure acethæmin in a weak solution of chemically pure sodium hydrate at ordinary temperatures, and precipitating the filtered solution without delay by neutralising with dilute sulphuric acid. The precipitated hæmatin was thoroughly washed, drained, and dried. In consequence of its absolutely amorphous pulverulent character, my magnetic observations on this body were conducted with the aid of tubes of very feebly magnetic glass, containing from 0·1 to 0·4 of pure hæmatin. The intensely magnetic character of hæmatin was as easily demonstrated as had been that of acethæmin.

8. *Preliminary Observations on the Electrolysis of Solutions of Pure Oxy-hæmoglobin and CO-hæmoglobin.*

The remarkably definite results of my research, which had shown that Oxy- and CO-hæmoglobin are decidedly diamagnetic substances, whilst their iron-containing derivatives, acethæmin and hæmatin, are

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* Refer to my previously quoted article in Schäfer's 'Text-book of Physiology,' and to Nencki and Zaleski's recent article "Untersuchungen über den Blutfarbstoff. I. Ueber die Aether des Hämins," 'Zeitschrift für Physiologische Chemie,' vol. 30, 1900, p. 384, *et seq.*

[redacted]

powerfully magnetic, naturally led me to speculate on the possible cause of these differences. It appeared to me that if hæmoglobin were found to be an electrolyte, apart from the interest which would attach to the discovery of the fact, a study of the products of its electrolysis might throw great light upon the question. Do we not know, for instance, that those compounds in which iron and other magnetic metals are present in electro-negative radicals are diamagnetic?*

In spite of my having made great efforts to purify as completely as possible the substances with which I worked, it is questionable whether their purity was sufficient for electrolytic researches. The experiments which I have yet made on this division of my subject must therefore be looked upon as strictly preliminary, and I hope in the course of the coming winter to extend them greatly, making use of compounds of hæmoglobin which have been subjected to far more frequent recrystallisation. In the course of these experiments, beside studying the proximate products of electrolysis with currents of different strength and potential, I intend to determine by the methods of Kohlrausch and Ostwald, with as great accuracy as possible, the specific conductivities of solutions of Oxy- and CO-hæmoglobin.

The following are the results of my electrolytic experiments which I wish at present to place on record:—

Firstly. When solutions of pure oxy-hæmoglobin are subjected to electrolysis at a temperature of about 15° C. between platinum electrodes, from twelve to sixteen cells of a carbon zinc bichromate battery being employed, and the current passing through the liquid being from 3 to 5 milliamperes, a rapid subsidence of the colouring matter takes place, the upper layers of the solution becoming perfectly colourless. The depositing colouring matter retains the spectroscopic character of oxy-hæmoglobin, and when stirred with it is absolutely and almost instantaneously soluble in the liquid from which it has separated. Exactly the same result occurs in the case of carbonic-oxide-hæmoglobin.

Secondly. On continuing the passage of the current through the solution in which precipitation has occurred, secondary reactions occur, gas is developed both at the anode and cathode, and in many cases a dirty white-brown deposit forms at the cathode.

Thirdly. Under conditions of strength of current and potential which were not determined with sufficient accuracy, and which I have not yet been able to reproduce at will, the solutions of oxy-hæmoglobin and CO-hæmoglobin have, under the long continued action of the current, on several occasions deposited at the anode an insoluble

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* W. Allen Miller, 'The Elements of Chemistry': Part I, "Chemical Physics," p. 422, London, 1855; H. du Bois, 'Propriétés magnétiques de la matière pondérable. Rapports présentés au Congrès International de Physique réunis à Paris en 1900,' Paris, 1901, Tome II, p. 460.

[redacted]

red colouring matter containing both the albuminous and the iron-containing residues of hæmoglobin. In the case of CO-hæmoglobin the compound deposited has presented the peculiar colour of CO-hæmoglobin.

General Conclusions.

The following are the conclusions to which I have been led by my experiments :—

1. The blood-colouring matter, oxy-hæmoglobin, as well as carbonic-oxide hæmoglobin and methæmoglobin, are decidedly diamagnetic bodies.

2. The iron-containing derivatives hæmatin and acethæmin are powerfully magnetic bodies. The differences in magnetic behaviour between the blood-colouring matter and acethæmin and hæmatin point to the profound transformation which occurs in the hæmoglobin molecule when it is decomposed in the presence of oxygen.

3. The preliminary study of the electrolysis of oxy-hæmoglobin and CO-hæmoglobin renders it probable that, in the blood-colouring matter, the iron-containing group, on which its physiological properties depend, is (or is contained in) an electro-negative radical: according to analogy, the iron in such a compound would possess diamagnetic and not magnetic properties.

In conclusion, I beg to acknowledge my indebtedness to Professor von Bunge, of Basel, to Professor Franz Hofmeister, of Strassburg, and to Dr. v. Ehrenberg, the technical director of the chemical factory of Messrs. Merck, of Darmstadt, for their great courtesy and kindness in placing at my disposal preparations of hæmoglobin prepared by themselves or under their direction. I have further to add that I reserve to myself the right of continuing without delay the researches of which the first results are contained in this paper.

"On the Resistance and Electromotive Forces of the Electric Arc."

By W. DUDDELL, Whitworth Scholar. Communicated by Professor W. E. AYRTON, F.R.S. Received and Read June 20, 1901.

(Abstract.)

The discrimination between resistances and electromotive forces in conductors, or apparatus, in which both of these quantities are functions of the current is considered, and it is pointed out that whether such an apparatus may be said to possess a resistance, or an E.M.F., or both, depends to a large extent on the nature of the definition of these quantities, and a definition of these quantities is adopted.

[redacted]

The essential stipulation is made that whatever means be used to measure the resistance and E.M.F.'s of the arc, the conditions of the arc must not be in any way changed by the test. It is considered that the main phenomena of the arc depend on the exact thermal conditions of its different parts, and on the distribution of the heated gaseous and other particles, so that it is necessary to maintain these constant during the test. This leads to the condition that not only must the testing current used be very small, but also that the test must be completed in an exceedingly short time after applying the same.

As illustrating how very short a time may be allowed to elapse, it was found that an appreciable change in the thermal conditions of an arc had taken place in 1/10,000 second after changing the arc current by as little as 3 per cent.

Historical.

A brief historical *résumé* is given showing that previous experimenters have not succeeded in measuring the true resistance and back E.M.F. of the arc, due to their not having realised the importance of completing the test before the conditions of the arc have had time to be altered by the testing current.

Those methods, similar to the Kohlrausch method of measuring the resistance of an electrolyte, in which an alternating testing current is superposed on the direct current, such as that employed by Messrs. Frith and Rodgers, who found that what they measured as the resistance of the arc had in some cases a negative value, are shown to have failed owing to the frequency of the alternating testing current not being high enough. This frequency should be, instead of a few hundred periods per second, as used by previous observers, many thousand periods per second, in order that the conditions of the arc may not vary, and the true resistance may be obtained.

Preliminary Experiments.

In the preliminary experiments the oscillatory discharge of a condenser was superposed on the main direct current through the arc, and was used as the testing current, the wave-forms of the superposed oscillatory P.D. and current being recorded by means of an oscillograph. If the arc behaved as a non-inductive resistance, the waves of P.D. and current should be similar curves, and in phase. This is found *not* to be the case with frequencies up to 5000 periods per second. The author concludes from these experiments that, each increase made in the frequency of the superposed alternating testing current has led to the arc conditions being less affected by it, and, in consequence, to the arc behaving more and more like an ordinary non-inductive resistance, and therefore that much higher frequencies are required to obtain the true resistance. In fact, frequencies up to 120,000 periods per second were finally used. Owing to experimental difficulties in employing the above method with much higher frequencies, a fresh method was adopted.

Basis of Method adopted.

An apparatus A is considered which has resistance and E.M.F., but no self-induction, or capacity, and through which a steady current is flowing. There is mixed with the steady current an alternating testing current. It is shown that, if the apparatus A possess a true resistance, and if the frequency of the testing current be such that *the conditions of the apparatus are not in any way changed by it*, then the resistance of A will be a constant over the range of variation of the current, and equal to the impedance of A to the superposed alternating current.

A criterion that the apparatus A has a constant resistance is that the power factor of A with respect to the alternating testing current must be unity. It is concluded that in order to prove that the arc has a true resistance and to find its value it is necessary to show :—First that it is possible to find a value of the frequency of the testing current for which the power factor of the arc with respect to this current is unity; second, that the power factor remains unity and the impedance constant, even when the frequency is greatly increased above this value; thirdly, to determine the value of the impedance of the arc under these conditions, which will be its true resistance.

Method of Measuring the Impedance and Power Factor.

Owing to the high frequency of the testing current finally used, viz., 120,000 periods per second, it was difficult to devise a satisfactory method of measuring the impedance, and power factor; wattmeters and dynamometers could not be used, as at these high frequencies their windings behaved more like insulators than conductors, owing to their self-induction. The method finally adopted was the well-known three voltmeter method, for which three pieces of special apparatus were used—

(1) An alternator to produce the high frequency currents.

(2) A new measuring instrument called a "Thermo-galvanometer" to measure the three voltages.

(3) A standard resistance with which the impedance of the arc was compared, which had a time constant of only 2·7 × 10^{-7} second.

The High Frequency Alternator.

The alternator is of the inductor type; it was belt driven from two discs by means of a figure of 8 drive, each disc being separately belted the source of power so as to balance, as far as possible, the pull the alternator spindle due to the driving belt. The speed of the alternator was 35,400 revolutions per minute, and the highest frequency 120,000 periods per second. To give an idea of how very high this frequency is, it is mentioned that if a frequency of 100 periods per second be represented by 10 inches, a very ordinary scale in plotting curves, then the squared paper that would be required to plot the curve between impedance and frequency for the solid arc, which extends over the range from 250 to 120,000 periods per second, would be 1,000 feet, or about 1/5th *mile* long.

It was found that the spindle alone of the alternator without the inductor could be driven at 60,000 revolutions per minute, or 1,000 revolutions per second.

A table of high frequency alternators shows that this alternator gives a frequency seven or eight times as high as the highest value previously attained.

The Thermo-galvanometer.

The principle of this new instrument consists in causing the current to be measured to flow through a very fine wire, the heat radiated by the wire being measured by a modified Boys' radio-micrometer. The instrument is practically non-inductive, and may be used equally well for direct or alternating currents. The actual instrument used has a resistance of about 18 ohms, and gives a deflection of 500 scale divisions at a scale distance of 2000 divisions (1 scale division = 1/40th inch) for a current of about 9×10^{-4} ampere.

Telephone and microphone currents can be easily measured with this instrument.

Results Obtained by Varying the Frequency.

This, the fundamental investigation of this communication, consists in varying the frequency of the superposed alternating testing current to see whether, at a sufficiently high frequency, the conditions of the arc remain constant. The criterion that the conditions of the arc remain unchanged has been shown to be that the power factor, as measured with the superposed alternating current, is unity. Under these circumstances the true resistance will be equal to the impedance. It is experimentally found by sufficiently increasing the frequency, that the power factor approximates asymptotically to + 1, and that for the highest frequencies used, it is + 1 to within the limits of experimental error, therefore at these frequencies the variations of the P.D. and current obey Ohm's law, and the impedance of the arc is equal to its true resistance.

With *solid* carbons the power factor at 250 periods per second is − 0·91, *on increasing* the frequency it decreases numerically until it *vanishes at 1950* periods per second, with further increase of frequency the power factor increases rapidly at first, then more slowly becoming asymptotic to + 1, and finally practically attains this value at 90,000 periods per second; above this frequency the power factor is within the limits of experimental error + 1 up to the highest frequency used, viz., 120,000 periods per second. The impedance of the *solid* arc increases with increase of frequency from 0·97 ohm at 250 periods per second to 3·8 ohm at 90,000 periods per second, above which it remains practically constant. *The true resistance of the above arc* 3 *mm. long between* 11 *mm. solid* "*Conradty Noris*" *carbons, and through which a current of* 9·91 *amperes is flowing, is found to be* 3·81 *ohms.*

The P.D. accounted for by ohmic drop is therefore 37·8 volts out of an observed P.D. arc of 49·8 volts, so that *there appears to be a real back E.M.F. opposing the flow of the current, in this arc of* 12 *volts.*

With *cored* carbons the power factor at 250 periods per second is + 0·67, and it increases until it is practically + 1 at 15,000 periods per second, and remains unity within the limits of experimental error up to the highest frequency tried of 50,000 periods per second, the impedance becoming practically constant as with solid carbons. *The true resistance of the above arc* 3 *mm. long between* 11 *mm. cored* "*Conradty Noris*" *carbons, and through which a current of* 10 *amperes is flowing, is found to be* 2·54 *ohms and the back E.M.F.* 16·9 *volts.*

The fact that the solid arc has, at low frequencies, a negative power factor, indicates that the arc is supplying power to the alternator: this is shown to be the case by means of a wattmeter. This is not, of course, at variance with the principle of conservation of energy, as the alternating energy given out by the arc is derived from the direct current energy supplied to it. This fact that the solid arc is capable of transforming, under suitable conditions, direct current into alternating current is the basis of the "Musical Arc" recently shown for the first time, at the Institution of Electrical Engineers.

Effect of Varying the Direct Current.

Having found that it is possible to measure the true resistance and back E.M.F. of the arc, the effect of changing the direct current, the arc having a constant length of 3 mm., is examined.

The resistance of both the *solid* and the *cored* arcs is found to increase with decrease of the current through the arc, apparently tending to become infinite for current O.

The back E.M.F. of the *solid* arc first decreases with increase of current and then increases again, having a minimum value of 11·3 volts at about 6 amperes. With *cored* carbons the back E.M.F. increases with increase of current from 12·2 volts at 1 ampere to 18·5 volts at 20·8 amperes. The high P.D.'s required to maintain small current arcs are shown to be due to the high resistance of these arcs.

The connection between the resistance r and the current A for the *cored* arc, length 3 mm. between 11 mm., "Conradty Noris" carbons, can be approximately expressed over the range 1·5 to 20 amperes by

$$(r + 0{\cdot}25)\,\mathrm{A} = 29.$$

For the *solid* arc, length 3 mm. between the same size and make of carbons, and over the range 1·5 to 11 amperes, the relation is

$$r = \frac{33{\cdot}5}{\mathrm{A}} + \frac{42}{\mathrm{A}^2}.$$

Effect of Varying the Arc Length.

The direct current through the arc being kept constant, the change in resistance and back E.M.F. due to change of arc length is examined. It is found that both for *solid* and for *cored* arcs increasing the length increases the resistance, the curves between resistance and length being very similar to those between P.D. arc and length. This latter curve is generally assumed to be a straight line for *solid* arcs, but such was not the case over the wide range of length, 1 to 30 mm., used for these experiments.

Effect of Varying the Nature of the Electrodes.

Both the resistance and the back E.M.F. are found to depend greatly on the composition of the electrodes; thus simply soaking a pair of solid carbons in potassium carbonate, reduced the resistance of the arc between them from 3·81 to 2·92 ohms, and increased its back E.M.F. from 12 volts to 15·6 volts, the arc length and direct current being kept constant: similar results were produced by introducing other impurities. The author is of the opinion that the resistance of an arc between *perfectly pure carbon* electrodes would be very high, so high that it might be impossible to maintain a true arc, and that traces of impurities are essential to provide the carriers of the electric charges in the vapour column.

Seat of the Back E.M.F.

In order to determine whether the back E.M.F. and resistance are localised at the electrodes, or are distributed along the vapour column, a search carbon was introduced into an arc 6 mm. long between *solid* "Conradty Noris" carbons, 11 mm. diameter, current 9·91 amperes. The impedance to the high frequency testing current, of that part of the arc between the search carbon and each of the main carbons, was measured for three different positions of the search carbon. From these tests it is deduced that the resistance of the above arc, as a whole, consists of three parts—a resistance at or near the contact of *the positive* electrode and the vapour column of about 1·61 ohms; the resistance of the vapour column, about 2·5 ohms; and a resistance at or near the contact between the vapour column and the negative electrode of about 1·18 ohms.

The back E.M.F. consists of two parts located at or near the contact between the electrodes and the vapour column. That at the *positive* electrode, about 17 volts, *opposes* the flow of the direct current while that at the *negative* electrode, about 6 volts, *helps* the flow of the direct current, *i.e.*, is a *forward* E.M.F.

Conclusion.

The author considers that the new facts given in the paper assist in formulating a consistent explanation of the resistance and back E.M.F. of the arc. The values found for the resistance of the vapour column and for the contacts between it and the electrodes offer no serious difficulties. The greater part of the two E.M.F.'s are considered as being most probably due to thermo-electric forces, and experiments in support of this view are described, in which it was found possible to obtain a P.D. of 0·6 volt by unequally heating two *solid* carbon electrodes with a blow-pipe flame, the voltmeter indicating that the hotter carbon was positive to the cooler. By using *cored* carbons and adding potassium salts, this P.D. was increased to 1·5 *volts*. It is pointed out that the differences of temperature existing in the arc must be many times as great as those which it is possible to produce with the blow pipe, as the cooler electrode must be red hot, or else it does not seem to make contact with the surrounding flame.

On the Resistance of an Electrolyte.

In measuring the resistance of an electrolyte by the Kohlrausch method, it is often assumed that the errors due to polarisation are avoided if the frequency of the alternating or interrupted current used, is as high as a few hundred periods per second. To investigate the accuracy of this assumption the arc was replaced by a cell containing sulphuric acid, density 1·20 (temperature 20° C.), as the electrolyte, and its impedance and power factor tested exactly the same way as those of the arc. It is found with this cell that it was not until the frequency exceeded 10,000 periods per second that the electrolyte behaved as a non-inductive resistance, and the errors due to the polarisation were avoided. If the resistance of this cell were tested in the ordinary way at a frequency of 100 periods *per second*, the value obtained would be over *twice* its true resistance. It is concluded that unless other methods are adopted to eliminate the effects of polarisation, *it must not be assumed that the use of alternating currents of ordinary frequencies of a few hundred periods per second, eliminates the possibility of errors due to polarisation.*

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END OF THE SIXTY-EIGHTH VOLUME.

Harrison and Sons, Printers in Ordinary to His Majesty, St. Martin's Lane.

REPORTS

TO

THE MALARIA COMMITTEE

OF

THE ROYAL SOCIETY.

FOURTH SERIES.

LONDON:
HARRISON AND SONS, ST. MARTIN'S LANE,
PRINTERS IN ORDINARY TO HER LATE MAJESTY.

1901.

CONTENTS.

THE ANATOMY AND HISTOLOGY OF THE ADULT FEMALE MOSQUITO.

By S. R. CHRISTOPHERS, M.B. Vict.

Received August 13, 1900.

[PLATES 1—6.]

The structure of the Mosquito has become of considerable importance since the discovery by Ross of the changes undergone by Proteosoma in a species of mosquito. Moreover, a knowledge of the structure of mosquitoes is necessary in following out not only the development of the parasites of bird and human malaria, but also of Filaria, and possibly of other disease-producing parasites.

We have therefore in the present article described more fully than has yet been done not only the gross anatomy, but also the minute structure, of the organs and tissues of Culex and Anopheles.

The Culicidæ are a highly-specialised group of Diptera. Their muscular, respiratory, vascular, and reproductive systems are to a large extent similar to those of other Diptera.

The genera of Culicidæ do not differ very much from one another in their general anatomy, and still less in the minute structure of their tissues. The differences between Culex and Anopheles, apart from external characters, are chiefly to be found in a generally more robust exoskeleton in Culex, and in the possession of sacculated salivary glands by Anopheles, whereas those of Culex are strictly tubular.

PART I.—THE GROSS ANATOMY.

The Exoskeleton.

As in most insects, the body consists of head, thorax, and abdomen. (Plate 1, fig. 1.)

The Head.—A large portion of the head is formed by the large compound eyes. These occupy the whole of the lateral portions of the head, and approach very close to one another anteriorly. Inferiorly they actually meet in the middle line. In the space between the eyes are the large basal joints of the antennæ. Beneath the origin of the antennæ are the combined clypeus and labrum with the proboscis.

The head is connected with the thorax by a narrow membra neck, in which are two lateral chitinous plates (cervical sclerites).

The Thorax.—This, as in other insects, consists of three segme the pro-, meso-, and meta-thorax. Of these, as in other diptera, mesothorax is the larger, and the prothorax is very small.

Each segment consists of a dorsal piece or notum, a ventral piec sternum, and a lateral portion or pleuron. In the well-developed m thorax the notum consists of several portions, of which the l scutum and the smaller scutellum and post-scutellum are readily s In the other segments these divisions are not readily made out. I in the meso- and meta-thorax the pleuron consists of two large pl the epi-merum and epi-sternum of each segment respectively.

The prothorax is collar-like in shape. The pronotum is undevelo but on either side of the base of the neck are two conspicuous cesses, which consist of two freely movable plates (patagia).

From these, on either side, pass downwards the two rod-sh pleural bodies connected below with the prosternum.

The mesothorax forms the greater part of the thorax. There large ovoid scutum. Posterior to the scutum there is a thick tr verse ridge, the scutellum, which shows very prominently in lo tudinal sections. Posterior to this, and forming the roof of the th behind the wings, is a large plate, which sends inwards a process, to which the posterior portion of the great antero-posterior w muscle group is attached. The mesosternum forms two large surf behind the first pair of legs, and projects laterally above the mi coxa. The episternum and epimerum are two large plates pl laterally. In the pleuron of the mesothorax is the largest spirac the body, the first thoracic stigma. Several small detached plates present in its neighbourhood.

The metathorax is narrow and ring-like. It bears the haltere homologues of the second pair of wings in neuroptera, &c., and a large spiracle, the second thoracic stigma. From the notum sternum large chitinous processes project inwards (apodemes). T give attachment to both thoracic and abdominal muscles.

The Abdomen.—The abdomen consists of eight segments. Each sists of a tergum and sternum connected laterally by the ple membrane. The pleural membrane continues unbroken throug the length of the abdomen, and carries the abdominal spiracles, opposite each segment. From the last segment project two flap- processes, which are used in the deposition of ova.

The Wings.—The wings arise from the mesothorax. They are directly associated with the main masses of wing muscles which inserted into the walls of the thorax. The variation in the shap the thorax caused by the contractions of the muscles causes the and down movement of the wings.

The Legs.—The legs arise from each segment of the thorax. The proximal joint is the large coxa. Between this and the femur is the small trochanter. The other joints are the tibiæ and tarsi.

The Alimentary Canal.

The alimentary canal is specialised on account of the blood-sucking habits of the mosquito. It differs from many insects in not possessing any cæcal diverticula of the mid-gut. It also differs in the possession of five Malpighian tubules, these being in insects usually even in number. (Plate 1, fig. 2.)

The parts of the alimentary canal are as follows:—

The mouth The pharynx with pumping organ The œsophagus The œsophageal diverticula	The fore-gut.
The homologue of the proventriculus The stomach (so-called) The pylorus	The mid-gut.
The pyloric dilatation The small intestine The colon The rectum with rectal papillæ	The hind-gut.

The mouth, pharynx, and œsophagus are ectodermal in origin, and both the mouth and pharynx are lined with chitin. The hind-gut is also ectodermal in origin; it does not possess, however, any portion lined with chitin. The mid-gut is the true digestive portion of the tract.

The Pharynx.—The pharynx, which is lined throughout its extent with chitin, passes upwards and backwards through the ganglionic ring formed by the supra- and infra-œsophageal ganglia and their commissures. At first it is narrow, but posteriorly becomes a large chamber (the pumping organ).

The pumping organ occupies with its muscles a large portion of the head behind the level of the cerebral ganglia. In the state of rest its lumen is triradiate in transverse section. The walls are formed of three large and thick chitinous plates, one placed on either side and one superiorly. Into each of these plates powerful muscles are inserted. Those of the superior plate consist of two muscular masses, taking their origin from the occiput. Those of the lateral plates consist on each side of a single large muscular mass arising from the lateral portions of the head. The plates are connected by thin non-chitinous membrane, and their edges are rolled so that they form a

spring capable of returning to their original position so soon as
separating force of the muscles ceases. (Plate 1, figs. 3 and 4.)

Posteriorly, where the pharynx becomes very narrow, a sharp
occurs and a valvular action is produced. The whole forms a
powerful suctorial apparatus.

The Œsophagus.—Immediately beyond the pumping organ
chitinous layer ceases, and the rest of the fore-gut is formed of e
sively thin membrane. At the junction of the two portions a s
bend occurs, and the floor projects so as to form a valvular flap.

The thin-walled œsophagus is a large dilated sac, whose walls
supported by surrounding structures. Into the posterior wall of
dilated and thin-walled œsophagus projects the papilla-like ant
portion of the mid-gut.

The Diverticula of the Œsophagus.—From the œsophagus two or
diverticula, similar in nature to the œsophagus, extend backw
Of these one is of great size, and usually contains air. This
usually extends into the abdomen, and is a prominent object in
sections and sections. In the newly-hatched mosquito it is small
rapidly becomes large enough to extend into the abdomen. (Pl
fig. 3.)

The Homologue of the Proventriculus.—There is no true proventri
as in many insects. There is, however, an interesting fold of the
gut into the mid-gut which represents this organ. The an
portion of the mid-gut has been noted as projecting into the d
œsophageal pouch. This portion consists of both ectodermal
endodermal portions, and represents the proventriculus in
insects (see "Histology," Part II). The muscular bundles are
increased, and the whole forms a valvular muscular organ. (Pl
fig. 3.)

The Mechanism of Feeding.—The powerful pumping action
must result from a drawing asunder of the three large chit
plates of the pumping organ is very evident. These plates, also,
drawn apart must, by reason of their spring-like shape, revert to
original positions close together, without any muscular aid. Poste
the valve-like arrangement mentioned before prevents regurgitatio

In mosquitoes as usually killed, the proventriculus and ant
portion of the mid-gut are considerably distant from the post
end of the pumping organ, so that the large delicate walled œsoph
chamber with its extensive diverticula intervene. Immediately
feeding, however, though blood is very evident in the mid-gut,
even in the calyx-like proventriculus, yet in the œsophagus the
no trace. As this latter is so large and has such delicate walls,
evident that, in the act of feeding, the calyx-like proventriculus
be applied directly to the posterior opening of the pharynx,
shutting off the capacious œsophageal pouch. The large œsop

diverticulum probably acts, not only as an air chamber to specifically lighten the body of the mosquito, but also as an air pad to distribute the pressure of the large coagulum formed in the mid-gut after feeding. In a fed mosquito a transparent area is generally to be seen in front of the opaque mass of blood in the abdomen. This transparent area is the abdominal portion of the air-containing œsophageal diverticulum. (Plate 1, fig. 3.)

The Mid-gut.—The mid-gut extends from the proventriculus to the origin of the Malpighian tubes. It consists of two portions which merge into one another—an anterior narrow portion, and a large dilated posterior portion, which becomes greatly distended after feeding. Unlike most insects there are no cæcal appendages in the mosquito. Posteriorly there is a marked constriction, with strong muscular bundles, which forms a very marked pylorus. (Plate 1, fig. 2.)

The anterior narrow portion of the mid-gut lies in the thorax, and does not become distended with blood. The posterior portion when fully dilated fills the greater portion of the abdomen, the viscera being pushed into the last few segments. (Plate 3, fig. 2.)

The Hind-gut.—The hind-gut is short and passes in one or two bends from the pylorus to the anus. Immediately beyond the pylorus there is a considerable dilatation which is poorly supplied with muscular fibres : into this open the five Malpighian tubules. For a short distance beyond this the lumen is narrow (small intestine), but becomes gradually larger (colon). At the termmation of the colon there is a slight constriction, after which the canal dilates again to form the rectum. (Plate 1, fig. 2; also Plate 3, fig. 1.)

Into the rectum project six solid growths, the so-called rectal glands, which are, however, papillæ. Posteriorly the rectum ends in the anus close above the gynæphoric canal.

The appendages of the alimentary canal are :—

The Salivary Glands.—The salivary glands consist of six tubular acini lying three upon either side. Those of one side lie generally one above the other in the long axis of the body, their anterior ends lying close against the prosternum, where the ducts coming from each acinus unite to form a single duct. The upper and middle acini generally lie with their distal ends close to the proventriculus. The lower acinus passes towards the thoracic ganglion. Occasionally an acinus becomes bifid at a short distance from its termination. A common abnormality also is a small accessory acinus near the proximal end of an acinus. A duct can be seen traversing almost the entire length of each acinus. Shortly after leaving the acinus the three unite to form a single duct. The duct of each side passes up into the neck, and lies close to the nerve cords passing between the thoracic and the cerebral ganglia. Beneath, and in contact with the lower surface of the sub-œsophageal ganglion, the ducts of each side unite to form a common salivary duct which passes forwards and enters the chitinous portion of the alimentary canal close to the base of the proboscis.

The Malpighian Tubules.—These are five in number and open the first portion of the hind-gut immediately beyond the pyl Their blind ends are held in position in the neighbourhood of rectum by tracheal branches. They pass forwards in loops a their origin, so that, in transverse section, as many as ten ma seen cut across.

The Muscular System.

The chief muscular masses in the mosquito are contained in thorax. They are chiefly muscles moving the wings and legs.

Wing Muscles.—There are two large muscular masses on either of the thorax, passing from the dorsal to the ventral body Between these bundles there is a space, in the lower portion of w lies the alimentary canal, main air tubes, and other structures. upper portion of the space is occupied by a second series of l muscular bundles, passing from the front to the back of the th Neither of these large masses of muscle are inserted directly int wings, the up and down movement of the wings being cause alterations in the shape of the thorax, consequent on the contrac of the vertical and horizontal fibres respectively. (Plate 2, fi and 5.)

There are, however, a few fibres arising from the lateral portio the thorax, and inserted about the base of the wings.

Leg Muscles.—These occupy but little space in the thorax. rise to a large extent from the internal processes of the exoske (apodemes), and are inserted into neighbouring portions of the li They arise also from one segment of a limb and are inserted another.

The Muscles of the Body Segments.—These arise from one seg and are inserted into the next. They are arranged dorsally ventrally in lateral groups throughout the abdomen.

A small muscle is also situated on each side, passing vertically the tergum to the sternum. These on contracting flatten the abdo

Muscles in association with the Alimentary Canal.—Several im tant muscular masses are connected with the large chitinous pum organ. A pair of muscles arises from the occipital region of exoskeleton, and is inserted into the upper plate of the organ. large muscle arises on each side, and is inserted into each of the la plates.

In the thorax a small muscular band rises from the neighbour of the first pair of legs, and passes upwards close to and outside salivary glands of each side. The contraction of this band must e pressure upon the salivary glands. (Plate 2, figs. 1 and 2.)

Anteriorly and posteriorly small muscular bundles pass from the dilated portion of the mid-gut to the abdominal wall.

The Tracheal System.

Respiration is entirely carried on by tracheæ. These take their origin from external openings—the spiracles, and eventually terminate in minute capillaries in the actual tissues of the insect. In culex and anopheles there is no development of large or multiple air sacs in connection with the tracheal system, as in many insects. In their case probably the large œsophageal diverticulum plays the same part.

The spiracles are placed both in the thorax and in the abdomen. The thoracic spiracles are two in number, situated in the meso-thoracic and meta-thoracic segment respectively. Of these the anterior one is the largest in the body. The second thoracic spiracle is also much larger than the abdominal spiracles. The abdominal spiracles are situated in the pleural membrane, one in each segment. (Plate 1, fig. 1.)

The Tracheæ.—Very large tracheæ pass inwards from the anterior thoracic spiracles. (Plate 2, fig. 3.)

1. A large branch passes forwards towards the neck and gives off a branch which passes down on either side of the middle line to the two anterior coxæ and the salivary glands. The main branch continues on through the neck, and supplies the head with numerous large branches.

2. A large branch passes upwards and backwards along the edge of the meso-scutum, and gives off branches which supply the wing muscles. A smaller branch also passes forwards and supplies the muscles of the thorax.

3. The largest trachea in the body (main trachea) passes downwards, backwards, and inwards, so as to lie on either side of the anterior portion of the alimentary canal. Numerous branches are given off from this trunk to the thoracic muscles, the alimentary canal, and legs. Posteriorly the trunk is continuous with a trachea passing forwards from the second thoracic spiracle, thus forming on either side a large tracheal loop.

Large tracheæ also pass inwards from the posterior thoracic spiracles.

1. Branches pass forwards and join in a loop with the main trachea, also backwards to join the abdominal system.

2. Branches pass downwards to the meta-thorax and posterior pair of legs.

3. Branches pass inwards to the muscles and mid-gut.

From each abdominal spiracle a short thick trunk passes inwards which gives rise to the following branches:—

A dorsal branch ramifying beneath the tergum and joining the branch of the opposite side.

[redacted]

A sternal branch supplying the sternal plate and muscles, also joining the branch of the other side.

Loop branches passing to the trunks anterior and posterior.

Branches passing inwards and supplying viscera. Branches from the first, second, third, and fourth abdominal tracheæ supply mainly the mid-gut, those from the fourth and fifth the ovaries, those from the sixth and seventh the genital organs.

The Vascular System.—As in most insects where the respiratory system ramifies throughout the whole body, the vascular system is not well developed. A dorsal vessel or heart and an anterior prolongation of this (aorta) are the only closed blood vessels. Apart from the dorsal vessel the blood circulates in large blood spaces, which lie between the lobes of the fat-body and among the muscles and viscera.

The dorsal vessel passes close beneath the tergal plates throughout the abdomen. It is very thin walled, and is not provided with valves. The upper portion is attached to the dorsum at intervals by suspensory fibres (muscular), so that a festooned appearance is given in longitudinal section. There is, however, no true division into compartments. Laterally large cells (pericardial cells) are arranged throughout its entire extent, and fibres of a muscular nature (alary muscle) pass from the body wall and end in branches in close connection with the dorsal vessel (see "Histology," Part II). (Plate 4, fig. 1.)

At the first abdominal segment the dorsal vessel dips down beneath the mesophragma, lying as it does so, in direct contact with the cuticle. In the thorax it again arches upwards, and lies between the lower portions of the antero-posterior wing muscles close above the anterior portion of the mid-gut.

In the anterior third of the thorax it divides into two smaller portions which pass outwards, and coming in contact with the salivary ducts enter the neck.

Blood spaces without definite walls occur throughout the body. The thorax especially contains large spaces among the muscles, and the complex fat-body which lies between and supports the organ is everywhere bathed with blood fluid. (Plate 1, fig. 3.)

The Nervous System.

The ganglionic system in the Culicidæ is considerably developed. The head ganglia are large and complex. The thoracic ganglia are large and compressed so as to form a large ganglionic mass. The ganglia of this system are as follows:—

a. Lying around the pharynx is a ganglionic ring composed of large supra- and infra-œsophageal ganglia with their commissures. From these, large nerves go to the eyes, antennæ, and mouth parts.

b. In the thorax lying below the œsophageal diverticulum and close to the sterna is a large compound ganglion showing evidence of its origin from the conjoined ganglia. Between this and the head ganglia are two long slender nerve cords, which pass in the neck in close relation with the salivary ducts. From the thoracic ganglion large nerves pass to the limbs, and posteriorly nerve cords connect it with the first abdominal ganglion.

c. The abdominal ganglia lie with their connecting commissures close upon the abdominal sterna. The last ganglion lies just below the junction of the oviducts to form the common oviduct. A large nerve passes from it among the viscera of the last few segments.

The Visceral System.—Small ganglia connected with the main ganglionic system occur in connection with the viscera. The most important of these are two small groups of large nerve cells lying in front of and above the thoracic ganglion, with the middle portion of which they are connected by nerves. They lie laterally beneath the œsophageal diverticulum and anterior portion of the mid-gut, and are not far removed from the salivary glands. Another small ganglion occurs above and in front of the proventriculus. (Plate 4, fig. 5.)

The Reproductive System.

The organs of the reproductive system are—

1. Ovaries.
2. Oviducts and common oviduct.
3. Mucus gland and duct.
4. Spermathecæ and ducts.

The ovaries occupy a variable position dependent upon the state of their development. In the newly-hatched mosquito they are small bodies lying in the fourth and fifth abdominal segments close by the posterior portion of the mid-gut, and attached to the body wall by numerous tracheæ. As they enlarge they push the mid-gut, hind-gut, and Malpighian tubes towards the ventrum, so that eventually the ovaries occupy nearly the whole of the posterior portion of the abdomen. Each ovary consists of very many follicular tubes, each containing egg follicles in different stages of development (see "Histology"). In the mature ovary the lower follicles have in every tube become the large completely-formed egg. (Plate 6, fig. 5.)

The oviducts are muscular tubes passing from the ovaries. They join beneath the rectum to form the common oviduct, which is still more abundantly supplied with muscle fibres, and which eventually opens beneath the anus.

The spermatheca is a chitinous sac, which in the impregnated female is filled with a mass of spermatozoa. Its duct is long and twisted and opens into the common oviduct near its termination.

The mucus gland, globular or ovoid in shape, opens by a short duct *into the same region.*

The Fat-body.—The adipose tissue is disposed in two ways.

1. As a general lining to the body wall, being nearly everyw
present directly beneath the cuticle (Plate 3, fig. 1), and

2. As lobular masses lying in among the organs and mus
Thus a large pad lies over the compound thoracic ganglion, and s
processes which lie in among the salivary glands and other vis
Other smaller masses lie in the head and abdomen. (Plate 1, fig.

PART II.—HISTOLOGY.

Methods.—The examination of the fresh tissues frequently re
structures not easily seen in fixed preparations. The tissues are
dissected out in normal saline of low tonicity, 0·3 or 0·4 per cent
insect juices have a lower isotonic point than those of mamr
Better preparations of both tissues and included parasites are usu
to be obtained by the use of fixed tissues. Several tissues (inclu
the salivary glands and mid-gut) may, when dissected out, be sprea
means of the edge of a slide or cover-glass, and rapidly dried. T
fixed and stained, give beautiful preparations of sporozoites, as we
certain parasites in the mid-gut, hind-gut, &c.

For fixing mosquitoes as a whole, watery solutions are
generally so good as alcohol, on account of the difficulty of penetra
from the nature of the exoskeleton and the large amount of air
tained in insect tissues: very good results are obtained by fixing
hardening in absolute alcohol, and proceeding at once to embe
paraffin. It is best, so soon as considerable hardening has taken p
to make a minute incision into both the thorax and abdomen.
fixing portions of or isolated organs of mosquitoes saturated solu
of perchloride has advantages over alcohol and fixes the cells of
mid-gut extremely well. It does not penetrate, however, well
undissected mosquitoes. Picric acid gives good results with isol
organs. The changes in the mid-gut cells during digestion are
shown.

Both Culex and Anopheles, but especially the latter, cut readil
paraffin or celloidin. For staining smear preparations and sect
hæmatein gives very good results: sporocysts and sporozoites, as
as the normal tissues, are well stained.

The stellate cells in connection with the tracheal endings upon
mid-gut, &c., are frequently well shown by gold chloride. Hei
hein's hæmatoxylin gives good results with the salivary glands,
also the muscle fibres in connection with the alimentary canal.

The Histology of the Alimentary Canal and Appendages.

The epithelial lining differs considerably in the mid-gut from
the fore-gut or hind-gut. In the mid-gut the possession of a

striated border by the epithelial cells is characteristic. The muscular fibres of the alimentary canal are striated throughout.

The Fore-gut.—The anterior portion of the fore-gut is lined by chitin and does not differ from the cuticle in structure. It consists of a single layer of cubical cells of small size. The œsophageal dilatation and its diverticula resemble one another in structure. In the adult mosquito they consist of an extremely delicate membrane formed of a single layer of flattened cells, with externally some scattered muscular fibres. In fresh preparations peculiar wrinklings of this membrane are seen which may appear like bundles of sporozoites. A similar appearance is seen in the dilated portion of the hind-gut just beyond the pylorus.

In the pupa the œsophageal diverticulum is seen passing backwards as a narrow tubular organ lying beneath the mid-gut. It is in this stage lined with well-marked cubical epithelium. In a freshly-hatched mosquito this organ is frequently undistended, and shows a narrow lumen surrounded by a single layer of large cells. These cells retain very little trace of protoplasm, which, however, may still be present in fine strands, and around the nucleus, which is pushed to the outer portion of the cell. (Plate 4, fig. 5.)

In the majority of mosquitoes the walls of the œsophageal diverticulum are crowded with micro-organisms and bodies which appear to be protozoal in nature.

The Mid-gut.—There is but little structural difference between the narrow anterior portion of the mid-gut which lies in the thorax and the posterior dilated portion which lies in the abdomen. In many insects there are cæcal tubes or pouches opening into the anterior portion of the mid-gut. These are, however, quite absent in the adult mosquito. The main thickness of the wall consists of epithelium; external to this is a thin coat of muscle fibres. (Plate 4, fig. 2.)

The epithelium consists of a single layer of large cells which are columnar in the undistended organ, but become flat and pavement-like when the organ is full of blood. They have a finely-reticulated protoplasm, which stains more deeply towards the free border. Stained with Heidenhein's hæmatoxylin, alcohol-hardened specimens are seen to contain numerous stained granules collected especially in the outer portion of the cell. These are especially abundant in the anterior portion of the mid-gut. They have also very frequently a number of small clear vacuoles (droplets) which become more frequent and of larger size towards the free border of the cell. The most marked feature of the cell is the clear striated border which is present in all the cells of the mid-gut, but absent in all other portions of the alimentary canal. The striated border is best marked in the undistended organ and becomes almost invisible in the fully distended state when the cells are much flattened. (Plate 5, fig. 1.)

The nucleus of these cells is large and centrally situated. The chro-

[redacted]

matin is arranged in small stellate masses arranged circumferentially and centrally and connected with one another by fine threads of chromatin. There is a body which stains less deeply generally to be made out (karyosome) in the centre of the nucleus.

Occasionally young cells are to be seen near the basement membrane.

The muscular coat is very thin. It consists of an open mesh-work of long muscle fibres running longitudinally and circularly. In the large posterior portion of the mid-gut these fibres form a very regular series of large square or rhomboidal meshes. In the narrow anterior portion they are more closely approximated so that the muscular layer here is more evident in sections.

The individual muscle fibres are very long, fusiform, striated fibres. On the outer surface of the mid-gut lie numerous large branched cells in which the small tracheæ end, and from which bundles of minute structureless air tubes pass into the wall of the mid-gut. These cells are frequently well shown in gold chloride specimens. Similar cells occur throughout the viscera in connection with the tracheal endings. (See "Tracheal Endings.")

The Homologue of the Proventriculus.—Mention has been made in Part I of a fold occurring at the anterior extremity of the mid-gut. This consists of an invagination of a portion of the fore-gut into the mid-gut. The mid-gut is also folded in with the portion of fore-gut, so that in this region there is a double thickness of mid-gut wall as well as the fore-gut. There is an increase in the muscular fibres of the mid-gut at this point, especially the circular fibres, so that a very distinct mass is formed homologous to the proventriculus of many insects. There is no chitinous development, however, and the structure would appear to act only as a muscular sphincter. (Plate 1, fig. 3.)

The Hind-gut.—The nature of the epithelium and arrangement of the muscle fibres differs somewhat in different portions of the hind-gut. Structurally the small and large intestine are similar, whilst the dilatation beyond the pylorus, and especially the rectum, differ from these.

The dilatation which occurs at the origin of the Malpighian tubules is thin-walled and poorly supplied with muscle fibres. The cells lining it are small and flattened. (Plate 3, fig. 1.)

The intestine is lined with a single layer of large cubical cells: external to these is a muscular coat. The cells of the intestine have large nuclei which have a similar, though more open, arrangement of the chromatin than the nuclei of the mid-gut. The protoplasm is finely reticular, and stains less deeply than the cells of the mid-gut. Stained with Heidenhein's hæmatoxylin, no granules are present as in the cells of the mid-gut. They have no striated border. (Plate 4, fig. 3.)

In the rectum the cells become small and flattened. There are, however, here bodies usually termed rectal glands. These are papillæ covered with a single layer of much hypertrophied cells resembling those lining the small intestine and colon. (Plate 4, fig. 4.)

The muscular system of the hind-gut is very similar to that of the mid-gut, consisting of very large fusiform, striated cells arranged circularly and longitudinally. The circular fibres in the small intestine lie outside the longitudinal, and pass spirally around the mid-gut. Towards the termination of the intestine longitudinal fibres also lie outside the circular. In the rectum and extending throughout the hind-gut and mid-gut, in both Anopheles and Culex, there are, in a large proportion of specimens, swarms of a flagellate organism. (Plate 5, fig. 3.)

The Salivary Glands.—The salivary acini lie in a cleft in the fat-body, which latter comes in close contact with the glands. Each gland acinus consists of a single layer of large cells limited externally by a delicate sheath (basement membrane) and internally by the intra-glandular duct wall. (Plate 5, figs. 6 and 7.)

In Anopheles the intra-glandular duct becomes larger as it approaches the termination of the acinus, and forms a large cavity.

In Culex the duct remains of the same diameter throughout the acinus, and terminates abruptly near the end of the acinus without any dilatation.

In both Culex and Anopheles there are two types of gland acinus. These are recognisable both in the fresh gland and in fixed specimens. From their appearance in the latter they may be termed

(1) The granular type.
(2) The clear or colloid-like type.

The Granular Type.—The greater portion of the acinus consists of cells whose nucleus and protoplasm has been pushed to the outer portion of the cell by a large mass of secretion which occupies almost the whole of the cell. In the fresh gland this secretion appears as a clear refractile substance, and can by pressure be made to exude from the cell in refractile globules. In specimens hardened in alcohol, this clear secretion appears as a granular mass occupying the greater portion of the cell. It stains faintly with hæmatein, and shows under high powers ($\frac{1}{16}$ oil immersion) a coarse reticulum and isolated globules, an appearance probably due to the precipitation or coagulation of the secretion by the alcohol. Considerable variations exist, however, in the appearance of this granular secretion both in the different mosquitoes and in different parts of the same gland. In anopheles the greater portion of the gland contains cells densely crowded with granular material. Very frequently, however, the terminal portion contains cells in which only a few large globular masses exist. (Plate 5, fig. 9.)

The protoplasm of the cell occupies in the fully-matured gland only the extreme periphery, and the nucleus, which is much degenerated, is pushed to the outer portion of the cell, and usually lies in the angular interval left at the base of two or more contiguous cells. In the granular type of gland this disappearance of the protoplasm and nucleus from view is more pronounced than in the clear type of gland.

The Clear or Colloid-like Type.—Of the last-mentioned type there are two acini upon either side; of the present type there is but a single acinus upon either side, which usually lies between the two acini of granular type. (Plate 5, fig. 7.)

In the fresh gland the cell outlines are not so distinct as in the granular type, and the secretion when extended by pressure is much less refractive. In alcohol-hardened specimens, the acinar cells contain a large mass of clear homogeneous secretion which, as in the last-mentioned type, fills almost the entire cell, and pushes the protoplasm and nucleus to the periphery.

In the clear type, however, the protoplasm is always in greater amount than is the case with the granular type, and the nucleus never becomes so greatly degenerated. The clear homogeneous secretion stains readily with hæmatein, and may even stain quite deeply. With Heidenhein's hæmatoxylin it frequently becomes almost black. It resembles very much in appearance colloid substance as it is seen in the mammalian thyroid.

In Anopheles this substance also distends the central duct space within the acinus. In this situation an appearance is sometimes produced which resembles faintly-stained sporozoites, but which is a normal condition.

The Maturation of the Glands.—In freshly-hatched mosquitoes both types of acinus consist of large glandular cells arranged round the lumen. These contain a large centrally situated nucleus, and have protoplasm containing a large number of coarse granules staining with hæmatein. In the portion of the cell nearest the lumen a vacuole of varying size is situated. This is the commencement of the large mass of secretion which, in the mature gland, occupies the entire cell. In the granular type of acinus the vacuole contains granules; in the clear type it resembles the colloid-like secretion. (Plate 5, fig. 8.)

Further Variations in the Cells of the Salivary Acini.—In the granular type of gland the greater portion of the acinus is composed of cells of the character described above. A portion, however, usually exists which differs considerably in structure. This portion adjoins the duct, and may in Anopheles reach as much as one-quarter of the entire gland in length. In this portion of the gland the cells are much smaller than those containing the granular secretion, so that the diameter of the acinus is much less here, and a sudden increase takes place when the portion containing the granular secretion is reached. The cells lying towards the duct differ from those lying towards the acinar end of this portion. There is, however, no line of demarcation between them, the one gradually becoming changed into the other. In the centre of each cell is a clear body, pushing the nucleus and protoplasm to the outer portion of the cell. Towards the duct end in the centre of this clear substance is a darker portion continuous with the duct lumen. As the cells come to lie nearer the distal portion, this central dark lumen becomes obliterated. This structure, though present in Anopheles, may be absent in Culex. In certain Culex another variation in the gland cells frequently occurs. The portion of the gland lying close to the duct, instead of being less in diameter is greater. The cells composing this portion are columnar in shape, with centrally situated nuclei and no contained secretion.

In certain specimens it is not uncommon to find cells occupying a peripheral position, and not approaching the lumen, which contain a substance resembling the colloid-like secretion of the clear type of gland.

Changes after Feeding.—Very little change occurs in the glands after feeding. They are for the most part still quite full of secretion. Probably a very small amount only of secretion is used with each puncture.

The Ducts.—The intra-acinar ducts vary in Culex and Anopheles. In Culex they remain narrow and tubular throughout the entire length of the gland. In Anopheles they become large spaces in both types of acini, but especially in the clear type. The duct is lined throughout by a clear homogeneous skeletal material which is continuous with a similar substance dividing the cells of the gland from one another. Into the duct the secretion-filled cell opens by means of a small opening.

The duct after leaving the acinus, consists of a thick-walled tube, with a central spiral thread resembling the spirals in the trachea. The wall is homogeneous, but contains many nuclei.

The Malpighian Tubules.—The Malpighian tubules are tubular bodies with cæcal ends, which open into the hind-gut. The cells are extremely large, being, next to the pericardial cells, the largest in the body. Each cell contains a large nucleus, and contains numerous large granules, which stain feebly with hæmatein, but powerfully with Heidenhein's hæmatoxylin. Numerous fatty granules are also present. Each cell is wrapped round a central lumen, the cells being arranged alternately, so that a zig-zag appearance is given in section. The inner portion of each cell is markedly striated, the lumen being thus bounded by a striated area. In relation with these tubules, a large number of tracheæ and tracheal end-cells exist.

In certain conditions the Malpighian tubule cells may be found quite free from granules, though otherwise unchanged. This change occurs in mosquitoes with large numbers of a flagellate organism (previously noted) in the rectum and hind-gut.

The Muscular System.—The muscular fibres of the mosquito are without exception striated. Those of the wings differ in structure very much from those of the limbs and body segments. The muscle fibres of the alimentary canal are large fusiform cells, with a single large nucleus with some surrounding protoplasm. The muscle fibres in connection with the heart are much branched. (Plate 4, fig. 2.)

Many of the fibres contain a very marked sarcolemma and space between this latter and the fibre. This space is usually seen occupied by extremely delicate branching threads, which stain feebly with hæmatein.

In the pupæ there exist some large cells of peculiar nature in association with the sheaths of the muscle fibres.

The structure of insect muscle is described in many works on histology, and does not need repetition here.

The Tracheal System.—The larger tracheal vessels consist of a single layer of flattened cells with an inner chitinous layer. In smaller tubes the cells embrace the entire vessel, the nucleus frequently being bent around the lumen. The cells of the tracheal vessels contain numerous small clear vacuoles (chitin formation). The chitinous lining possesses a thickening in the form of a spiral thread, which may become unwound and lie stretched as a wavy thread in fresh preparations. The smaller tubes contain the spiral thread until they become from 2 to 5 μ in diameter. They then divide to form bundles of excessively minute air capillaries, which enter among the tissue cells. The division into capillaries takes place in the substance of large branched cells situated at the termination of the tracheal vessels. The cells often appear cribriform in section from the number of air capillaries. These cribriform cells in connection with the tracheal endings are well seen in the mid-gut and Malpighian tubules. They are, however, seen best of all in the undeveloped ovary of the newly-hatched mosquito, which is extremely rich in bundles of capillary air tubes.

The Vascular System.—The dorsal vessel is a delicate walled tube composed of longitudinal and oblique fibres with a nucleated inner layer. The fibres may be traced directly from the terminations of the branched alary muscle fibres. The alary fibres break up into fibres which pass in close connection with the large pericardial cells, and eventually form (1) fibres passing into the dorsal vessel as longitudinal fibres, (2) fibres joining in an anastomosis in connection with the floor of the dorsal vessel. (Plate 4, fig. 1.)

The pericardial cells are extremely large cells lying on either side of the dorsal vessel throughout its whole extent. They are by far the largest cells in the mosquito, varying from 30 μ to 50 μ in long. diameter. They are elongate or pear shape in form and contain several nuclei. The nuclei usually show signs of degeneration. The peripheral portion of the cell stains more deeply than the central portion, which contains the nuclei and small stained granules. There are a considerable number of masses of a light yellowish pigment resembling that found in the large visceral ganglia cells. The fibres from the branches of the alary muscles pass over and around the pericardial cells to reach the dorsal vessel. From their structure and situation the pericardial cells appear to be of the nature of ganglion cells. (Plate 5, fig. 5.)

The Fat-body.—The fat-body, both where it occurs as a portion of the body wall and where it lies as free lobulated masses, consists of cells containing numerous oil globules. The cells are of considerable size, and their borders may be frequently traced as polygonal areas. The nuclei are oval in shape with a central mass of chromatin and chromatin threads. Besides oil globules the cells contain granules staining with hæmatein, and minute droplets of a highly refractile, dark substance, which gives the appearance of pigment. These droplets are larger in amount in old mosquitoes than in those freshly hatched.

The Nervous System.—The ganglia of the ganglionic system consist of an outer portion of nerve cells and an inner portion of non-medullated nerve fibres. Considerable complexity exists in the larger ganglia, especially the head ganglia. (Plate 5, fig. 4.)

The ganglia of the visceral system differ greatly from those of the ganglionic system. The ganglion cells are few in number and of large size. They possess clear reticular protoplasm, a little denser around the periphery than in the centre. Around the inner margin of the denser peripheral portion small stained points are arranged. In the centre a variable number of granules of yellowish pigment exist. (Plate 6, fig. 1.)

The Reproductive System.—Each ovary consists of a large number of follicular tubes whose lower ends open into the ovarian tube, and whose upper ends terminate in a delicate supporting filament (terminal filament). The apex of the ovary is formed of a single follicular tube whose filament is attached to the fat-body of the 4th segment.

Around the whole ovary there is a delicate nucleated sheath.

Each follicular tube contains one or more egg-follicles in different stages of development. In the freshly-hatched mosquito each follicular tube contains an undeveloped egg-follicle. As this develops, a second and a third undeveloped follicle appear above it, which again undergo development into mature eggs. The follicle at first consists of two to four large cells with large nuclei surrounded by a single layer of smaller epithelial cells. (Plate 6, figs. 2, 3, 4.)

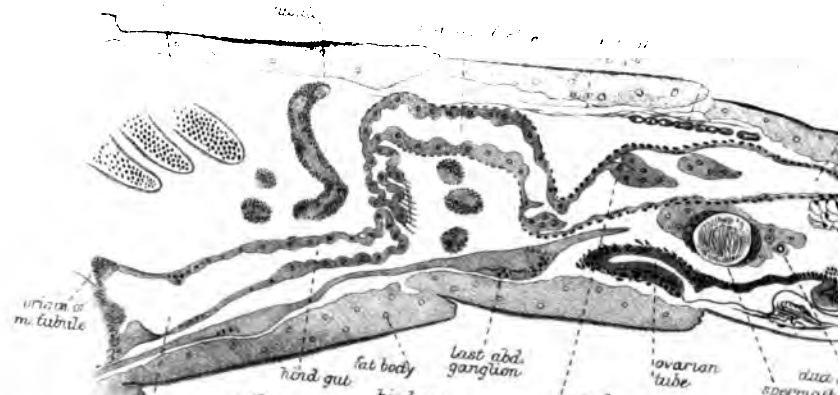
The central cells then increase in size and number, so that many very large cells are contained in the now enlarged follicle. The surrounding epithelial cells also become larger, and rapidly increase in number so as to form a layer of regular cubical cells surrounding the follicle. The central cell nearest the ovarian tube is the ovum, the rest are nurse cells, and eventually disappear. Both the ovum and the nurse cells increase greatly in size. The nurse cells have clear protoplasm and extremely large nuclei, which exhibit karyokinetic figures. The ovum contains very numerous yolk granules, which occupy the whole of its substance, except a thin coating of granular protoplasm. Still later this thin external layer can only with difficulty be made out. (Plate 6, fig. 4.)

The nucleus of the ovum undergoes very pronounced changes. It appears as an irregular mass, staining uniformly with nuclear stains. This mass becomes more and more distorted and broken up, and eventually disappears. It may frequently, however, be seen as irregular masses of staining material even in the mature egg. A portion of the nucleus is seen very early to be separated off from the rest, often surrounded by the latter. This portion (female pronucleus) is small and difficult to detect in sections in the more mature ovum. As the ovum increases still more rapidly in bulk, the nurse cells become crowded into the distal portion of the follicle and eventually disappear, so that, in the mature egg, no trace of them is to be seen. The epithelial layer surrounding the follicle becomes much flattened, and forms eventually a covering to the egg (chorion). The outer portion of this covering (exochorion) is transparent, and marked with oblique parallel markings. Over the proximal end, *i.e.*, the end lying towards the ovarian tube, the chorion forms a globular mass ornamented with rows of pits. This is the micropylar apparatus through which the spermatozoa penetrate the ovum.

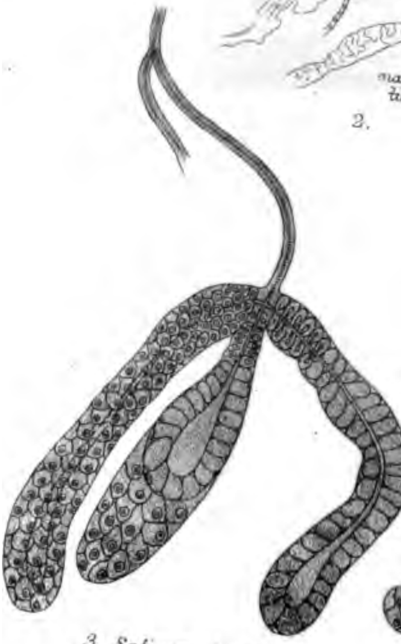
Frequently in Anopheles a large portion or the whole of the adult ovum consists of a mass of sporozoa. These consist of numerous small cysts, each containing eight round or crescent-shaped bodies, each with a central chromatin spot. (Plate 6, figs. 6, 7.)

The ovarian tube arises in the centre of the ovary, and receives on all sides the follicular tubes. It is lined with a single layer of small cubical epithelium. After passing out of the ovary, a considerable number of striated muscular fibres are arranged in a loose network around it, and pass from it to surrounding structures. There are also muscular fibres in the ovary itself in connection with the ovarian tube and egg-follicles.

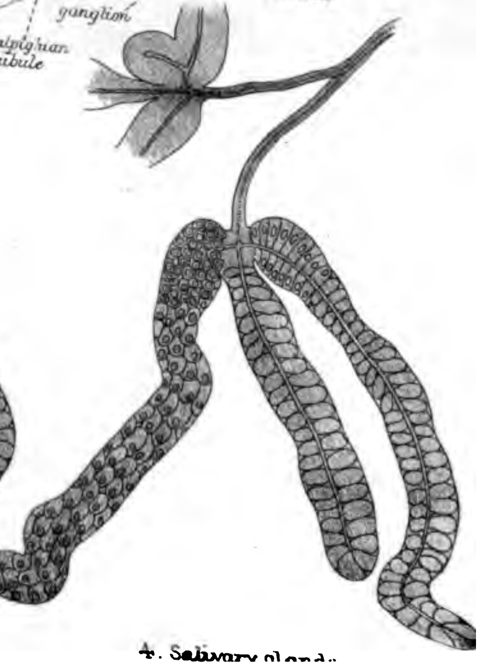
The spermatheca consists of a chitinous sac, with large cells lying externally. These resemble the cells of the cuticle, and contain droplets. They do not cover the whole of the surface of the spermatheca. The contents of the spermatheca in the fertilised insect consist of a mass of spermatozoa, which, in the fresh state, may be seen revolving with great rapidity within the sac. The spermatozoa have a narrow, slightly-curved head and a long tail. The duct of the spermatheca is narrow and thick-walled, and contains muscular fibres. Certain large cells lie in connection with the duct externally. The mucus gland contains cells filled with secretion. There are small nuclei in connection with the intra-acinar duct. (Plate 6, figs. 8, 9.)



2.

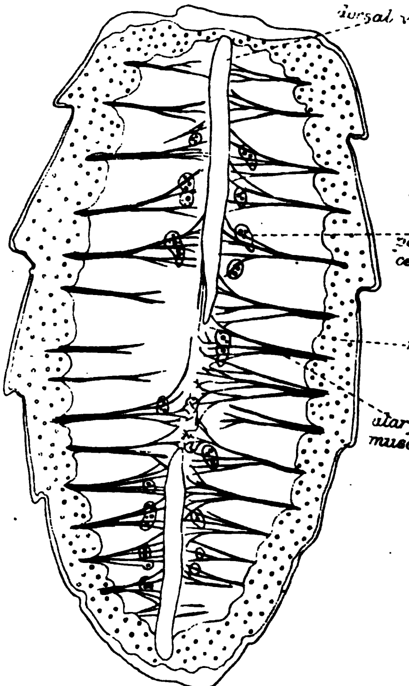


3. Salivary glands
Anopheles.

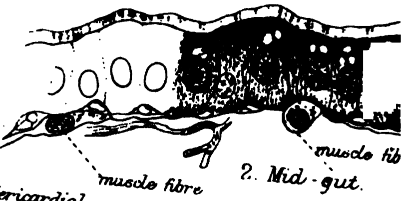


4. Salivary glands

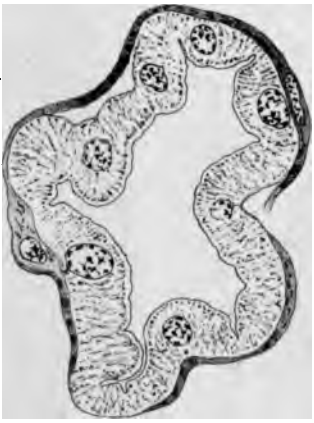
Christophers. Female Mosquito.



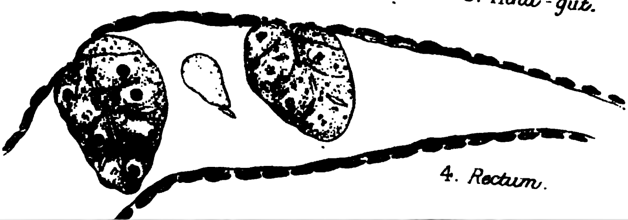
1. Dorsal vessel.



2. Mid-gut.



3. Hind-gut.

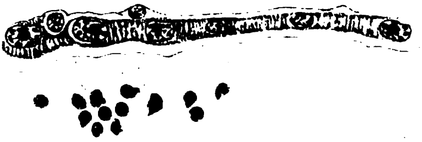


4. Rectum.

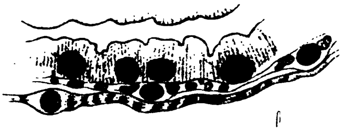
5. Nervous system. L.S. Section of nympha.

West, Newman

[redacted]

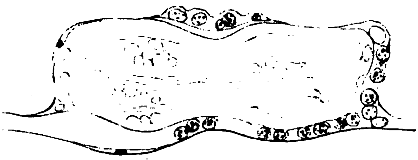


1. *Mid-gut distended.*

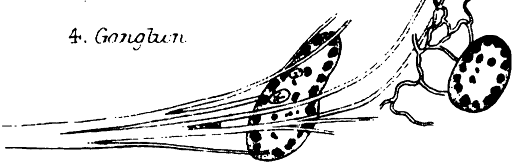


2. *Hind-gut.*

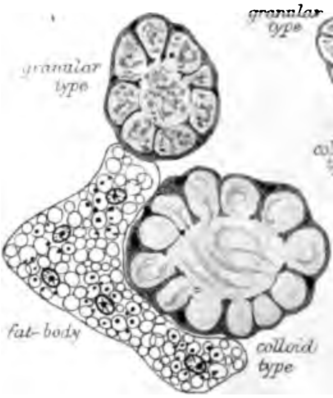
3. *Parasites in hind-gut.*



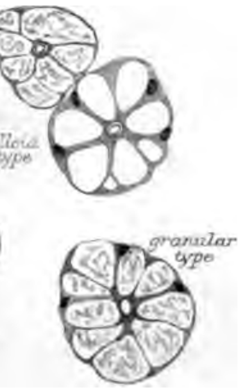
4. *Ganglion.*



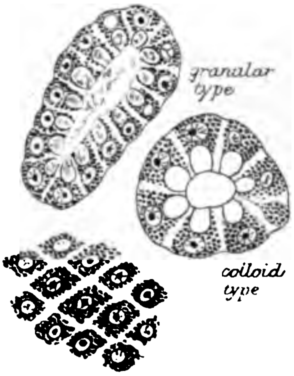
5. *Pericardial cell and alary muscle.*



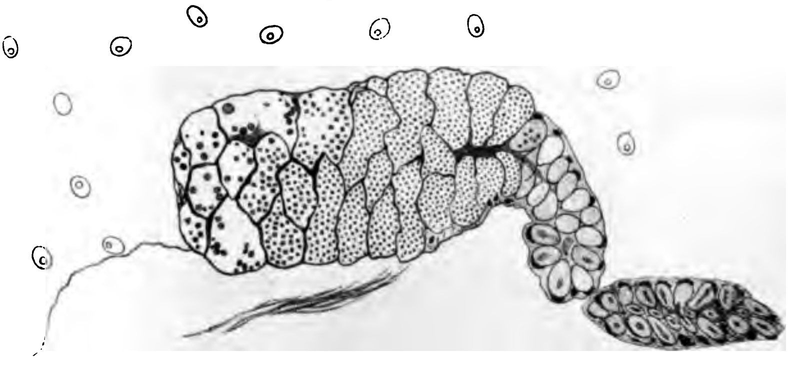
6. *Salivary glands anopheles.*



7. *Salivary glands culex.*



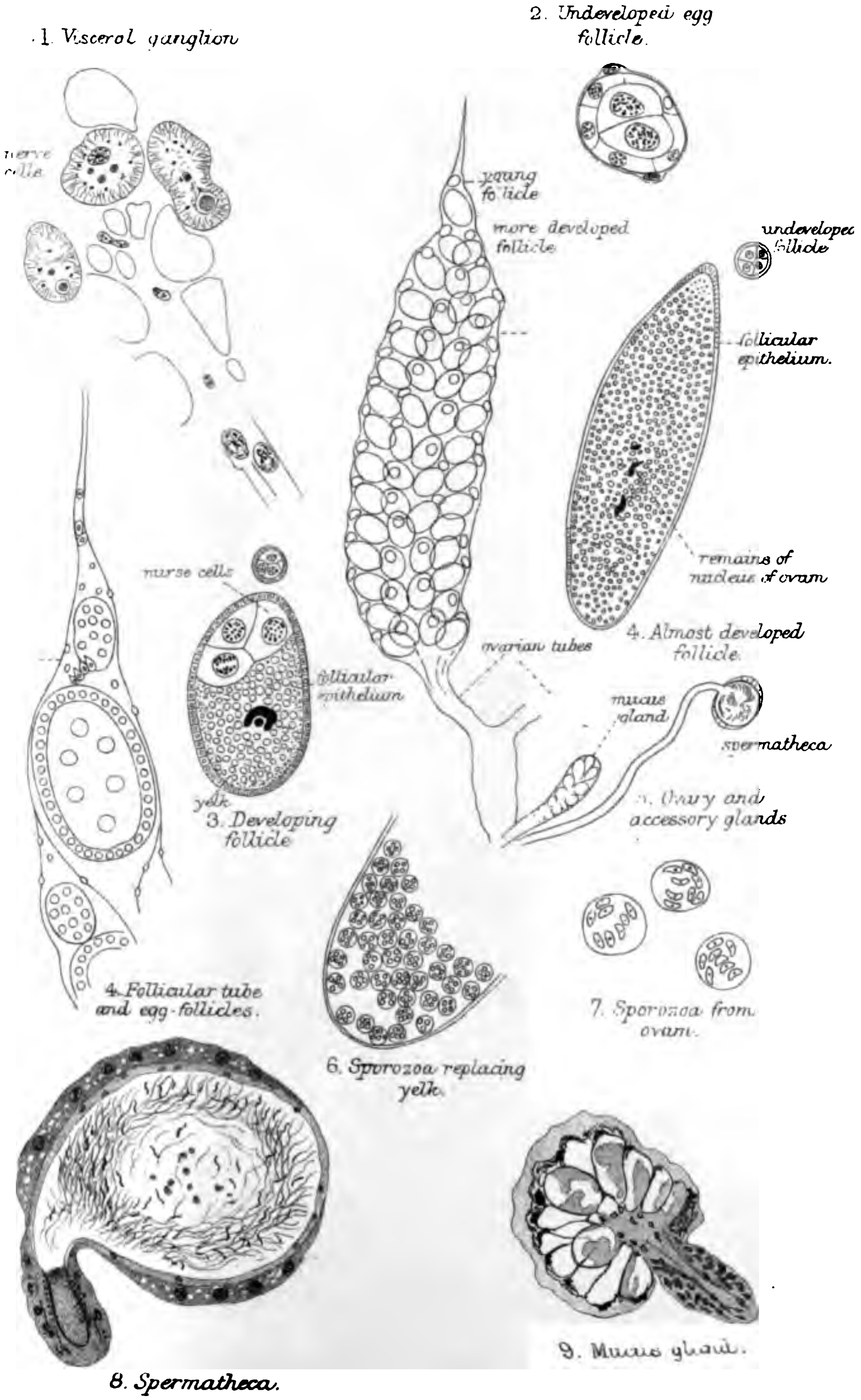
8. *Glands of newly hatched anopheles.*



9. ***Longitudinal section of salivary gland of anopheles, granular type.***

West.

[redacted]



1. Visceral ganglion

2. Undeveloped egg follicle.

3. Developing follicle

4. Almost developed follicle.

4. Follicular tube and egg-follicles.

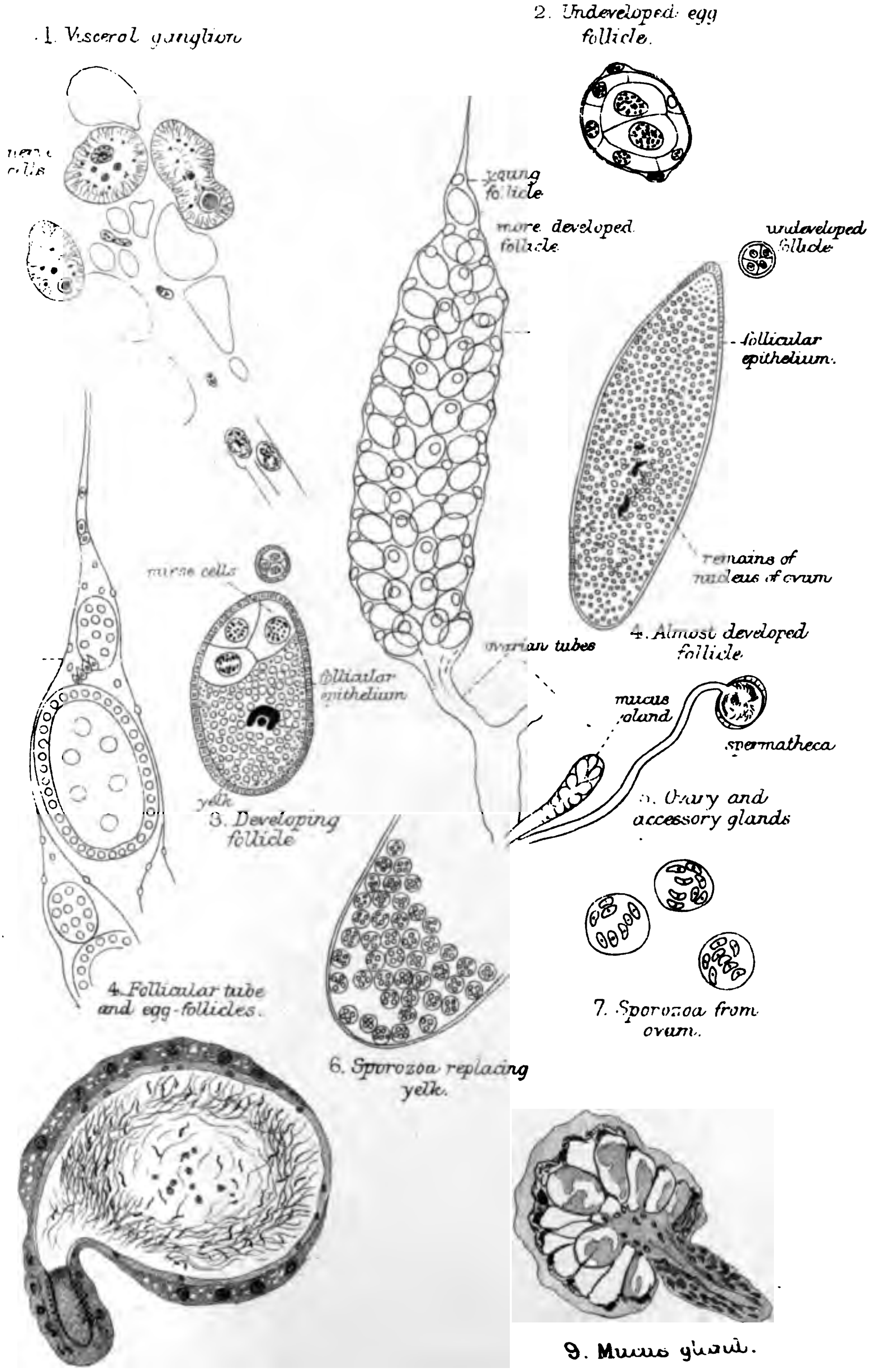
5. Ovary and accessory glands

6. Sporozoa replacing yelk.

7. Sporozoa from ovum.

8. Spermatheca.

9. Mucus gland.



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CONTENTS.

REPORTS, &c., FROM MESSRS. STEPHENS AND CHRISTOPHERS, WEST COAST OF AFRICA.

"The Proposed Site for European Residences in the Freetown Hills." By J. W. W. STEPHENS, M.D. Cantab., and S. R. CHRISTOPHERS, M.B. Vict. Received November 26, 1900.

As a scheme for building European houses on the plateau above Freetown is under consideration, we, at the suggestion of Sir Frederick Cardew, K.C.M.G., investigated the neighbourhood of the proposed site. There are on these hills two straggling villages, Leicester and Gloucester, shown on the accompanying plan, but, apart from these, large areas are entirely free from habitations.

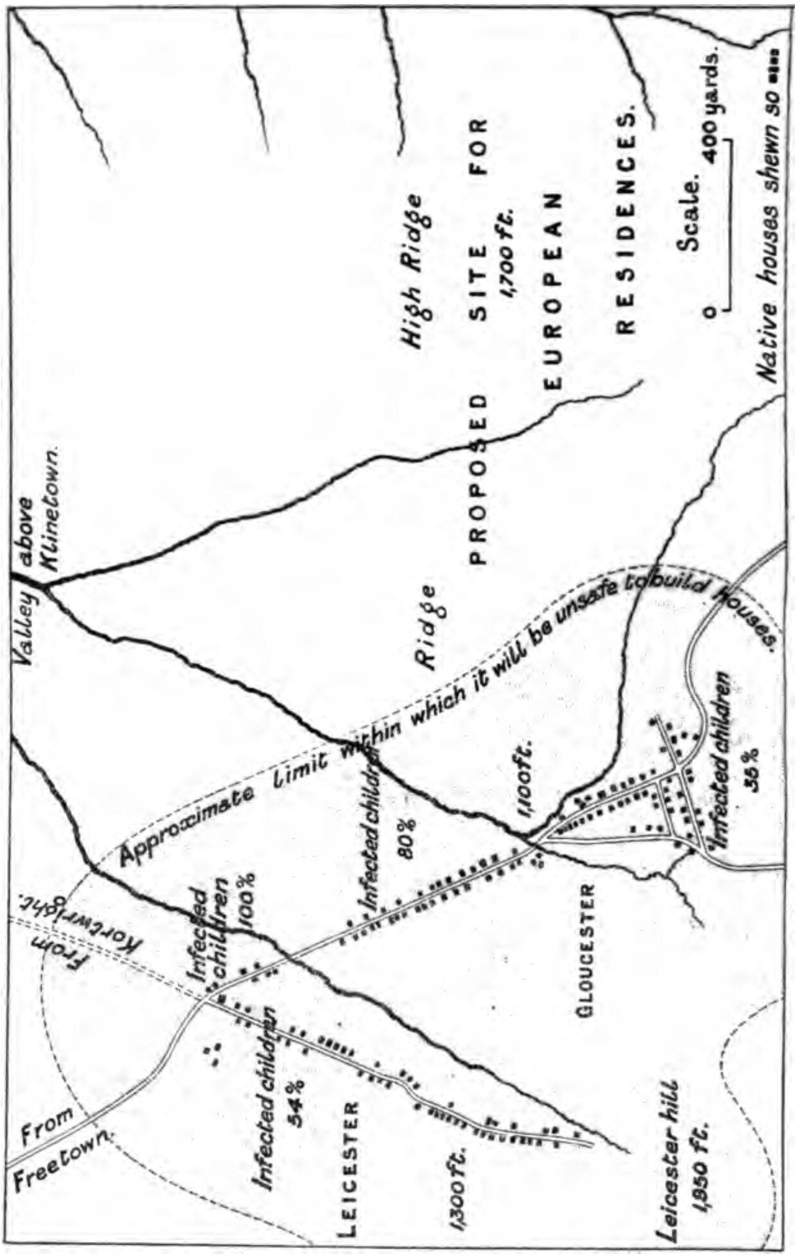
The children in Leicester and Gloucester show a considerable percentage of malarial infection, varying from 50 per cent. to 100 per cent. A portion of Gloucester, however, which is situated on a steep hillside, showed a diminished infection, namely, only 35 per cent. We believe the low figure observed in this part of Gloucester to be due to the extreme dryness of the hillside there, giving few opportunities for the existence of Anopheles, for elsewhere, as in Blantyre, at an elevation of 3000 feet, with numerous breeding grounds, malaria is rife.

There is, then, malaria on these highlands, and native quarters are here, as elsewhere, centres of malarial infection. Our surmise expressed in our first report on Freetown—that it would not be the elevation but the possibility of segregation which would make the scheme a success—was therefore correct.

We consider, then, that the proposed site—

(1) By reason of its remoteness from native dwellings;
(2) By reason of its dryness, if well chosen, giving few opportunities for Anopheles to breed;

will afford a complete freedom from malaria. It is essential, however, that native houses be rigidly excluded, and, as far as possible, native servants' quarters also. For we have seen elsewhere that even where breeding grounds are scarcely to be found, yet, under certain conditions, *Anopheles, and these*, moreover, infected, may occur.



Plan of portion of high ground above Freetown showing area to be avoided in choosing site for European houses.

It may be urged that we have overlooked the possibility of mosquitoes flying in from these villages, and as extraordinary statements with regard to the flight of mosquitoes have lately appeared in print, it will not be out of place to record here our experience during nearly two years' residence in Africa in towns and in the bush under varying conditions :—

1. In Blantyre we occupied a house within 50 yards of Anopheles breeding grounds, and the house was naturally infested with Anopheles.

2. In a house 200 to 300 yards from the same breeding grounds we never observed any.

3. At Blantyre Hospital we never observed Anopheles, although breeding grounds were less than ¼ mile away.

4. In Freetown we have at different times occupied five houses, all less than ¼ mile, some much nearer, from innumerable breeding grounds, and in only one of these on one occasion did we observe Anopheles, and in that case the source was found in the neighbouring garden.

5. In Accra, in Bungalow 15, we never observed Anopheles, although plentiful less than ½ mile away. Although in Accra it was stated that Anopheles flew in from a village 9 miles away, yet we found breeding grounds in profusion in Accra itself which completely explained their existence.

6. We have camped many nights a little distance (¼ to ½ mile) outside villages, and have not caught any Anopheles, though they were abundant in the villages.

These facts—and we could amplify them if necessary—must make it quite clear that Anopheles do not fly large distances, but remain in the neighbourhood of native huts, where they get a plentiful blood supply. From these they do often fly abroad, but it is at most a few hundred yards and not 15 miles.

Climatically, the change must be most beneficial. Even at an elevation of 700 feet (about half that of the proposed site) the atmosphere is fresh and even exhilarating, and one experiences the greatest relief after residence in Freetown with its most enervating foul atmosphere.

"The Increase in the Number of Large Mononuclear Leucocytes as a Diagnostic Sign of Malaria." By J. W. W. STEPHENS, M.D. Cantab., and S. R. CHRISTOPHERS, M.B. Vict. Received November 26, 1900.

In our first report ("Malarial and Blackwater Fevers of British *Central Africa,*" p. 20) we noted the occurrence of an increase in the proportion of the large mononuclear cells—also described by other authors in malaria.

We further showed the relation of this change to the temperature curve. That usually this change is absent during the pyretic periods, but very pronounced in the apyretic periods, or immediately following the rise of temperature, if only one such occurs. We also noted that in certain cases this change was extraordinarily marked, the large mononuclears during the apyretic periods even outnumbering the polynuclear elements. Also that in certain cases the change was to be detected even during the pyretic periods, but that in these it was always still further evident in the apyretic. In others that during the course of the fever no such change occurred, but that it appeared immediately the temperature subsided, rapidly diminishing again during convalescence.

We also pointed out that this change was of the greatest diagnostic importance in cases of malaria which had been treated by quinine, and in which, therefore, parasites were extremely scanty or absent in the peripheral blood.

A discussion on cases of malaria in which parasites do not appear in the peripheral blood occupies an accompanying report. In these the use of two diagnostic points is usually sufficient to enable one to be certain of their nature, apart from the actual presence of parasites. These two diagnostic points are (1) pigmented leucocytes, and (2) the mononuclear increase.

(1.) Pigmented leucocytes, even in severe malaria, are often very few and often require for their discovery prolonged search in large films. In two cases, although very few pigmented leucocytes were found after long search during life, yet the examination of the spleen post mortem showed large numbers of pigmented mononuclear leucocytes. In other cases, however, they are abundant.

(2.) Often in a case where pigmented leucocytes are difficult to find, a glance is sufficient to show that there is an excess of the large mononuclear elements. In order to obtain accurate results, 1000 leucocytes should be counted, but a count of three or four hundred is generally sufficient for diagnostic purposes, and the numbers so obtained do not differ much from the value of more extensive counts.

In counting the leucocytes, a well-made film is requisite The film is spread on a carefully-cleaned *slide* by means of the shaft of a large needle. A drop of blood is taken up by touching it with the slide near one end. The drop is made to flow along the needle by a slight to-and-fro motion parallel to the surface of the slide, and the needle is then, with an even movement, carried along the slide. By this means a large and thin film is obtained. The leucocytes are gathered for the most part in the borders and terminal points of the film, and can now readily be counted.

The mononuclear increase :—

a. We have shown, then, in malaria this is an almost constant occurrence.

b. Further, in native children, for the same reason, the mononuclear value is rarely normal. The majority show a percentage of 20 to 30 per cent., or even much greater.

c. Finally, we believe from the results obtained (*vide* report on Summary and Conclusions on Blackwater) by leucocytic counts of a considerable number of Europeans living in the tropics, that an increase beyond 15 per cent. is proof of an actual or recent malarial infection, and indeed, with a value over 20 per cent., it is often possible by long search to find a pigmented leucocyte, and a value as high as this probably implies actual infection at the time.

The diagnostic value of this increase in cases where no parasites are present is, then, of great importance.

"Malarial Fever without Parasites in the Peripheral Blood." By J. W. W. STEPHENS, M.D. Cantab., and S. R. CHRISTOPHERS, M.B. Vict. Received November 26, 1900.

From time to time in the examination of Europeans suspected of having malarial attacks, and who presented a rise of temperature with more or less constant vomiting, headache, pains in the bones, &c., we have been forced to conclude against the diagnosis of malaria, as no parasites were found, even after repeated examinations, or the number of parasites was so scanty as to cause doubt if they could be causally connected with the attack. We refer to cases in which no quinine had up to the time of the blood examination been given, for in the presence of quinine no such conclusion from a negative examination would be justifiable. How frequent these cases may be we have no means of estimating, and further, as a rule, there is no means of proving conclusively that such cases are malarial.

We give the following instances of which we have notes :—

Case I.—J. Blantyre. Daily rises of temperature to about 100°. Then, after a few days, a tertian rise. Daily vomiting. It was only after prolonged examination for some days that a single ring-form parasite was found.

Case II.—S. Lagos. Well-marked subjective symptoms. Daily rises of temperature above 100°. Several blood examinations were *made before any* quinine had been taken. After prolonged search no parasites were found. In a few days the temperature was normal. A leucocytic count now gave

Large mononuclears	24 per cent.
Small „	10 „
Polymorphonuclears	66 „

but no pigment was found. We felt certain that this was a case of malaria, and a re-examination of the blood taken, before quinine, now revealed, after again long search, one parasite, confirming thus the diagnosis based entirely on the leucocytic count.

Case III.—The following is a case where clinically there was not the slightest doubt as to the malarial nature of the attack, but there was absolutely no proof objectively.

C. Sierra Leone.

28.10.00. Evening temperature, 99·4°. Feeling unwell.

29.10.00. 5 P.M. Temp. 103°. Much vomiting. Blood examination negative. Quinine, 1·0 gramme. Mostly vomited.

30.10.00. 6 P.M. Temp. 100°. Vomiting continually. Blood examination negative. Quinine hypodermically.

		29th, 5 P.M.	30th, 8 A.M.	30th, 6 P.M.
Leucocytes :	Large mononuclears ...	16·4	15·2	15
	Small „ ...	7	11·2	14
	Polymorphonuclears ...	76·6	73·6	71

The two cases of malaria produced experimentally in England by Anopheles brought from Italy, reported by Dr. Manson and Mr. Rees, also show this condition.

Case IV.*—P. M. Bitten by infected Anopheles. 29 and 31.8.00. Also on 2 and 4.9.00. Also 10 and 12.9.00.

13.9.00. 9 A.M. t. 99°. 4.30 P.M. t. 101·4°. Headache, lassitude, chilliness, pains in the back and loins. Repeated blood examinations negative.

14.9.00. t. ranged between 101° and 102°. Subjective symptoms exaggerated. No parasites.

15.9.00. 7 A.M. t. 100·4°. No parasites.
4 P.M. t. 103·6° Delirium. No parasites

16.9.00. 8 A.M. t. 98·4 One doubtful parasite.
7 P.M. t. 102·8°.

17.9.00. 10 A.M. t. 99°. Several parasites. Two pigmented leucocytes. Later many tertian parasites.

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* "Experimental Proof of Mosquito Malaria Theory," Manson, 'Brit. Med. Journ.,' September 29, 1900, p. 950.

Had quinine been given on the 14th or 15th there can be no doubt that subsequent examinations would likewise have revealed no parasites.

Case V.—G. W.* Fed infected mosquitoes on his blood (? 14.8.00).
28.8.00. Feeling ill. 5 P.M. t. 101·6°. No parasites.
29.8.00. One pigmented leucocyte.
30.8.00. Four pigmented leucocytes.
1.9.00. 8 P.M. t. 101°. No parasites.
2.9.00. 9 P.M. t. 102°. Midnight, 104·4° No parasites.
3.9.00. Morning. Parasites.

The two cases illustrate the fact that a high temperature may occur for some days without the existence of parasites in the blood. For the purposes of the experiment quinine was not given until the diagnosis had been established. Had quinine been given early, as universally in practice is the case, there would have been no evidence of the existence of parasites in either of these cases. They are, then, of particular value as showing that *a high temperature persisting for some days is not necessarily accompanied by parasites*, so that the absence of parasites does not necessarily exclude a malarial infection.

We think that such cases as these are by no means isolated, and although, broadly speaking, it is true that there is no malaria without parasites in the peripheral blood, yet exceptional cases make it extremely important for diagnostic reasons that some other means (*e.g.*, a serum reaction) for the diagnosis of malaria be discovered.

Another class of cases in which the clinical symptoms of malaria are often pronounced, though no parasites occur in the peripheral blood, is seen after the taking of quinine in the course of an ordinary attack.

The following cases show how a high temperature may persist for some days, but, nevertheless, no parasites be found. In these cases parasites were detected before quinine had been taken, but more commonly the patient is not seen until after the administration of quinine, and then so far as parasites are concerned the examination is negative.

Case VI. C. 11.10.00. t. 102°. Numerous parasites.

Leucocytes	Large mononuclear ...	8·6 per cent.
	Small „ ...	6·6 „
	Polynuclear	84·8 „

12.10.00. Thirty-six grains quinine since last examination. No parasites. No pigment.

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* "Experimental Proof of Mosquito Malaria Theory," Rees, 'Brit. Med. Journ.,' *October 6, 1900*, p. 1055.

13–17.10.00. Thirty grains of quinine daily. High temp. No parasites.

18.10.00. First day of normal temperature.

No parasites. No pigment.

Leucocytes	Large mononuclear ...	30 per cent.
	Small " ...	15 "
	Polynuclear	55 "

Showing a well-marked mononuclear increase.

Case VII. M. 12.3.99. t. 104·8°. Parasites. Mononuclear increase.

13.3.99. t. 102·4°. Parasites. Mononuclear increase. Quinine.

14.3.99. t. 101°. Parasites scanty. Mononuclear increase. Quinine.

15.3.99. t. 101°. No parasites. Mononuclear increase. Quinine.

16.3.99. t. 101°. No parasites. Mononuclear increase. Quinine.

17.3.99. t. 100·4°. No parasites. Mononuclear increase. Quinine.

18.3.99. t. 99°. No parasites. Mononuclear increase. Quinine.

The bearing of the examples given above on the argument usually adduced to prove that blackwater is non-malarial, viz., that parasites are absent or in quite insufficient amount to account for the symptoms, is obvious. The argument fails; a complete absence of parasites in all cases of blackwater would not necessarily exclude malaria. Further, we believe that in a different class of cases, viz., those suffering from constant attacks of fever, who yet at the same time are more or less constantly taking quinine, parasites are frequently absent.

"The Tonicity of the Blood in Malaria and Blackwater Fever."

By J. W. W. STEPHENS, M.D. Cantab., and S. R. CHRISTOPHERS, M.B. Vict. Received November 26, 1900.

IN our report on the "Distribution of Anopheles" in Sierra Leone, pp. 64 and 73, we appended some observations on the tonicity of the blood in malaria and blackwater fever. The method used was rough, and it was difficult to express accurately in words differences which, however, were quite well appreciated by the eye, and which could be best expressed by some colorimetric method. Lesage,* using such a method, expresses his data in the form of a curve, and the results are more striking and easily followed. As we had no convenient means of estimating the hæmoglobin set free by the various solutions used, the following method was devised as being an improvement on that previously used, and capable of fairly accurate expression in numerical values, which could if necessary be represented in the form of a curve.

The stem of the ordinary Thoma-Zeiss pipette is divided into ten divisions. The drop of blood used for making the observation of tonicity was that contained in two of these divisions, so that five observations could be made simultaneously with the same specimen of blood taken from the patient's finger.

Four salt solutions were used, viz., 0·41, 0·39, 0·37, 0·35 per cent. In a control experiment, then, two divisions of the blood in the pipette were added to 1 c.c. of each solution in a small test tube. The last two divisions were added to 1 c.c. of water. Complete hæmolysis, of course, takes place in this solution. The colour given by this was for convenience' sake called 100 per cent. Solutions were also prepared in water, and this can be readily done, for purposes of comparison in which the amount of hæmoglobin was 90, 80, 70 per cent., etc., to 10 per cent. So that we had a series of standards with which the colour in the respective tubes containing salt could be compared.

These standards have the advantage of being solutions of Hgb., like that resulting from hæmolysis. They have the great disadvantage that they are not permanent.

In making an observation of tonicity, 1 c.c. of each of the four salt solutions was used, and the fifth tube contained water. The colour of this tube being now compared with that of the controls, the amount of Hgb. could be readily determined in terms of the standard control. A correction for differences in the amount of Hgb. in the tube containing water is necessary, otherwise a low reading may give a false view of the amount of hæmolysis, which may actually be greater than the control in a case where it is apparently less. On the other hand, the amount of hæmolysis in a malarial patient, is really less than it should be if no correction is made for anæmia.

Examples of the tonicities in malaria and blackwater fever are:

	0·41 per cent. salt.	0·39 per cent.	0·37 per cent.	0·35 per cent.	H_2O.
I. Malaria, 1...	25	40	60	—	—
II. ,, 2...	40	65	80	90	90
III. Control.....	0	20	65	90	100
IV. Blackwater..	0	0	0	20	—

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* *Lesage, 'Comptes* Rendus Hebdomadaires de la Soc. de Biol.,' Juillet 28, *1900, p. 719.*

The observations on the tonicity in malaria are quite in accord with those we have previously recorded.

In the blackwater case we did not at the time observe the value with water, but the anæmia was quite insufficient to account for the low tonicity which we have observed also in three other cases; in the remaining cases it was the same as the control or slightly raised.

We may summarise here these and our previous observations.

1. In malaria we have constantly observed a high tonicity.
2. In blackwater there is occasionally a remarkably low tonicity, in other cases it has the normal value or somewhat raised value as in malaria. The low or normal value in blackwater may be due as we have previously suggested to the fact that the weak corpuscles—those of high tonicity—are destroyed, or it may be due to the fact that the tonicity of the corpuscles, as a whole, is changed after the liberation of hæmoglobin. If hæmoglobinæmia is present (and we have only observed it in two cases) it however will not materially interfere with the reading of the values, as the amount due to this cause can also be determined in a hyper-tonic solution.

The presence again of a yellow serum may cause difficulty.

We may add to these conclusions a third derived from a series of observations on native blood.

3. The tonicity of native blood is often remarkably low: a low value not observed by us in any European blood.

The difference may be as great as 0·04 to 0·06 per cent. salt.

"Blackwater Fever. Cases IX to XVI. Summary and Conclusion."

By J. W. W. STEPHENS, M.D. Cantab., and S. R. CHRISTOPHERS, M.B. Vict. Received November 26, 1900.

I. RECORD OF CASES.

Case IX.—M. Sierra Leone. Blackwater many times previously. Had fever three weeks before present attack, was taking quinine, still feeling unwell continually.

21.3.00. 3 A.M. shivering attack. 6 A.M. t. 100°. Quinine, 1·0 gramme.

22.3.00. 6 A.M. t. normal. Quinine, 0·6 gramme. 5 P.M. t. 101°. Quinine, 0·6 gramme.

23.3.00. 6 A.M. t. normal. Quinine, 0·6 gramme. 10 A.M. rigor. 12.30 P.M. Blackwater. 7 P.M. urine contained hæmoglobin, but not in large amount. Urobilin present.

25.3.00. Urine. No. Hgb. Urobilin present.

Blood examinations :

23.3.00. No parasites. Several leucocytes have fine grains of pigment. A few have golden yellow pigment.

Leucocytes :

17.3.00	Large mononuclear...	22·9	per cent.
	Small „ ...	2·7	„
	Polynuclear............	73·4	„
23.3.00	Large mononuclear...	17	per cent.
	Small „ ...	3	„
	Polynuclear............	70	„
24.3.00	Large mononuclear...	23·6	„
	Small „ ...	6	„
	Polynuclear............	68·6	„
25.3.00	Large mononuclear...	19·3	„
	Small „ ...	14·7	„
	Polynuclear............	65·1	„
26.3.00	Large mononuclear...	15·2	„
	Small „ ...	8	„
	Polynuclear............	76·7	„

Case X.—T. Sierra Leone.

31.3.00. In evening vomited after food; later took quinine, 0·6 gramme.

1.4.00. Early morning (before 6 A.M.). Blackwater.
Urine. Oxyhæmoglobin. Urobilin absent.
Blood. No parasites. Two pigmented mononuclear leucocytes.

Leucocytes :

10 A.M.	Large mononuclear...	18·75	per cent.
	Small „ ...	11·4	„
	Polynuclear............	69·85	„
3 P.M.	Large mononuclear...	27	„
	Small „ ...	19	„
	Polynuclear............	54	„

4 P.M. Hæmoglobinæmia.

2.4.00. 8 A.M. 0·5 gramme quinine hypodermically. 2 P.M. vomiting. 3 P.M. urine, methæmoglobin. No urobilin. t. 98°.

No further examinations made. Death. No autopsy.

Case XI.—E. Lagos. 2½ years in Soudan, 20 months in Lagos.

Much fever during first year and on voyage home. Does not use a mosquito net.

11.7.00. Feeling unwell in morning. 8 A.M. quinine, 0·6 gramme. Got wet through during day. 8 P.M. quinine, 0·6 gramme. 9 P.M. passed a dark urine. No hæmoglobin; no urobilin; no bile pigment.

12.7.00. 4 A.M. darker urine. Methæmoglobin and oxyhæmoglobin (slight). Spleen palpable. Earthy pigmented (jaundiced) condition of skin.

13.7.00. Hæmoglobin well marked.

14.7.00. Hæmoglobin, very weak bands.

Blood examinations:

12.7.00. Parasites. Pigmented leucocytes.

Leucocytes	Large mononuclear ...	21·5 per cent.
	Small " ...	16·4 "
	Polynuclear	61 "

13.7.00. No parasites. Pigmented leucocytes.

Leucocytes	Large mononuclear ...	11·5 per cent.
	Small " ...	12 "
	Polynuclear	75 "

Blood serum rather yellow.
Hæmoglobinæmia doubtful.
Tonicity of blood identical with that of a normal control.

Recovery.

Case XII.—D. Lagos. Blackwater two or three times previously. "Influenza" attack when last home.

17.7.00. Feeling unwell. Temp. raised. Took quinine, two or three 2-grain tabloids. Worse in evening (? more quinine). Rigor in night.

18.7.00. Rigor. Blackwater. Methæmoglobin. No urobilin. Blood. No parasites. No pigment.

Leucocytes	Large mononuclear ...	6·4 per cent.
	Small " ...	4·5 "
	Polynuclear	89 "

19.7.00. Death. No autopsy.

Case XIII.—A. Lagos. 3rd attack of blackwater, last, 1 year 9 months ago. Suffering from slight fever attacks previous to present attack.

10.8.00. Pigmented leucocyte.
18.9.00. Quinine, 0·3 gramme.
19.8.00. 6 P.M. Quinine, 0·3 gramme.
10 P.M. Blackwater.
20.8.00. 7 A.M. t. 103°. Urine. Methæmoglobin. No urobilin. No bile pigment.
5 P.M. t. 103·4°. Jaundice.

Blood examinations:
20.8.00. 7 A.M. No parasites. No pigment.

Leucocytes	Large mononuclear ...	21·5 per cent.
	Small „ ...	13·5 „
	Polynuclear	65 „

Hæmaglobinæmia. Tonicity slightly raised.
5 P.M. Typical pigmented mononuclear leucocyte.

Leucocytes	Large mononuclear ...	21·6 per cent.
	Small „ ...	17 „
	Polynuclear	61·3 „

21.8.00. 5 P.M. t. 102°.

Leucocytes	Large mononuclear ...	18·5 per cent.
	Small „ ...	17 „
	Polynuclear	65·5 „

Death, midnight. No autopsy.

Case XIV.—B. Lagos. Much fever recently. Taking a quinine mixture for last few days (about 0·3 gramme daily).
19.9.00. 5 P.M. t. 102°. 9.45 P.M. blackwater. Quinine, 0·6 gramme (quinine probably after blackwater, but doubtful when). Methæmoglobin. 12 P.M. 0·3 gramme quinine.
20.9.00. 4 A.M. Rigor. t. 106·2°. 2 P.M. no Hgb. No urobilin.

Blood examinations: Extreme anæmia. 10–20 per cent. Hgb. No parasites. No pigment.

Leucocytes	Large mononuclear ...	23 per cent.
	Small „ ...	23 „
	Polynuclear	54 „

Tonicity slightly lowered or normal. Determination very difficult *owing to extreme anæmia.*

Case XV.—C. s.s. "Sobo." Blackwater in June. Invalided home. Fever on board ship.

27.9.00. Quinine, 0·6—1 gramme. Blackwater some hours after in the evening.

28.9.00. Blood examinations: No parasites. No pigment.

Leucocytes	Large mononuclear...	24·8 per cent.
	Small " ...	13·6 "
	Polynuclear............	61·5 "

Case XVI.—Cl. Sierra Leone.

4.10.00. Vomiting.

5.10.00. Went to bed. Quinine, 0·6 gramme in evening.

6.10.00. 6 A.M. Quinine, 1·0 gramme. Blackwater.
9 A.M. Quinine, 1·0 gramme.
9 P.M. Urine with small amount of hæmoglobin only.

Blood examinations: No parasites. 2 pigmented mononuclear leucocytes. 1 pigmented polynuclear leucocyte.

Leucocytes	Large mononuclear...	11·6 per cent.
	Small " ...	12 "
	Polynuclear............	75·5 "

7.10.00. Urine. Trace only of Hgb.

Leucocytes	Large mononuclear...	15·5 per cent.
	Small " ...	10 "
	Polynuclear............	74 "

II. SUMMARY.

I. *Relation of Blackwater to Malaria Tropica.*—While it is true that malaria may be very prevalent in a country with little or no blackwater, yet, on the other hand, blackwater fever has never been shown to exist in the absence of malaria, and, on the contrary, it can hardly be a matter of coincidence that in those countries where malaria fever is most malignant, there also blackwater is a scourge.

Further, it is characteristic of their co-existence that the type of malarial fever is the æstivo-autumnal (malignant tertian), or tropical parasite, although very occasionally blackwater and mild tertians have been found together. Thus, in those regions of Africa where malaria and blackwater co-exist, we have the following figures:—

German East Africa ...	89 per cent. malarial cases = tropical parasite (Koch).
British Central Africa...	100 per cent. malaria cases = tropical parasite (Malaria Commission).

Sierra Leone	100 per cent. malaria cases = tropical parasite (Malaria Commission).
Gold Coast	100 per cent. malaria cases = tropical parasite (Malaria Commission).
Lagos	100 per cent. malaria cases = tropical parasite (Malaria Commission).

Further, there is this difference between the malarial fever (æstivo-autumnal) of Italy and that of tropical zones of Africa, that in the latter malaria *prevails throughout the year* without any seasonal intermission. It may be true that malaria is more prevalent in the tropics in the intermediate times between the rains and dry season, but on this point there seems to be a considerable difference of opinion. Statistics are by no means convincing, as at all times many cases of fever are not recorded at all. Yet, whenever we have examined Anopheles from native huts, even in the middle of the dry season, we have found no appreciable difference in the number infected, and so Europeans are subject to a constant all-the-year-round infection. As a matter of fact, if we take a number of Europeans, as on a railway, we find that they are more or less constantly suffering from slight fevers, which show no seasonal prevalence. There is, then, no definite intermission in the danger of infection, and this fact, viz., constantly occurring infection, constitutes an important difference from the fevers of temperate climates, where, in the winter, there is a marked decline in infection.

It has been stated that the seasonal prevalence of blackwater bears no relation to that of malaria. And, in fact, statistics have actually been published based upon an indiscriminate compilation of native and European cases, none of which were examined microscopically. If we consider alone the doubtfulness of so-called "fever" in adult natives, such statistics are quite valueless, and it is futile to discuss seriously arguments based thereon as to the seasonal prevalence of malaria and blackwater. Speaking broadly, in most places in tropical Africa there is no very definite seasonal prevalence of either malaria or blackwater.

II. *Premonitory Symptoms in Blackwater.*

In a very large proportion of blackwater cases the patient has for two or three days previously had considerable rises of temperature with vomiting and other symptoms. This initial illness is rarely seen by the medical man, nor are blood examinations made at this time, so that the nature of the illness is often obscure. The character of the temperature curve, however, when obtained, and the almost invariable presence of parasites when a blood examination is made prior to the blackwater, render it very probable that the initial illness which so

[redacted]

commonly occurs before the taking of quinine is *malaria*. Were blackwater to depend alone upon the taking of quinine, one would not expect to find this initial illness so constant a phenomenon.

III. *The Absence of Malarial Parasites in Blackwater.*

A common feature in blackwater cases which are not seen very early is that there is a complete absence of parasites. This is evident from Table I, where in only one case were there parasites present during the blackwater.

If blackwater is a process independent of malaria, then we should expect in those cases where parasites were present that they would follow their usual cycle of development with characteristic temperature curve, superadded to that due, *ex hypothesi*, to the blackwater. But this is contrary to our own experience and that of all observers who have examined the blood microscopically.

Parasites disappear, and do so rapidly: as there is almost always without exception a history of quinine, we think that this will to a large extent account for their disappearance. If we were dealing with an equivalent number of cases of malaria instead of blackwater, as we have shown in an accompanying report, the percentage of cases in which parasites would be found subsequent to the taking of quinine, would be remarkably low. Quinine alone would quite well account for the fact that parasites are so rarely found in blackwater. Whether any other factor is responsible we have no means of saying.

We have previously quoted cases where, although malarial parasites were absent at the time of the blackwater, yet later, under conditions which excluded the possibility of a fresh infection, parasites have reappeared, showing the presence of a malarial infection which at the time of the blackwater was not evident. We had at the time overlooked several instances of this kind recorded by A. Plehn* and F. Plehn.† They are sufficiently important, we consider, to justify us in calling attention to them here.

Examples of Cases where Parasites originally present disappear with the Onset of Blackwater, or, where originally absent, they have appeared later.

1. 4.9. Fever. *Scanty parasites.*
5.9. Quinine, 1·0 gramme. 2 hours later blackwater. *No parasites.*
16.9. Weak and feverish. *Parasites.*

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* 'Berträge zur Kentniss von Verlauf und Behandlung der Tropischen Malaria in Kamerun.'

† 'Die Kamerun Küste.'

	17.9.	12 midnight, shivering. 1 A.M., blackwater (? quinine previously).
2.	13.11.	Morning, quinine, 1·0 gramme. 12 noon, rigor. 4.30 P.M., blackwater.
	14.11.	A *single parasite* found.
	22.11.	Numerous parasites.
3.	4.10.	Occasional *parasites.*
	5.10.	Morning, quinine, 1·0 gramme. 12 noon, blackwater.
	6.10.	*No parasites.*
4.	3.9.93.	9 A.M., slight fever. Quinine. Rigor. Blackwater. *Numerous parasites.*
	4.9.93.	Urine clear. 8 A.M., t. 103°. Vomiting. Blackwater. *No parasites.*
	5.9.93.	Convalescent.
	19.9.93.	Slight fever.
	20.9.93.	6 A.M., quinine, 1·0 gramme. 9 A.M., rigor. 10·45 A.M., urine, no Hgb. 12 noon, urine, Hgb. *Numerous parasites.*
	21.9.93.	*No parasites.*
	9.10.93.	Fever.
	10.10.93.	7 A.M. Quinine, 1·5 grammes. 9 A.M. Rigor and blackwater. *Parasites scanty.*
5.	13.11.94.	Many crescents and *parasites.* Quinine, 1·0 gramme. 1 hour later. Rigor and blackwater.
	16.11.94.	*No parasites.*
6.	6.6.84.	Slight fever.
	7.6.94.	6 A.M. Quinine, 1·5 grammes. 8 A.M. Rigor. Blackwater. *Numerous parasites.*
	8.6.94.	Urine clear. 12 noon. t. 102°. Blackwater.
	9.6.94.	No parasites.

In an accompanying report (p. 7) we have shown how commonly ordinary malarial infections, more especially when quinine has been taken, fail to show any parasites. We thus have in undoubted malaria a parallel condition to that in blackwater.

IV. *Relation to Quinine.*

A consideration of the cases recorded by Tomaselli (the first was recorded forty years ago), by Karamitsas, by the Roman school (Marchiafava, Celli, Bignami), by A. Plehn and F. Plehn, and lately by Koch, make it perfectly clear that quinine can under certain conditions induce hæmoglobinuria, and that there are no reasons for believing that *tropical hæmoglobinuria* (blackwater) in any way differs from the *quinine hæmoglobinuria* of Europe.

One of Tomaselli's cases :—*

August, 1860. First attack of malaria. Cured by quinine.

1. A month later. A relapse. 1 gramme of quinine. Some hours later—rigor, high fever, vomiting, hæmaturia, and icterus (*blackwater*).
2. During remissions of the fever a larger dose of quinine was again given per rectum owing to the vomiting. The result was as before only more intense (*blackwater*).

   No more quinine was given. Recovery took place in a few days.
3. A month later. Mild fever. A decoction of quinine well borne, but the fever being intense on repeating the dose the result was very different. About 5 hours after the quinine, rigors, hæmaturia, vomiting, icterus (*blackwater*).

   The fever lasted 18 hours. Then defervescence.
4. Fifteen days later. A relapse. 1 gramme quinine sulphate per rectum. 4 hours later—tremors, vomiting, bloody urine, icterus (*blackwater*). Recovery. 2 months of good health.
5. 21st April. Fever with rigor; vomiting. 23rd. A still more grave paroxysm, so that it was thought necessary to again try quinine. Antimoniate of quinine in decigramme doses every 2 hours. The first dose was given precisely when the malarial paroxysm began to remit. Hardly 2 hours after the first dose had been given there set in rigors, vomiting, hæmaturia, &c. (*blackwater*).
6. 25th April. A fourth febrile paroxysm. Urine now clear. Fearing the fatal effects of a return of another paroxysm, quinine was, in consultation, again ordered as soon as the remission commenced. 50 centigrammes of the bisulphate in a clyster were given 6 A.M. on the 26th. Two hours later the usual train of symptoms—hæmaturia, icterus (*blackwater*), death.

One of Koch's cases :—†

Patient four years in Cameroons. Had blackwater seven times, always following quinine. Patient now in Berlin. From time to time slight fever attacks.

Got wet. Rigor. t. 40·6°. Took two doses of quinine, 0·2 gramme.

Next day, blood examination negative.

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* 'La intossicazione chinica e l'infezione malarica' (Comm. Salvatore [illegible]aselli).

ch, 'Über Schwarzwasserfieber (Hæmoglobinurie)'; s. 316.

Some weeks later, fever attack. By instruction had taken no quinine. Blood examination positive. (Large pigmented tertians.)

Patient advised to take methylene blue and no quinine, but after a few days he consulted another physician, who ordered him quinine.

Scarcely had he taken the quinine when a violent attack of *blackwater* ensued. Brought into hospital.

2nd. (4 × 0·1) gramme quinine—a few hours—*blackwater*. t. 40·5°. No parasites.

6th. (4 × 0·1) gramme quinine—a few hours—*blackwater*. t. 41·0 . No parasites.

14th. (4 × 0·1) gramme quinine—a few hours—*blackwater*. t. 39·5°. No parasites.

24th. (4 × 0·1) gramme quinine—a few hours—*blackwater*. t. 41·5°. No parasites.

It would appear from the criticisms made on Koch by many writers that they have not taken the trouble to acquaint themselves at first hand with his writings, for views are constantly attributed to him which certainly are not to be found in his writings; and, further, there seems to be a general impression, at least among English writers, that Koch was the first and only person to enunciate the quinine hypothesis. Such an impression, a knowledge of the literature of blackwater would have removed. A study of 200 cases published by competent observers, and our own cases, has convinced us of the causal connection between quinine and blackwater.

Among our own cases we have not met with one in which quinine could be excluded beyond all doubt, but, on the contrary, the blackwater followed more or less closely after the quinine.

Why quinine at one time can produce blackwater and a few hours or days later not, it is impossible in the present state of our knowledge to say. We can only expect that a solution will be forthcoming when toxic hæmoglobinurias generally are more closely investigated, and when some new light is thrown upon such an obscure disease as the paroxysmal hæmoglobinuria of temperate climates.

V. *Evidence of Malaria in Blackwater.*

We have previously seen that, in a large proportion of cases of blackwater, parasites are not to be found by the most careful search. This, indeed, has led some authors to conclude that many cases of blackwater occur without any accompanying or closely-preceding malarial infection.

A study of cases, however, of undoubted malaria in which quinine has been administered leads us to consider that parasites in the peripheral blood are not necessarily present even in undoubted cases of malaria, and that their absence in blackwater may be quite compatible with a severe malarial infection. We therefore examined the blood in our cases of blackwater with a view to determine whether or no they showed the less striking evidences of malaria such as we still find in ordinary cases of malaria treated by quinine, *i.e.*, the presence of pigmented leucocytes and an increase in the large mononuclear leucocytes. We have pointed out elsewhere that in cases where the autopsy revealed severe malarial infection, pigmented leucocytes have been extremely rare in the peripheral blood, and that it is often only at certain times that the increase in large mononuclear leucocytes is to be detected. We do not, then, expect in every case of malaria to find pigmented leucocytes in abundance, or to find without repeated examination a marked leucocytic variation. In blackwater, also, if it is malarial in nature, we should not expect in every case gross evidence of malarial infection, more especially as blackwater for the most part occurs in those who have been some years in the tropics and who suffer from modified attacks of malaria rather than severe attacks.

In the accompanying table (p. 24) a tabular arrangement of our sixteen cases of blackwater is given showing the evidence of malarial infection at the time of the attack or immediately prior to it. It will be seen that in one case (Case 3) blackwater came on in the course of an ordinary severe attack of malaria, that with the onset of blackwater there was a coincident disappearance of parasites. In Case 11, which was seen earlier in the disease than usual, parasites were at first present, but later disappeared. In Cases 2, 4, 5, 8, 9, 10, 13, 16, at least one typical crowded pigmented leucocyte was found, and in several cases these were common. In Cases 14, 15, 17, although neither parasites nor pigmented leucocytes were seen, yet the number of large mononuclear leucocytes was in every case over 20 per cent., a percentage which we have in Table II shown is very strong evidence of malarial infection. One case only (Case 12) has failed to yield evidence of malarial infection, and in this case our investigation was confined to a single blood examination and hampered by the fact that the only films available were badly made. In Case 1 fresh films only were examined, and as pigmented leucocytes were not especially searched for, and as the leucocytes were not counted, we have omitted it from the list.

In 16 cases of blackwater we have, then, evidence of malarial infection in 15, *i.e.*, in 93·8 per cent. As in Koch's cases, parasites themselves were found in over 40 per cent., we think it highly probable that, had attention been paid to pigmented leucocytes and the proportion of leucocytes, his cases would have shown an equally high percentage of malarial infection. Two post-mortems in which no pigment was found are certainly against this view, but we would point out that in a case of blackwater described by Dr. Thin, although there was only extremely scanty pigment in the spleen, yet there were sporulating parasites in the brain; also that in these cases of Koch death occurred on the 5th and 10th day respectively after the onset of the blackwater, possibly long enough for the pigment from a mild attack to disappear. In five post-mortems of our own we have found abundant pigment occurring in such a way as to make it certain that it arose from very recent attacks coincident with the onset of the blackwater. As no parasites were found (except in one case where numbers of developing gametes were found) it would appear that the disappearance of parasites from the peripheral blood is often further followed by a disappearance of parasites from the internal organs.

In our own cases, then, we have five autopsies showing recent malarial infection, and 93·8 per cent. of our cases showing undoubted evidence of malarial infection in the peripheral blood.

It has been urged that the occasional presence of parasites in blackwater is accidental and dependent on the fact that the subject of blackwater is living in a highly malarious country.

A considerable number (44) of Europeans living in the tropics were therefore examined by us for evidence of malarial infection, viz., either parasites or pigmented leucocytes or an increase in the mononuclear leucocytes. The result of this examination is given in Table II. It will be seen that most of the communities chosen are those especially liable to malarial fever, and indeed among the Roman Catholic community mosquito nets are rarely used, whilst on both the Lagos and Sierra Leone railways malarial infection is most rife. Yet in the blood of these individuals we find parasites with the greatest rareness, nor are pigmented leucocytes much more frequent. A certain number show a percentage of large mononuclear leucocytes above normal, but most of these do not reach as high a value as in most of the blackwater cases, the blood examination having often been no doubt too late in convalescence to show marked percentages. Those showing parasites or pigmented leucocytes are under 10 per cent., whilst including those with even a poorly-marked mononuclear increase only 20 per cent. show evidence of malarial infection.

It is thus abundantly evident that the malarial infection demonstrable in over 90 per cent. of blackwater cases is not dependent on the accidental occurrence of malaria, but must be a causal connection.

We must accordingly assign to the hæmoglobinuria of the tropics a malarial origin, though recognising that it is by no means a mere malarial attack of extreme severity.

Table I.—To show the occurrence of Malarial Infection in Blackwater.

Cases.	Parasites.	Pigmented leucocytes.	Autopsy.	Large mononuclear leucocytes.	Small mononuclear leucocytes.	Polymorphonuclear leucocytes.	Proof of malarial infection at time.	Parasites present in peripheral blood.	Remarks.
2*	—	pig. leucs.	much pigment.	22·7	14·6	60·7	Yes	No	
3*	numerous parasites	,, ,,	,, ,,	55·9	—	43·0	,,	Yes	22.5.99. Before onset of blackwater.
		,, ,,	—	19·3	—	80·0		No	24.5.99. Shortly after onset.
4*	3 crescents	,, ,,	—	48·8	8·4	41·6	,,	,,	
5*	—	—	—	30·6	7·8	61·6	,,	,,	
6*	—	—	much pigment.	—	—	—	,,	—	Post-mortems only.
7*	—	—	much pigment.	—	—	—	,,	—	Post-mortem only.
8*	—	pig. leucs.	much pigment.	12·0	7·0	80·0	,,	No	
9	—	,, ,,	—	23·6	6·0	68·6	,,	,,	
10	—	,, ,,	—	27·0	19·0	54·0	,,	,,	
11	parasites	,, ,,	—	21·5	16·4	61·0	,,	Yes	12.7.00. Case seen earlier than usual.
		,, ,,	—	11·5	12·0	75·0		No	13.7.00. Blackwater still present.
12	—	—	—	6·4	4·5	89·0	No	,,	Only a single blood examination made.
13	—	pig. leucs.	—	21·0	13·5	65·0	Yes	,,	
14	—	—	—	23·0	23·0	54·0	,,	,,	
15	—	—	—	24·0	13·6	61·5	,,	,,	
16	—	pig. leucs.	—	12·7	10·5	77·0	,,	,,	6.10.00.
				15·5	10·5	74·0		,,	7.10.00.
17	—	—	—	22·7	12·6	64·0	,,	,,	Convalescent, 6 days.

* Note.—See the First Report to the Malaria Committee. Case I is not included on account of the insufficiency of the examination.

Table II.—To show the occurrence of Malarial Infection in Europeans taken at random, more especially from Communities suffering much from Malaria.

		Parasites.	Pigmented leucocytes.	Large mononuclear leucocytes.	Small mononuclear leucocytes.	Polymorphonuclear leucocytes.	Eosmophyl leucocytes.	Proof of existing or very recent malarial infection.	Remarks.
Lagos R. Catholic fathers	1	—	—	12·3	17·6	58·6	11·3	No	
	2	—	—	16	20·6	61·6	1·6	?	
	3	—	—	18·6	19·8	61·2	2·4	Yes	
	4	—	—	13	19·5	61·5	6	No	
	5	—	—	10·6	25	62	2·3	,,	
	6	—	—	19·5	19	59·2	2·2	Yes	Slight fever at time.
	7	—	—	15	8	74·6	2·3	No	Fever at time.
Lagos R. Catholic sisters.	8	—	—	13·3	17·6	66·3	2·6	,,	
	9	—	—	11·2	23·2	64·5	1	,,	
	10	—	pig. leuc.	10·6	14·3	67·6	7	Yes	
	11	—	—	10·6	29	57·3	3	No	
	12	Crescent	—	10·5	17·5	71·5	0·5	Yes	
	13	—	—	13·5	23	62·5	0·75	No	
	14	—	—	13	34	51·5	1·5	,,	
	15	—	—	20	15·5	61	3·5	Yes	
	16	—	—	13·2	21·7	61·7	3·2	No	
Lagos merchants' clerks.	17	—	—	7	18·5	74	0·5	,,	
	18	—	—	14·5	21	61·5	3	,,	
	19	—	—	13	6·75	60·7	9·5	,,	
	20	—	—	14·5	24·5	56	5	,,	
	21	—	—	10	12·7	73	4·3	,,	

Table II.—*continued*

		Parasites.	Pigmented leucocytes.	Large mononuclear leucocytes.	Small mononuclear leucocytes.	Polymorphonuclear leucocytes.	Eosmophyl leucocytes.	Proof of existing or very recent malarial infection.	Remarks.
Lagos Government railway men	22	—	—	11·3	20·3	67	1·3	No	
	23	—	—	13·6	39·3	46	1	"	
	24	—	—	13	20·5	58	3·5	"	
	25	—	—	7·6	15·3	76·3	0·6	"	
	26	—	—	18	26·5	53	2·5	Yes	
	27	—	pig. leuc.	12	19	66·5	2·5	"	
	28	Crescents	—	26·6	19	54	0·5	"	Fever at time and previously.
	29	—	—	12	31	51	6	No	
	30	—	—	12·5	22	65·5	—	"	
	31	—	—	12·7	11	74·6	2	"	
Sierra Leone railway men	32	—	—	11·3	17	68·6	3	"	
	33	—	—	20·3	24·3	52·6	2·6	Yes	Temperature 104° day before quinine.
	34	—	—	14	18·3	67·3	0·3	No	
	35	—	—	13	15	70·6	1·3	"	
	36	—	—	15	20·8	60	4·1	"	
	37	—	—	10·5	14·5	73	1·5	"	
	38	—	—	11	13	72	4	"	
Government officials	39	—	—	9·6	11·3	75·3	3·6	"	
	40	—	—	12·6	16·3	50·3	11	"	
	41	—	—	10	21·3	66·6	2	"	
	42	—	—	10·6	11	78·3	—	"	
	43	—	—	13	13·1	65, 4	8·5	"	
	44	—	—	10·2	16·5	69	5·2	"	

III. *Conclusion.*

1. That blackwater is malarial in origin, yet cannot be considered as an attack of malaria.
2. That quinine is, in the great majority of cases, the proximate cause.
3. That there is not a single fact in evidence of a special parasite being the cause of blackwater. Blackwater more closely resembles paroxysmal hæmoglobinuria, and possibly hæmoglobinuria in horses, than Texas fever.

Protection from malaria, then, would diminish the chances of blackwater fever, and measures directed against malaria would, if successful, tend to diminish the amount of blackwater, which at present is pre-eminently the cause of death among Europeans in tropical Africa.

Malaria is, we believe, a preventible and avoidable disease; consequently the European in the tropics, who thinks it worth while to avoid malaria, will have little fear of being attacked by blackwater fever.

We cannot conclude our report without acknowledging our indebtedness to the medical officers of the colonies we have visited, to Dr. Gray, Zomba; Dr. Kerr-Cross, Blantyre; Dr. Prout, Sierra Leone; Dr. Knight, Accra; Dr. Strachan, Dr. Pickels, and Dr. Best, Lagos. Also to the medical officers on the Sierra Leone and Lagos railways, Dr. Leach, Dr. Rowlands, and Dr. McGahey.

We have especially to thank Dr. McVicar, Blantyre; Dr. Berkeley, Freetown; Dr. Knight, Accra, and Dr. Hopkins, Lagos, for much help and for much trouble undertaken on our account. Also Dr. Scott and Dr. Elmslie, British Central Africa, and Dr. Todd, late of Umtali, for specimens of blackwater cases.

REPORTS, &c., FROM DR. C. W. DANIELS, EAST AFRICA.

"Some Observations on the Common Anopheles of British Central Africa, the Haunts and Habits of their Larvæ during the Dry Season, 1899." By C. W. DANIELS, M.B. Received January 8, 1900.

These observations were made in, and refer only to the Dry Season, April to October. A further series of observations will be required for the Wet Season.

The commonest and most widely distributed Anopheles is a small dark one* with legs of a uniform colour and two light bands on the palpi. It is found at all heights from 4200 feet down to 200 feet above the sea-level. It is also met with all round the Lake Nyassa and down the Shiré River for at least 150 miles. This represents the limit of my observations. In some of these places it is so numerous as to be a pest. In others it is only found with difficulty.

Under experimental conditions it will only lay its eggs on still water. The motion of the surface of the water produced by the wind is quite sufficient to prevent the deposit of eggs.

The eggs are laid on the surface of the water in little clumps. They are separate and lie horizontally on the water. They readily adhere to any solid body with which they are brought in contact. As a consequence of this adhesiveness they are often found adhering to the sides of the vessel containing them, especially if the water has been disturbed by wind or movement. It is probably on account of this property that they are so difficult to find under natural conditions.

The eggs hatch in two or three days. If allowed to dry, or if completely immersed for half an hour, they will not hatch.

The larvæ are very small, and difficult to see for the first two or three weeks. Their habit varies under the different conditions met with, but they usually are easily found in small numbers.

To determine their haunts in the Highlands, I have examined all the waters in Blantyre and the immediate neighbourhood at the end of the dry season, with the following results.

The larvæ are found constantly in the swamps or shallow pools marking the outlets of the springs which form the sources of the

* Since identified by Mr. F. V. Theobald as Anopheles funestus.

numerous streams. These pools are usually overgrown with grass. The larvæ are of all ages, from the quite young to the pupal forms. In the streams arising from these springs, larvæ are also constantly found in places where the current is slight, particularly where the water is screened from sun and wind by overhanging banks or grass. When such a stream reaches a level portion and spreads into a pool or swamp, the larvæ are often abundant, but not if the water is stagnant or markedly peaty.

The larvæ are of different ages, but I have not observed very young forms in the streams. This suggests that the larvæ in these situations have been carried down from the springs; but as they are found day after day in the same places and sometimes as pupæ, these streams, if they are not actually the breeding grounds, at least distribute the mosquitoes and allow the further development to take place.

Several of these streams join to form a small rivulet, the Mudi, which is in places several yards wide. This I have followed for some three miles, and all along at points have found these larvæ.

The larvæ are also found in irrigation trenches used for gardening purposes, under similar conditions to those found in streams.

In none of these springs, streams, or trenches did I find any fish, so these must be rare. The natives say there are some, but that they are not abundant in the upper reaches.

These breeding grounds abound in the Highlands, even after prolonged dry weather. In an area of about two square miles I found no fewer than eleven of these springs, and I know of four others now dry which were active early in the dry season, and from the lie of the ground it is certain that there were many more in the first months of the dry weather.

On leaving the Highlands true rivers are found. These run into the Shiré, which rises from Lake Nyassa. The Shiré and these rivers swarm with small and large fish.

The Shiré, as traced from the lake, shows the conditions under which larvæ are found in waters swarming with fish. The river is the main if not the only breeding ground of the mosquitoes, as they are found at no great distance from the banks, and their prevalence varies with the favourable nature or otherwise of the conditions in the river for the existence of the larvæ.

The Shiré River on leaving the lake runs through low, sandy, alluvial land. The banks are usually low, swampy, and covered with rank grass and reeds. Any holes, such as hippopotamus tracks, are filled with peaty water. In these holes I have never found the larvæ, and the water, if added to that in which larvæ are growing, will speedily kill them.

From the edge of the banks grows a short grass which extends right out into the stream, sometimes for 20 yards or more. This grass is supported by a close meshwork of floating but submerged roots. Masses of this grass may become detached from the bank and form floating islands. Above the false bottom formed by the close meshwork of floating roots is shallow water, into which fish will not have ready access; in this water the Anopheles larvæ, of all ages, are found. They are not found in great numbers, but are found constantly, and are more numerous near the bank. Where this grass abounds the mosquitoes are numerous, even after months of dry weather, when the river is at its lowest, and all other water is gone.

Lower down, the Upper Shiré expands into a shallow lake, Lake Pamalombi, covered with tall reeds in great part. The floating grass is not abundant. In the wet season mosquitoes are very abundant, but are not very plentiful at the end of the dry season.

Below this lake there is little grass with floating roots; its place seems to be taken by a coarser grass rooted in the bottom, but also throwing out plenty of aqueous roots, so that a meshwork, though not very close, is formed. I found larvæ amongst this in places where it was thick. In the later part of the dry season the mosquitoes here are far less numerous than in the early part, when there are extensive swamps.

So far this Upper Shiré is navigable from the lake. It is about seventy miles long. The next portion, the Middle Shiré, is a series of rapids seventy miles long with a total fall of some 1200 feet. The current varies greatly. In some places the stream is slack enough to allow of a ferry, and in one of these places there was abundance of this fixed grass. Here the Anopheles were found. The same grass was seen in patches all along the river. In one part the river flows through deep rocky gorges with great rapidity; we camped here for the night, but found no mosquitoes.

On the west bank, at the time I was there, there were only two rivers running into the Shiré; in one of them there was much fixed grass, and on its banks there were plenty of Anopheles. The other had a rocky bed, and I am informed that there were no mosquitoes there.

Below these rapids is the Lower Shiré, navigable from the sea. The fixed grass was very abundant here, but the Anopheles were not very abundant, though both the larvæ and adults were found without difficulty. The climate is very different on the Lower river and much hotter. Culices of several species, including a large yellow one which carries the *Filaria nocturna*, abound.

The only other important water is Lake Nyassa, 1540 feet above the sea and 350 miles long. No mosquitoes are found in the open. The banks at the places I visited were fringed with reeds. There was no floating grass and very little grass growing into the lake. Mosquitoes are rare in many places on the lake shore.

In the lake itself I found Anopheles in one place only.* This was in a sheltered bay where the reeds extended for a long distance out. The larvæ were not found among the reeds, but just at the edge of the lake, where grass was growing and a kind of small water-lily.

At this time the streams running into the lake were in many cases dry or reduced to a series of stagnant water holes, in which no larvæ of Anopheles were found. In other places there was a series of water holes with a small stream connecting them; in some of these the larvæ were found. Replacing the end of the stream in some places was a small pool at the lake level, but separated from it by a sandy bar. In these pools the larvæ were constant.

The different situations in which the larvæ are found under these diverse conditions have points in common. In all, the water is fresh, and kept so. It is more or less permanent. Fish are scarce, or the larvæ are protected from them.

I have at times found the larvæ in small pools without any connection with other water, and the larvæ were sometimes over two weeks old. In some such puddles, which I was able to watch, the larvæ soon died or the puddle dried up. In the last case the larvæ were not restored by adding water. As the shortest period I have observed for the larvæ to reach maturity has been thirty-two days, the chances of such larvæ reaching maturity in the dry season must be very small. Even pools large enough to contain water all through the dry season after a few months become stagnant, and larvæ are not found in them.

Observations made on larvæ under artificial conditions explain in the main the reasons for the natural distribution. The constant motion of the lake would be unfavourable for the laying of eggs. The eggs when laid would be carried by the waves and attached either so high that they would be dried, or so low that they would be submerged, and therefore not hatched.

The length of time required for the growth of the larvæ with their susceptibility to stagnation explains the need of some permanent fresh-water supply. In captivity fresh water has to be added almost daily, or they will often die.

There is no difficulty in understanding how the larvæ are able to exist in running water. If larvæ be placed in an open vessel when there is a strong wind blowing, the water is put into rapid rotation; but the larvæ, without any apparent motion, are able to maintain their position, adhering by their tails to the side of the vessel. If attached to a floating object it will rotate with the water, and the larvæ with it, without any signs of inconvenience. They are also able to move against a strong current for short distances.

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* *Subsequently, in 1900,* I found Anopheles larvæ in many similar places at the *Lake edge.*

[redacted]

The conditions inimical to their existence are stagnation, putrefaction, or peatiness of the water. Their most important natural enemies are small fish. In addition, the larvæ, either of the same or a different species, will at times devour a younger one. If Cyclops are very numerous they will destroy the very young, but not the older larvæ.

There is one condition under which I have uniformly failed to find these larvæ, though those of Culices may be found, and that is in wells, unless the surface of the water is flush with the ground. The native wells are mere holes dug in the ground at or below a spring. In the dry weather the water-level is below the surface of the ground, and only Culices, if any larvæ at all, are found. The European wells are brick and are often covered. It is exceptional to find any larvæ at all in these, and those are not Anopheles. To kill the larvæ it is not necessary to dry them. If the superjacent water be poured off, they will not live more than a few hours in the liquid mud. Advantage might be taken of this to kill the larvæ in irrigation trenches, as diverting the water for a few hours two or three times a month would probably kill off the larvæ in it.

The breeding grounds in the wet season will have to be a specia study, but with our present knowledge it is probable that in the Highlands they will be confined to the springs, but those will be both more extensive and more numerous.

In the river the floating grass will be little affected, but extensive areas near the river will be flooded, and there the larvæ will be able to live during, and for some time after, the wet season, till the water becomes peaty or stagnant.

The adult mosquito bites mainly at night, but occasionally in the day. Unlike many of the Culices it does not leave the house in the day, but will be found at dawn near the bed. When disturbed it flies upwards, so that by the time a room is swept out, or a free current of air established, it will be found high up on the wall only.

Prophylaxis.—In a well-watered country any complete extinction of the species would appear to be impracticable.

In any given area they might be exterminated or much reduced. This will be costly in such sites as Blantyre, with numerous springs and rivulets.

Probably the best means would be the erection of wells with a clear pipe or brick overflow below the surface of the ground wherever there is a spring. The streams themselves should have their banks kept clear of brush and long grass, and places where the stream spreads out into a marsh have a graded drain through them. In the rivers the floating grass should be detached for a considerable distance above and below any settlement early in the dry season. If the long grass and reeds were cut down and the banks kept clean, the period during which the mosquitoes are prevalent would be much reduced.

Some of these measures are required on other grounds. In the bush surrounding the sources of the rivers and streams is much filth, as it is used by the natives as a latrine.

More wells are required, as the water supply is inadequate unless much fouled river water is used.

The houses should be better ventilated, and top-ventilation introduced to give the mosquitoes fewer resting places in the houses. The narrow beds and mosquito curtains allow the mosquitoes to bite any part of the body which comes in contact with the net. In the morning numerous mosquitoes gorged with fresh blood are usually found on the outside of the net. The small mosquito-proof room with the bed inside is much safer.

Larvæ of other Anopheles are much rarer, but I have found them in the springs, and the streams running from them, so that they seem to have similar habitats.

"Distribution and Breeding Grounds of Anopheles in British Central Africa."

By C. W. DANIELS, M.B.

Received June 7, 1900.

In continuation of my report on the breeding grounds of Anopheles for the Dry Season, April–October, 1899, I have the honour to report as follows for the Wet Season, October 1899–March, 1900:—

The observations for this second period are in the main confirmatory, and in parts explanatory, of the observations in the previous dry season.

2. The observations were made in the Shiré Highlands at Blantyre, my headquarters during some portion of each month, and Zomba, in January, February, and March.

On the Upper Shiré (lake level) November, December, and March.

On the Lower river in February.

3. The increase in the number of mosquitoes has not been very marked at most places, except at Zomba. With the first onset of the rains there was an immediate decided increase in the number of mosquitoes infesting the houses. This, I think, was probably due to the mosquitoes seeking a more secure shelter than that afforded by grass, &c. This increase was not maintained; on the contrary, at Matope (Upper river) in November and December, fewer mosquitoes were found in the house than in May or September, when I had been there before.

The Breeding Grounds.

4. The wet season commenced unusually early (in October), with days of heavy rain alternating with periods of rainless weather. This weather continued till near the end of November. During December,

[redacted]

January, and the early part of February the rains were more continuous, and the periods of rainless weather shorter.

Since then the periods of fine weather have again been longer. The attached table shows the amount and distribution of the rains during the period under review. Perhaps the clearest way of indicating the effect of this season is to take as an illustration a single small drainage area. The one nearest is selected for description, as that is the one most constantly under observation, but the results have been confirmed by frequent periodical examination of other known breeding places in the immediate neighbourhood, and by numerous isolated examinations over 100 miles of road in the Shiré Highlands. The place is some distance from the mountains, and in gently undulating country. Down the hollow, the water during rains pours into the Mudi (the small river separating Mandala and the hospital from Blantyre and the Scotch mission). The position of this stream is marked by the belt of trees in the photograph*. The height of the ridges surrounding this hollow marks the watershed between this and another small water system. In the views taken, this adjoining water system runs nearly at right angles, though the water from it is also poured into the Mudi. About half way down the gully is a spring permanent all the year round, and round about it a swamp. This swamp, as is usual, is overgrown with tall blue grass, which here and elsewhere indicates permanently wet soil. It is further indicated in the photo by the natives who are standing just above it. From this spring a small stream runs to the Mudi, spreading out in places into shallow swamps, and in others overgrown and blocked with grass.

About the source of this spring and in places in its course where it spreads into shallow swamps, or in dry weather is running very slowly along the grassy edges, Anopheles larvæ were found constantly, both at the end of the dry season and all through the wet.

Above this permanent spring is a natural cutting dry from May to October, except during and immediately after showers.

In the early part of the wet season after each period of rain it soon dried up, in each spell of dry weather leaving a few small pools in which, up to late in November, no Anopheles larvæ were found. Towards the middle of December, even in dry days, water was to be found oozing from the sides of the cutting in places, and consequently the channel never became dry.

In many parts of the course of this cutting grass had grown, and in level portions shallow pools were formed, and from the end of December Anopheles larvæ were found constantly in such places.

In this valley were several deep pits left in brick making, and one of them was deep enough to contain water permanently throughout this

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* Not reproduced.

season. These pits have all red clay walls, and usually little vegetation; they are common throughout the Protectorate, as most of the houses are built of brick, but in none of them have I found Anopheles larvæ.

Towards the head of the valley there is a swampy area much trodden by cattle; in their tracks water collects, and will withstand several days dry weather, but no Anopheles larvæ were found in them. On the left-hand side of the valley, looking down it, is the public road. On each side of this is a cutting to carry off the water in rainy weather. With constant rains they are scoured out, and after two or three days dry weather they are dry. No Anopheles larvæ were found in them.

On the right-hand side of the road there is a small extent of flat land; on this ephemeral puddles only form, and in them no larvæ were found. There is also a cattle pond formed in red clay like the brickfield ponds; in this Culices in abundance, but no Anopheles, were present.

This valley fairly represents the usual conditions in the Shiré Highlands in the neighbourhood of Blantyre; and in the area of about two square miles, including Blantyre township, the Blantyre mission, Mandala, and the Blantyre hospital, there are some fourteen similar small valleys. In some there are two springs, in others the slope from the springs is steeper, and larvæ are only found near the springs, and in others the springs dry up before the end of the dry season.

The Anopheles larvæ found were not all of one species. In the valley I have taken as an example, larvæ of all the five Anopheles found in these Highlands were found at one time or another. In no other valley have I found the same number, but two or three species were commonly found together, and sometimes four. As the associated species differed at different times and in different places, I consider that all the Highland Anopheles have similar breeding places, and that the five were found in this valley was probably due to the more frequent examinations made.

The commonest larvæ found were that of the so-called "small black" Anopheles.

In my report on the dry season I pointed out that the Mudi itself, though a running stream, contained these larvæ.

With the onset of the rains this stream was converted into a muddy torrent. At first, with each period of dry weather, the river fell rapidly and became clear, and the Anopheles were again found in the same or similar sheltered positions to those of the dry season. This observation was repeated in several places, both on the Mudi and in other streams, in several of the dry periods in the first six weeks of the rains, and leads me to believe that the larvæ are washed down from the springs to such situations, rather than that they have been actually bred there.

In the broader flat valleys in the Highlands there are in the wet season extensive swamps; in these, Anopheles larvæ are rarely met with.

I had anticipated finding Anopheles larvæ in open puddles during the wet season. In only one instance did I find them, and that was in a shallow excavation not penetrating through the black soil, and near a stream, but not supplied by it or by any other stream. In this, numerous Anopheles larvæ and some Anopheles pupæ were found, but this was after a month with hardly a rainless day, and in low land on the low banks of a stream. On the Upper and Lower rivers (Shiré) Anopheles larvæ were found, as during the dry season (among the grass growing in shallow water, and in that on the floating grass prevalent in the Upper Shiré above Lake Pamalombi).

The river was considerably higher and the current stronger, in one place (Chikwawa) said to be three miles an hour.

In the marshy ground where in the dry season the water was stagnant or peaty, the abundant rains had in places reduced this condition, but in no instance did I succeed in finding Anopheles larvæ. Frequent examinations were made in many different places with negative results, but considering the extent of these swampy areas during the wet season, I cannot consider my negative results as conclusive. In some parts of them, at least, the conditions must be favourable for their development.

On the Upper Shiré only one Anopheles (the "small black") has been found by me.

On the Lower river the "small black" is also found, and in addition three others different from those in the Highlands, and in the river there three kinds of larvæ were found—those of the "small black" and two other kinds—which, however, I failed to rear. It is therefore probable that in the Lower river the different Anopheles have similar breeding grounds as is the case in the Highlands. The lake I was unable to visit.

I have paid particular attention to all kinds of puddles during this wet season. The instance given above is the only one I have met of larvæ being found.

In some instances, in small grass-grown hollows which only overflow with heavy rains, but into which water runs with slight ones, larvæ were found during the time when there were few successions of dry days. Such places are rare.

I subjoin a table showing the places in which larvæ have been found in the Protectorate in the year under review.

To a large extent, not only each country and district but even locality differs in details. The slope of the ground, its nature and permeability, will largely determine where water, suitable for the *breeding of these* mosquitoes, will be found, and whilst in British

Table showing Rainfall and Distribution of Rains during the Year in Two Places in Districts Nos. 2 and 3. The figures for Fort Johnston are for the previous Year; those for 1899—1900 were not obtainable.

Zomba. Shiré Highlands.

Month.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Rainfall for month	9·75	2·7	0·51	0·07	0·1	0·12	2·23	13·40	7·79	15·94	2·19	5·76
Number of days on which rain fell	18	12	6	3	1	1	4	19	21	25	11	12
Longest period without rain	4 days	7 days	19 days	28 days	30 days	29 days	12 days	5 days	4 days	Under 2 days	6 days	15 days

Fort Johnston, Upper Shiré (Lake Level).

Month.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Rainfall for month	0·38	*p*	0·2	0	0·12	0·05	0·38	1·73	8·66	7·54	8·68	6·89
Number of days on which rain fell	3	1	2	0	1	1	1	9	14	22	14	17
Longest period without rain	10 days	27 days	28 days	31 days	20 days	29 days	30 days	8 days	4 days	4 days	3 days	4 days

There were 79 days (consecutive) without a shower in these three months.

Description of Places.	Dry season, July to October.	Onset of rains, October to December.			Wet season, continuous.			Drying-up season, April to June.		
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April.	May.	June.
The Lake Shore—										
A. Clear, or only fringed with reeds.	0 0	0					0		0	0
B. Behind sand bars separated from lake.	+ +									+
C. Among thick vegetation....	+									
Shiré River—										
A. Open water	0 0	0	0	0		0	0	0		0
B. When sheltered by grass...	+ +	+	+	+		+	+	+		+
Swamps in Plains	0 0	0	0	0	+	+	0	0		0
Large Streams (Mudi, &c.)	+ +	+	+	0	0	0	0	0		
Slow Small Streams— With slow current, or blocked in places.	+ +	+	+	+	+	+	+	+		
Irrigation Trenches	+ +	+	+	+	+	+	+	+		
Springs—										
Permanent all the year round..	+ +	+	+	+	+	+	+	+	+	+
Permanent in the wet season and early dry season.				+	+	+	+	+	+	
Puddles—										
Permanent in wet season......		0	0	0	+	+	0	+ on the Zambesi		
Native Wells..................	Very rare, and only when the water level was nearly that of surrounding ground.									
European Wells...............	None found at any time.									

0 indicate that larvæ were not found. + indicates that larvæ were found. *No entry* that no sufficient examination was made; in some cases because none was possible; in others, as in April and May, because I did not then know in what places to look.

Central Africa a porous, rocky, or sandy soil, and low-level subsoil water, prevents puddles being an important breeding ground except under exceptional circumstances; under other local conditions, even with similar meteorological factors, they may be the leading one.

The obvious presence of Algæ is no necessity; on the contrary, if abundant, Anopheles larvæ are rarely found.

The kind of grass growing from the shallow water varies; when very tall, as the blue grass mentioned as forming a guide to the spring, they are only found at its edges, and more frequently in places amongst it where there is open water. In the floating grass in the Upper river they are more readily found some distance from the edge. This grass is only about one foot high out of the water. In the fixed grass below Lake Pamalombi, and in the Lower Shiré, they are rare, except for about a yard from its edge. This grass is several feet high. The differences are most probably dependent on degrees of light and shade, either directly, as affecting the larvæ, or as affecting the growth of suitable foods.

Prophylaxis I deal with separately.

BREEDING GROUNDS OF ANOPHELES IN BRITISH CENTRAL AFRICA.

(Supplementary Report.)

(Received January, 1900.)

Since I forwarded my Report on this subject, I have received copies of the 'British Medical Journal,' giving the results of similar investigations at Sierra Leone.

It is clear at the outset that we are dealing with different mosquitoes.

It may appear from my Report that little attention has been directed to "puddles." This was not the case. I was familiar with Ross's observations in India, and the first evidence I had of the existence of Anopheles in Africa was the presence of larvæ in a puddle on the way up the Zambesi. I failed to rear these larvæ.

In British Central Africa at first I mainly directed my attention to puddles, and it was only when I failed to find them there that I systematically looked elsewhere.

In the Upper Shiré district the soil is very sandy, and it is practically rainless for months; so puddles do not exist, unless the marshy tracts below or at the level of the river can be so called. In these, at any rate when the dry season is advanced, as I have already pointed out, the water is too peaty or stagnant for the larvæ to exist.

The suggestion has been made that the mosquito eggs may remain dormant for considerable periods. This is not the case here, as unless the eggs hatch within a few days they do not hatch at all.

No definite relationship between Anopheles breeding grounds and human habitations obtains here. The country is thickly populated, and native villages are always near permanent water, and consequently usually near Anopheles breeding grounds; but breeding grounds are also found at considerable distances from any dwelling.

Kerosene, as a laboratory experiment, readily kills the larvæ, but its application to the actual breeding grounds here is impracticable, as the water supply of the people would be affected.

The alterations produced by the wet season, so far, are as anticipated. The swamps surrounding springs are larger, and so the breeding grounds more extensive. They are also more numerous, as springs previously dry are now running. In some of these the larvæ were found early in the dry season, but not at the end of it. They are now again found, but only young forms.

The streams are fuller, and running stronger, and larvæ are now no longer found in them.

Development of " Crescents " in the " Small Dark " Anopheles prevalent in British Central Africa.

By C. W. Daniels, M.B. Received March 5, 1900.

The following observations were made on mosquitoes fed on an adult male European who had had " fever " off and on for a month. The first blood examination was made on November 23, and crescents only were then found. At that time and on the following morning he had fever, which left him in the evening. Crescents continued to be present in fair numbers, usually five or six in a fresh blood slide, and on November 26 I took him to Matope, on the Upper Shiré River, as there the Anopheles* I wished to experiment with are usually plentiful.

He remained at Matope for eight days. The mosquitoes (Anopheles) were far less abundant than at any of my previous visits, and a considerable number were required for control experiments, so I was only able to feed sixty-eight on the patient.

Of these sixty-eight, five died at various periods after feeding, but were too dry and brittle for dissection. Six died within thirty-six hours of feeding; these did not have any zygotes. The remaining fifty-seven died from two to nineteen days after feeding on the patient, and were examined—twenty-seven, or 47·5 per cent., had zygotes.

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* *Identified* by Mr. F. V. Theobald as *Anopheles funestus*.

The temperature varied from 70°—84° F.

This percentage is in excess of the true proportion of infections resulting from a single feeding, as most of the mosquitoes were fed on the patient more than once.

Nineteen had been fed once only—five, or 26 per cent., had zygotes.

Thirteen had been fed twice—six, or 46 per cent., had zygotes.

Sixteen had been fed three times—ten, or 62 per cent., had zygotes.

Nine had been fed four times—six, or 66·6 per cent., had zygotes.

In all, the fifty-seven mosquitoes had fed 129 times, and in many of the mosquitoes the zygotes were of different sizes and stages of development, corresponding to different feedings.

In the five fed once, the zygotes were all of the same age.

In the six fed twice, the zygotes were of one age in three, and of two ages in three.

In the ten fed three times, the zygotes were of one age in five, of two ages in two, and of three ages in three.

Of the six fed four times, they were of one age in two, of two ages in one, of three ages in two, and of four ages in one only.

So that 129 feedings resulted in forty-six infections, or 35·5 per cent. This is quite as large a proportion as I think could be expected from a moderately good "crescent case," considering the very small capacity of this mosquito's stomach.

The zygotes in general appearance and course of development resemble those of Proteosoma.

The earliest forms, those found towards the end of the second day after feeding, were 7 to 9 μ in diameter. They were oval, had no defined capsule, and only stained faintly with basic stains. The pigment, relatively abundant in some, retained a close resemblance to that of the crescent. In some, even at this age, there was evidence of division of the protoplasm.

The zygotes steadily increase in size, and by the fourth day measure 20—25 μ. A capsule was now distinct, basic stains were taken readily, and the pigment had no characteristic arrangement. They obviously project from the outer wall of the stomach.

Beyond increase in size there was little change on the sixth day, by which time they measure 30—35 μ. Some were slightly granular.

On the eighth day the granular appearance was marked and general. Pigment had diminished, and they measured 40 μ and more.

The capsule can readily be ruptured, but the contents when expressed were only a granular mass.

On the tenth and twelfth days the cysts have reached their maximum size, 50—55 μ, as measured uncompressed and without a cover-glass.

When the capsule was ruptured, the contents of the cyst were poured out into the surrounding fluid. They partly consisted of free nents, zygotoblasts (Ross's germinal threads), but mainly of clear spherical bodies with irregularly radiating masses of filaments attached by one extremity.

The arrangement of filaments attached to central body seemed to me conjectural in Proteosoma, but was clear in these cases. Zygotes were traced up to this stage in eight mosquitoes.

Only two were traced further. Both of these had been fed more than once, so the ages are uncertain, 12—16 days in one fed three times, and 14—19 days in the other, also fed three times. In both, a ruptured and other unruptured cysts were found in the stomach, zygotoblasts were present in the body fluids, and in a few cells only in the salivary glands.

No bodies resembling the " brown spores " were present, but the observations were too few for this negative evidence to be of value.

The mosquitoes used were not reared from eggs or larvæ, and may have fed on other animals before feeding on the patient.

Though I should have much preferred to have used such mosquitoes, I do not consider that the results are at all invalidated, for the following reasons :—

Quite young forms, 7—9 μ in diameter, were found in several many days in captivity, in one case ten days, but two days after it had last fed on the patient, and in others after eight, six, and four days' captivity. Mixed infections were found only after repeated feedings on the patient. In those fed otherwise (on self) the infections were single.

The frequency of infection varied with the frequency of feeding on the patient.

Control experiments all gave negative results. These were as follows :—Twenty-two mosquitoes before the arrival of the patient. During his stay, thirty-eight from the room on his right occupied by myself ; and twenty-four from the room on his left.

Thirty-nine others were fed on myself only, and examined four to eight days after the first feeding.

When the patient left, the mosquitoes were smoked out of the room, but on the second day sixteen were found in it and examined.

This gives a total of 139 mosquitoes, and zygotes were found in none, as against fifty-seven with twenty-seven positive results when fed on the patient.

To this I may add a large series of examinations of these mosquitoes in the past few months with negative results in all but one instance. In that already recorded a zygote was found in one out of four mosquitoes fed on a poorer crescent case than this.

The other known pigmented parasites in the district are Proteosoma, which is rare, and can be excluded, as its life-history is well known, and zygotes of such early development are not found so long after feeding. Halteridium is common, but it is not carried by this mosquito —at least my experiments with it have failed.

Of unknown parasites we can, I think, safely infer that in any in which the later stages are so similar to those of known parasites, the early ones will also be similar.

Other mosquitoes:—

Of a large grey Culex, found in the Highlands and Upper Shiré, fifteen were fed on the patient, in some cases several times. No zygotes were found. The blood capacity of this mosquito is considerable, so these negative results are of value.

Three specimens of a brilliantly speckled, black and white Culex also yielded negative results, and early in the year I fed several of the large yellow, filaria-carrying Culex of the Lower Shiré, and two species of Anopheles, on a richer crescent case than this, in all with negative results, but the numbers of mosquitoes used were too small for the results to be conclusive.

"Notes on 'Blackwater Fever' in British Central Africa." By C. W. Daniels, M.B.

(Received November, 1900.)

The following notes refer only to cases in the above district. I have included in them cases observed by others as well as those seen myself, and am particularly indebted for much information to the medical officers, both of the Administration and the various missions, as well as for much assistance from others.

Occurrence.—The disease affects Europeans and Indians. During the year, June 1899 to June 1900, there were 33 cases, 31 in persons of European descent and 2 Indians.

The *European* population in 1898 was given as 338. It is probably still under 400, so that some 8 per cent. of the European population had this disease in the year.

The *Indian* population, Sikhs and others, is about 200, so that the proportion attacked was 1 per cent. This is probably above the true figures, as with a nearly stationary Indian population there have only been 6 cases in the past 5 years amongst them.

*Natives** (Negroes).—Opinions are divided as to the occurrence of the disease in this class. None of the medical men have seen a case. None of the adults in the armed forces (including carriers: these average upwards of 1000); none of the adults attached to missions, nor of the children attending mission schools, have been attacked. These would average some thousands.

It has not been seen amongst the numerous infants and children

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* Vide Note 1 (p. 62).

brought to the missions for medical advice. Inquiries were made from 214 native mothers who have lost amongst them 313 children. They deny the existence of such a disease amongst the children, or of any of the deaths being due to it.

It can therefore, I consider, be concluded that this disease is at least of great rarity amongst the native negroes, and is much commoner in Europeans than in Indians.

Sex.—Both males and females are liable to the disease. Of 136 persons known to have had blackwater fever, 9 were females, or 1 in 15. At present the men (Europeans) seem, from returns received, only to be eight times as numerous as the women.

From this it might appear that the men are the more susceptible, but the figures are not conclusive, as the cases are collected from records of many years, and the proportion of females has increased of late. The greater number of women also are resident in the Highlands, and travel less than the men.

There is nothing to show that, under similar conditions, women are less susceptible to the disease than men.

Age.—The number of European children resident is small. Of those born the majority either die, are invalided, or early removed for prudential reasons. The only child attacked was a half-caste (European and native), aged about 5. The ages of the persons attacked vary from 19 to 38, the common age-limits of the residents.

Length of Residence.—This has a decided influence. Few cases occur during the first 6 months' residence. During the second half-year the number rapidly increases. They are most numerous during the second and third year, and become rare after 5 years' residence.

I can find no recorded first attack in any person resident more than 10 years. The number resident over that period is small.

The attached chart (No. 1) shows the variation for the period of residence. The incidence in the first half-year is taken as 1.

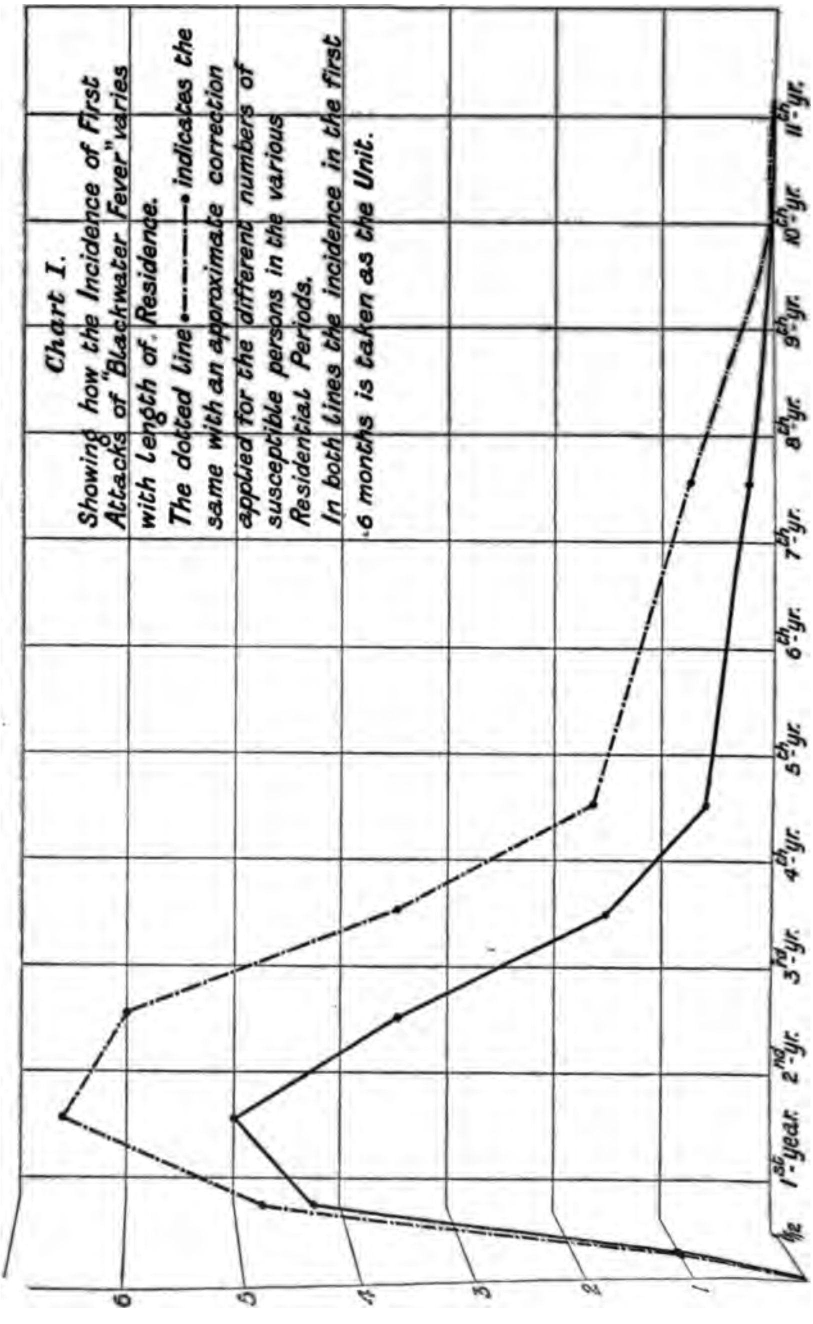
Out of 114 first attacks, where the information on this point is sufficiently definite, 4 were in the first 6 months, 17 in the second half-year, whilst for the 2nd, 3rd, 4th, and 5th years the numbers were 40, 27, 12, and 5 respectively. There were 9 cases from the 6th to the 10th year, and none after that length of residence.

A correction is required, as the number of persons in any residential period steadily diminishes. Many leave after the first term of service and do not return. This term of service varies from 2 to 5 years. Others are invalided, and some die or leave for other reasons earlier. Taking the figures obtained from the returns received from 242 residents as representing the numbers of persons of the different residential periods, we have an approximation to the true correction.

The effect of this correction is indicated by the red line in the *Chart (1): It* does not materially affect the character of the curv

[redacted]

According to both the corrected and uncorrected figures the liability to the disease is less after 5 years' residence than in the first 6 months.



Districts.—The greater number of the recorded cases have occurred in the Highlands at or about 3000 feet above the sea-level. For this there are two reasons. *First.* The number of residents in these Highlands is much greater than in the other districts. The correction for this alone reverses the figures. *Secondly.* Many of these cases were residents of other districts, visiting the Highlands for a change on account of ill-health, or for other reasons. Others were passing through the Highlands on their way home, sometimes when invalided home. Even of the Highland residents some of the attacks followed a short time after a visit to the lower lands.

On the other hand a few of the cases were in persons from the Highlands, attacked during a visit to other places. A true correction that would attribute each case to the district in which the disease was acquired is impossible. We know on the one hand that it may occur less than three months after arrival in Africa and also that attacks, and even first attacks, may develop months after leaving the country. The latent period may be long or short, and is variable.

Taking an arbitrary period of a fortnight as representing a not improbable latent period in a fair proportion of the cases, we should then find that the place of residence a fortnight or more previous to the attack would give a very different district-distribution of "blackwater fever" to that given by considering the place of onset.

In 97 cases (all 1st attacks) I have sufficient information on these points. The attack of "blackwater fever" commenced in 45 of these cases in the Highlands, in 40 at the Lake Level (Lake Nyassa and Upper Shiré River), and in 12 on the Lower Shiré River.

The susceptible (European) population is, in round numbers, 250 in the Highlands, 70 at the Lake Level, and 50 on the Lower Shiré River. I believe that this substantially represents the relative population of these districts for some years past.

It follows that if allowance be made for the number of susceptible persons in each district a very different district-incidence will be obtained.

Thus on the Lower Shiré, for each 10 persons residing there, 2·4 cases are on record; at the "Lake Level" for each 10 there have been 5·7; and in the Highlands for each 10, only 1·8 cases are recorded.

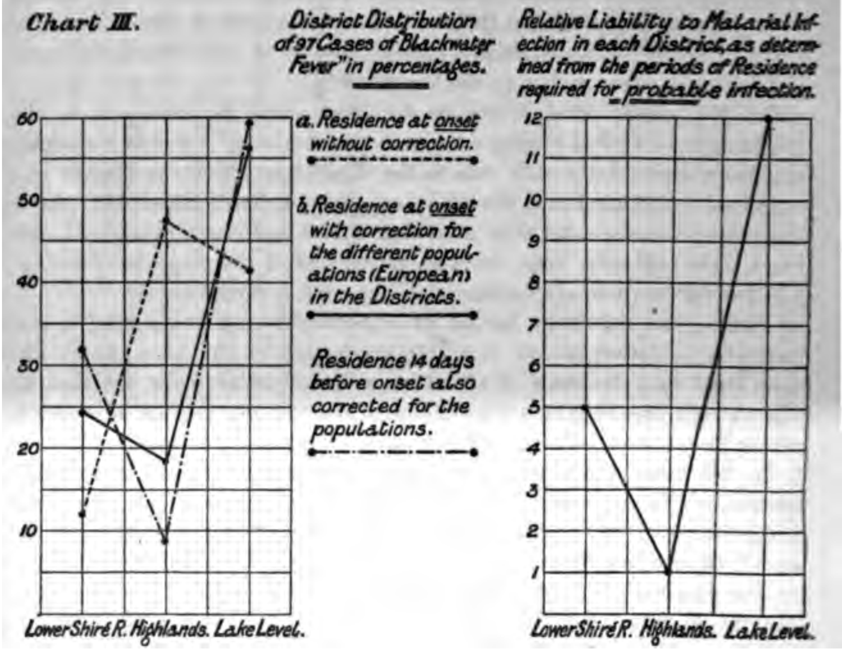
If we take the incidence in the Highlands as 1, that at the "Lake Level" will be 3·16, and on the Lower Shiré 1·33.

Some of these cases occurred immediately after arrival in a district, and should probably be credited to the district they had left. If we take the place of residence 14 days before the onset of blackwater fever instead of the place where the attack occurred, we find that of these 97 cases, 26 were resident in the Highlands, 51 at the Lake Level, and 20 on the Lower Shiré River 14 days before the attack commenced.

Corrected as before for the proportional numbers of susceptible persons in each district, we find that for each population of 10 there were 1·04 cases recorded in persons from the Highlands, 7·28 from places at the Lake Level, and 4·9 from the Lower Shire River.

Again, taking the Highlands as 1, the proportion from the Lake Level is 7, and from the Lower Shire is 3·8. Chart III indicates these relations.

Chart III.



Whether these corrections, particularly the second, are too great or too small I am not in a position to state. A correction is essential and I introduce these figures, admittedly inaccurate, because conclusions as to the prevalence of the disease in different districts have been drawn on the mere totals without considering the obvious fallacies. Such conclusions are misleading and not warranted by the facts.

The correction is right in principle, and in the right direction. I believe that it does not go far enough. Such cases as one in which a person free from fever left one Highland district, spent some three weeks at the Lake Level, where he had "fever," and then after three months in another Highland district, got "blackwater fever," should be assigned to the Lake Level districts, as the patient had frequent recurrent attacks of fever during the three months he was in the second Highland district before the attack of "blackwater fever." In my present table this case is credited to the Highlands.

Change of District.—It is a common belief among the older residents that a change of district, particularly from one level to another, causes "blackwater fever." Many cases have certainly occurred after such a change. The onset varies from a few hours to many days, or even weeks, after the change.

Cases occur in which there has been no change of district for months. Some of the cases are explicable on the ground that a belt of country where the incidence of blackwater fever is high has been traversed. In these cases some days may have been spent on the journey.

In British Central Africa changes of districts are frequent, and it is only a day's journey from the Highlands to a district a few hundred feet above the sea-level, or to one 1500 feet above the sea.

Exposure.—The attacks in a certain number of cases followed unusual exposure. In many cases there was no such antecedent.

"*Blackwater Fever" Houses.*—Two houses in particular have this reputation, as there have been several cases of "blackwater fever" in them. On inquiry, however, it is found that some of the cases were brought there with blackwater. The cases have occurred at long intervals, and it is doubtful in both houses if a single case was really contracted there.

Infection.—The disease is not considered to be in any way infectious. Wherever Europeans have settled, cases have occurred, but in no case do they appear to have been even remotely connected with previous cases. In such small groups as have occurred amongst parties of persons, the disease has in some of the instances broken out after the separation, and if dependent on a common cause that common cause was not a previous blackwater fever case.

Certain families seem more susceptible to the disease than others. Thus of one family of three brothers, two had it and died with hyperpyrexia. The third it is stated died with hyperpyrexia without blackwater.

Two other pairs of brothers had blackwater fever. In none of these cases was there any correspondence in the time of the attacks.

Venereal diseases and particularly *syphilis*, are by some supposed to be predisposing causes. Others consider excessive venery as a cause. Instances in support of this can be given, but in a considerable number of cases, including missionaries, such antecedents can be excluded.

Alcoholism can be excluded with even greater certainty. A large proportion of the cases occur in total abstainers. Some of these, as the members, male and female, of the missions, are above suspicion, and in a country where frequent transhipments of goods are required, and where all packages are carried for stages by carriers, any large supplies of alcohol to any of the scattered stations would attract notice and be commented on. Cases do also occur amongst persons known to be intemperate. I have not been able to satisfy myself that these are on the whole either more severe or more fatal.

These cases, as indicated in the at variety in the duration of the hæ quinine had been taken.

An exception to this statement mig tion of cases, in that amongst those taken there are no relapses, and n F. Plehn, however, gives the intermit non-quinine cases.

In the cases following the administ that the interval between the last dos disease is very variable, four days dow there is no relation between the amo or the duration of the attack.

In several of these cases larger d after the attack without any hæmog treated with quinine, sometimes in h ceases, as it does in cases untreated.

These observations show that blackw of quinine. In cases where quinine h a causative action, it must be assume of the dose, and that the resulting effe and time.

In a few cases there is stronger grou an important factor in the production o dose of quinine has been taken than usu

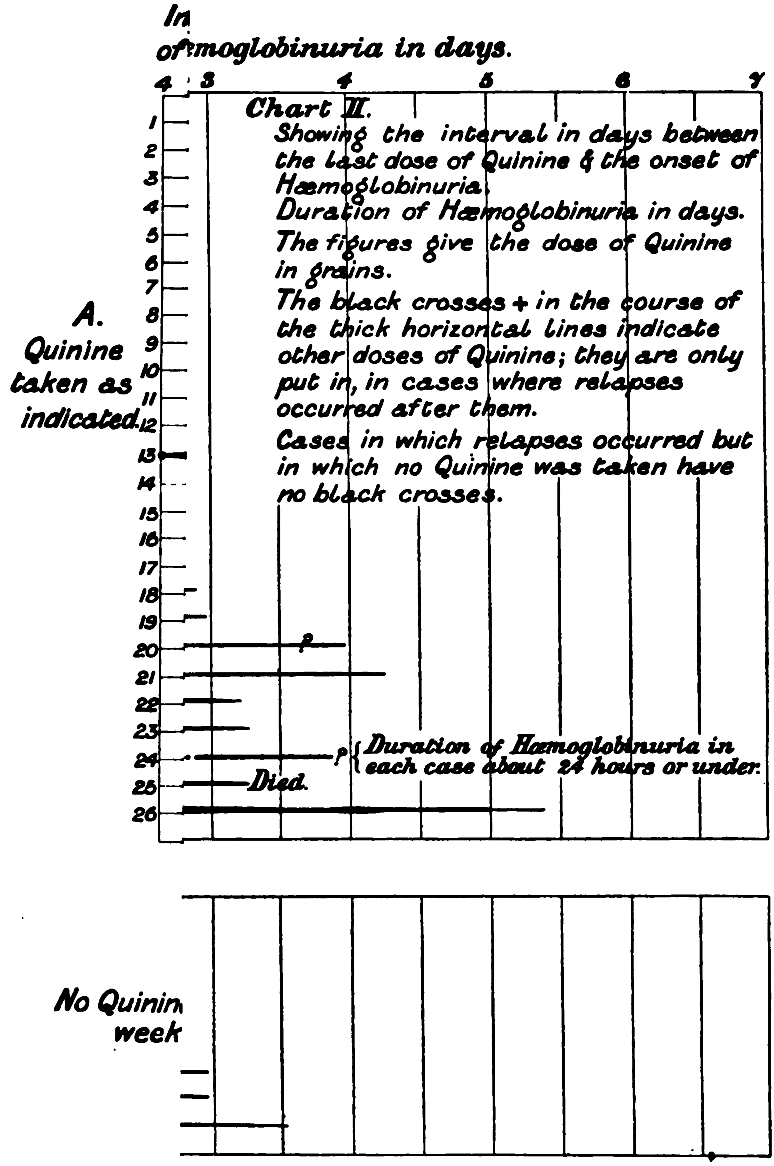


Chart II.
Showing the interval in days between the last dose of Quinine & the onset of Hæmoglobinuria.
Duration of Hæmoglobinuria in days.
The figures give the dose of Quinine in grains.
The black crosses + in the course of the thick horizontal lines indicate other doses of Quinine; they are only put in, in cases where relapses occurred after them.
Cases in which relapses occurred but in which no Quinine was taken have no black crosses.

N.B.—In a few o great majority quinine had been taken, and in the majority very shortly uite reliable.

(2.) The *exact* ti, even in the above cases, is uncertain; but for our purposes an error of t attack he did not recover. For these particulars I am indebted to Dr. McCarthy Morrough.

Such cases undoubtedly make a strong impression on the observer, but are not conclusive. Similar relapses occur in cases not treated with quinine. In one case (Chart II A, No. 26, and Chart XV) 6 grains of quinine were taken three to four days before the onset of the disease. The urine cleared completely twice, and nearly so a third time. In two other cases there was an intermission (Charts IV and XIV).

The rule in British Central Africa is to take quinine only when the temperature is down in "fever" cases. If this rule had been followed in these three cases quinine would have been taken shortly before each relapse and at no other time. (*Vide* Temperature Charts. The time when quinine would probably have been taken is marked *.)

If quinine had been taken, these cases would have seemed to prove the dependence of the relapses on quinine. In none of the three cases was any quinine taken after the onset.

With so variable a disease as "blackwater fever," statistics are useless, so no comparison can be made between cases treated with quinine and those not so treated. It is not difficult, however, to select cases very similar and running similar courses with and without quinine, and to show that a continuance of the quinine, even in large doses, has no material effect.

For the notes from which these cases are selected I am indebted to Drs. MacVicar, Hearsay, Gray, Cross, Hardy, and others.

Malaria.—The relation of the disease to malaria is certainly not a simple one.

I have made frequent examinations of fresh blood specimens and films in ten cases, and of films only in six more. These films, two or three a day, were sent to me by Drs. Hearsay and Gray in cases I could not attend.

In one only did I find malarial parasites during the period of hæmoglobinuria, and that was about one and a-half hours after the onset, and even in that case no parasites were found at any subsequent examination.

In none of the other cases did I find either malarial or other parasites either during the period of hæmoglobinuria or in the subsequent pyrexial period.

In three cases I had the opportunity of examining the blood before the onset of the disease during the prodromal pyrexia, and in each case "ring" parasites were found. In these cases the parasites had disappeared in the hæmoglobinuria period. In five of the other cases pigmented leucocytes were found, and in two (fatal cases), though no parasites or pigmented leucocytes were found, still at the post-mortem examination the finely-divided pigment characteristic of recent malaria was present in the organs.

These observations show that malarial invasion of a recent date is a common antecedent of "blackwater fever," and that the parasites disappear during the attack. The evidence is against "blackwater fever" being in any way due to an exceptionally numerous invasion.

The suggestion has been made that the parasites are in an internal organ, particularly the brain. The absence of cerebral symptoms in blackwater lends little favour to this hypothesis, and the continued absence of the parasites during several entire cycles from the peripheral blood is, to say the least, unusual. The absence of any marked effect from the use of quinine is also opposed to this view, or to any view which necessitates as an essential a continued malarial invasion.

In three cases I examined the blood during the intermissions (four). In only one of these did I find parasites in small numbers.

These results corroborate in the main F. Plehn's observations in German East Africa. He attributes the disappearance of the parasites to the destruction of them by the altered blood serum. As, however, he and others have observed parasites in some cases during the course of blackwater fever, this explanation is hardly tenable.

If the disappearance or destruction of the parasites, or of some generations of them, is an essential feature of the disease, this destruction may be the cause rather than the effect of the hæmolysis.

In the great majority of cases, blackwater is preceded for one day or more by "fever," indistinguishable clinically from ordinary attacks of malarial fever. As regards its parasitology, this prodromal fever was also indistinguishable in the three cases mentioned above.

To this rule I know of two exceptions. The first is doubtful, as the patient had been feeling "out of sorts" for some time, and in consequence had been taking quinine. He was however able to travel in the usual way by machilla (a hammock) 40 miles, dine in public, and spend the night with friends, who noticed nothing amiss. During the night blackwater fever supervened. It terminated fatally, and the post-morten examination gave pigmentary evidence of recent malaria.

In the second case the onset was very sudden. The patient was, to the best of his knowledge, in good health, and was shooting at a target from his verandah when some abdominal discomfort caused him to go to the latrine, where he found that he was passing blackwater. The case was a fairly severe three days' attack, ending in recovery. There was no medical attendance, and the blood was not examined.

I am not prepared, on the clinical evidence only, of this case to consider it as a conclusive proof of a non-malarial origin. The chief etiological ground for considering "blackwater fever" to be a disease *sui generis*, and unconnected with malarial fever, is the want of correspondence between the seasonal incidence of the two diseases.

In British Central Africa there is no very marked seasonal incidence i either disease, and such as it is, it differs in different districts.

A difference in the seasonal incidence of the two diseases is of little importance, as whatever view may be taken, “blackwater fever” rarely follows a first infection. It usually occurs after several attacks or recrudescences of malaria, and at a variable period sometimes, as in cases occurring in England months after possible infection. This in itself would lead to a seasonal incidence different from that of malarial infections.

The etiological grounds in favour of a malarial origin of blackwater fever are:—

(1) Its prevalence in certain malarial districts. The prevalence in British Central Africa varies with the “prevalence of malaria” in the district, when a correction is made for the varying number of susceptible persons. With further corrections there is a closer correspondence (*vide* Chart III).

(2) Liability to recurrence after considerable intervals, or, though rarely, first attacks of both diseases when the patient is far removed from possible sources of infection. (Note 2, p. 62.)

(3) Diminished susceptibility to both diseases after prolonged residence in an infective district.

With Europeans the common history is much “fever” in the first three or four years; after that, little fever.

With the natives “fever” is common in childhood, and in adult life very rare. A considerable number of these “fevers” have been shown by their parasitology to be malarial.

Enlarged spleens give evidence of malaria usually more or less chronic. The exact relation is unknown.

The age-incidence of this condition in the natives shows a rapid rise and gradual fall, similar to the residential-incidence of “blackwater fever” in Europeans (Chart IV).

The older cases of enlarged spleens, 10—15 years of age, are in the Highland children (10 out of 14), and the majority of those under one year (20 out of 24) at or below the 1,500 feet level. Similarly, the early cases of blackwater fever, those under one year’s residence, are mainly (14 out of 21) in persons resident at or below the 1,500 feet level, and the majority (10 out of 14) of those after four years’ residence are in persons mainly resident in the Highlands.

(4) If “blackwater fever” is a disease *sui generis* and not of malarial origin, it must also be either a disease originating *de novo*, or originating from some other unknown disease without the characteristic symptoms of hæmolysis and hæmoglobinuria.

Nature of the Disease.—“Blackwater fever” is essentially an acute hæmolysis of sudden onset, short duration, and spontaneous cessation. One of the products of the blood destruction is discharged in quantities with the urine as free hæmoglobin, or more rarely, as methæmoglobin.

It is accompanied by pyrexia, not definitely of malarial or other type. It is usually preceded by pyrexia, and is often followed by a more or less prolonged pyrexia, which may be continued, remittent, or irregular. In occasional cases hyperpyrexia occurs.

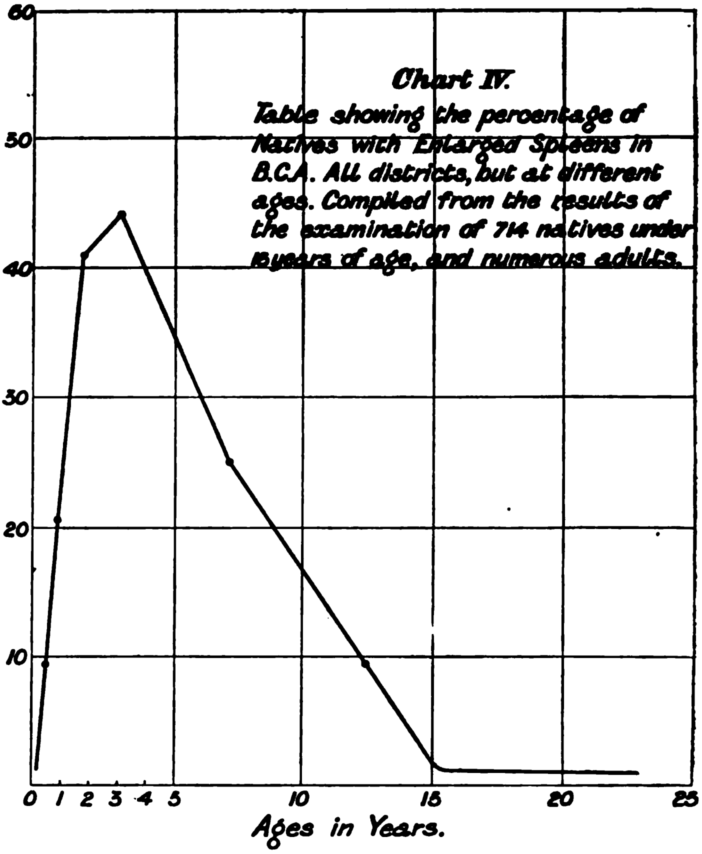


Chart IV.

Table showing the percentage of Natives with Enlarged Spleens in B.C.A. All districts, but at different ages. Compiled from the results of the examination of 714 natives under 15 years of age, and numerous adults.

The blood destruction is great. In cases where the hæmoglobinuria lasts for over two and a-half days, the number of red corpuscles fell to 1,038,000, 1,290,000, 1,366,000, and 1,680,000 respectively, from presumably little below normal.

Even in shorter cases, lasting about twenty-four hours, there is fall to below 3,000,000. In some cases at least, the hæmoglobin is more reduced than the corpuscles.

The prodromal pyrexia has not been much studied, as cases rarely come under medical observation at this stage, and even when they do, they are not recognised as blackwater at this period. During this stage rigors are unusual, and not marked. In this they resemble ordinary malarial attacks in British Central Africa. During the hæmoglobinuric period severe rigors are the rule; they are often initial, but may be later. Sometimes there are repeated rigors. Complete absence of rigor is rare, but does occur.

With the cessation of the hæmoglobinuria there is usually a fall in the temperature sometimes to subnormal. These changes and the subsequent pyrexia are illustrated by the Temperature Charts.

Shortly after the onset of the disease the conjunctivæ and skin show an icteric tinge closely resembling jaundice. In such cases as I have seen there has been no bile pigment in the urine. There can be little doubt that this colour is derived from the blood pigment. This coloration may be intense, especially in suppression cases.

The condition of the skin varies, but as a rule there is profuse diaphoresis even when the temperature is high. It is frequently intermittent.

The pulse-rate is not much raised considering the temperature, and in cases I have seen has been about 90, rarely up to 100. In other cases noted here it has sometimes been much higher.

As the anæmia advances the pulse usually becomes dicrotic. Respirations also become more frequent; 28—32, whilst keeping still, are not uncommon.

The severity of the disease varies greatly according, 1st, to its duration, and 2nd, as regards complications. The duration, when there are no relapses, varies from a few hours up to, as a common period, rather under three days. Some observers consider the last as the common type. Cases in which the hæmoglobinuria persists longer than three days are rare without either partial or complete intermissions.

There seems no reason to attempt to distinguish separate forms of blackwater fever. Intermediate forms occur as regards duration or any single symptom. Such divisions as "quinine form," "bilious" forms, &c., may be misleading and cause confusion.

Relapses are common. They may occur before the urine is quite free from hæmoglobin, in which case the hæmoglobinuric period may be much over three days. They commonly occur after the urine has been clear for a few hours, and more rarely after several days or even two or three weeks' intermission. There does not seem to be any definite relation between the primary attack and the relapses as regards duration. The first attack may be a short one, and the relapses long, or *vice versa*, or they may be each of about the same duration. (Charts II A, 22 and 23, and Temperature Charts IV, XIV, and XV illustrate this condition.)

Vomiting is a common symptom and is frequently severe and persistent. When excessive the prognosis is unfavourable. In rare cases there is either no or very little vomiting.

Hiccough is very common. It occurs in mild as well as in severe cases, and unless excessive is of no prognostic import.

Hæmorrhages are not a usual feature of the disease, but occur in some cases. The commonest form is epistaxis, but in two there was hæmatemesis and in one hæmorrhage from the bowel.

Glandular enlargement was noted in three of the collected cases, in each case in the neck. In one of these cases there was extensive suppuration, terminating fatally. In some cases of malaria there is glandular enlargement.

Gastro-enteritis with dysenteric symptoms appears to have occurred in several cases. This I have not seen.

The mortality of the disease is variously given. It is probably overstated as a rule. There is a tendency to report all deaths, when there has been no doctor in attendance, as "blackwater fever." On the other hand, cases that recover from what appears to have been "blackwater fever," in the absence of medical testimony, are doubted. The fatal cases are remembered whilst the recoveries are forgotten. For these reasons I consider that the figures given below exaggerate the gravity of the disease.

In all, I have collected some accounts of the disease in 136 persons from the district. Amongst them they had 184 attacks.

Of the 136 first attacks	31 or 22·7	per cent.	were fatal.
„ 33 second attacks	8 or 24	„	„
„ 15 third or fourth attacks	2 or 13·3	„	„

In this variable disease the mortality is no guide to the success of the line of treatment adopted. In the cases of a few hours' duration deaths are rare; in those lasting over two days deaths are common. A collection including a large proportion of short attacks will give a low mortality; whilst a series in which few of these mild cases are included will give a high mortality.

In British Central Africa some of the medical men seem to have seen little of the milder forms till this year, but they have occurred for many years past.

The supposition that the milder forms are on the increase, like the statement that "blackwater fever" itself is of recent appearance, is not, I think, warranted by the facts known.

The increased European population, greater facilities for travel, and the larger number of medical practitioners have enabled a larger proportion of the cases to be seen, and that at an earlier stage. The attention directed to the disease has led to cases being recorded which otherwise would have been speedily forgotten.

There are three main causes of death—suppression of urine, cardiac, failure, and hyperpyrexia.

Of these, suppression is the commonest. This is rarely complete, though the amounts passed may be very small, and at the rate of only a few drams daily.

I have not seen this complication. From notes supplied to me by Drs. Gray and Hearsay, we find that in one case 7 ounces of urine were passed in five days; in another, 8 ounces 1 dram were passed in five days; in another 2 drams in two days, and in another 25 ounces were passed in the first twenty-four hours of the disease, and only 10¾ in the whole of the remaining nine days.

It is noteworthy that, in spite of the small amounts of urine passed, not only does it become free from hæmoglobin, but even that it may be free from albumen. This shows that the products of the hæmolysis, failing a passage by the kidneys, are removed in some other way (Note 3).

In cases of blackwater fever terminating in recovery the amount of urine passed is variable. Whilst there is much hæmoglobin the amount passed is usually much above normal. As the urine clears it falls below normal and may remain below for days or only for a brief period. This variation takes place even in the milder cases. Urine Charts A (1), (2), (3), and (4) illustrate this condition.

Suppression usually occurs when the urine is commencing to clear, and this drop may be taken to indicate a tendency towards it. The hæmoglobinuric urine appears to act as a diuretic. There is evidence, however, that it acts as an irritant on the genito-urinary tract.

Micturition is frequent; sometimes urine is passed every hour or even more frequently. This is particularly so during the second day.

At this time much bladder epithelium is found in the urinary deposit. Dysuria and tenesmus are rare but occur. There is discomfort, rarely amounting to pain in micturition, and in two cases there was actual retention. Retraction of the testicles is common. These symptoms disappear as the urine clears.

It is tempting to attribute the suppression to mechanical causes. There is little evidence of any important structural change in the kidneys. With the disappearance of the hæmoglobinuria there is a great fall in the amount of albumen, and usually in a day or two and sometimes even after the first micturition none at all is found. Casts persist longer, and an occasional one may be found weeks after the attack.

The symptoms associated with this suppression are not those of uræmia. Consciousness is maintained till near the end; convulsions are very rare and even muscular twitchings are unusual. Vomiting is usually marked. The temperature is often subnormal. (Note 4.) Temperature Chart 12 is that of a suppression case reported by Dr. Gray, P.M.O., British Central Africa.

A *temporary suppression* could be accounted for, when it occurs *early, by the irritation* set up by the hæmoglobinuric urine; and the

[redacted]

late cases by the combination of the fall of the blood pressure, the anæmia and the cessation of the excretion of diuretic constituents of the urine (hæmoglobin), but neither of these sufficiently explain the persistence of the suppression.

They might explain the commencement but not the continuance.

The accumulation of pigment (yellow) and of ferruginous materials in the liver, as found post-mortem, indicate the alternative method of eliminating the hæmolytic products from the blood.

Cardiac failure is common. It has in several cases been the cause of death as a result of slight exertion.

Hyperpyrexia is not common, though pyrexia is often severe. In the cases of which I have notes, it occurred after the hæmoglobinuric period. It does not seem to be controlled by quinine or antipyretics (Temperature Charts 10 and 11).

Second attacks are common. Of the 136 patients, 33 are known to have had two or more attacks, 24 per cent. As many persons leave after one attack and do not return, this probably understates the liability. The longest interval between the first and second attack is nine years. It is often less than one year. Second attacks under a month would be considered as relapses.

The health between the two attacks is usually good.

F. Plehn states that the mortality is greatest in the first attacks. My returns are not sufficiently numerous to justify any decided conclusion, though the actual figures indicate a slight increase in the mortality in second attacks and a decreased one in subsequent attacks.

In some persons each attack resembles the first. Thus one person has had three attacks each lasting only a few hours, another had two attacks within a year, each lasting just under two days, and a third two attacks, each lasting two and a half days.

This is not an invariable rule, as one person whose first attack lasted under twenty-four hours had his second attack nine years after, which lasted a full three days.

This tendency to persistence in type of the disease in an individual perhaps accounts for the absence of a markedly increased mortality with later attacks.

A severe first attack is fatal, or the person permanently leaves the country. Second attacks will, in the majority of cases, be in persons who had slight or only moderately severe first attacks, and as far as the type remains the same will have slight or moderately severe second attacks.

Treatment.—The popular belief in an excessive mortality from "blackwater fever" has led in the past to somewhat heroic treatment. The rapid course of the disease, with the progressive failure in strength, has resulted in frequent changes in treatment before any one method has had a sufficient trial.

Errors as to the true nature of the disease have been common. By some it seems to have been considered as a hæmorrhage, and hæmostatics, such as ergot, perchloride of iron, &c., have been freely resorted to, not only by the mouth or hypodermic injections but also by intrarenal injections.

Restriction of fluids seems to have been advocated by some partly for this reason, but mainly with the idea of checking vomiting. Quinine has been very freely used by some, subcutaneously and otherwise.

Comparisons of the mortality under different treatments is useless on account of the varying severity of the disease.

Judging from individual cases I have seen under various methods of treatment, and comparing them with notes of other cases supplied to me, I do not think that any treatment hitherto employed has the slightest influence on the duration of the hæmoglobinuria or hæmolysis.

From the depth of colour of the urine passed in the early stages, the duration of the attack can be fairly correctly estimated, unless relapses occur, irrespective of treatment.

Parallel cases, with or without quinine or any other specified drug, can be easily found. Alteration or cessation of a treatment does not make any material difference.

Quinine has little or no effect on the temperature, and antipyretics, such as phenacetin, have so temporary an effect, sometimes followed by a greater rise, that I consider their use doubtful and their repeated use dangerous (*vide* Temperature Chart 4).

Whatever the connection with malaria may be, I think quinine should be avoided unless there is direct evidence of *present* malarial infection as shown by finding parasites. Even when parasites are present, I should be inclined to use it with caution, as it increases the vomiting, and in large doses causes much depression.

The treatment, therefore, is necessarily *symptomatic*. The chief danger is, or is heralded by, suppression, and consequently diuretics have been extensively used.

Terebene, introduced by Dr. Kerr Cross, has been extensively employed, and a considerable number of cases so treated have recovered. In the cases I saw, no effect seemed to follow its use or disuse. In cases of suppression, no rise in the amount of urine has followed its administration. Considering the signs of genito-urinary irritation present in the blackwater stage, a less irritant diuretic would appear to be indicated, but I cannot say that I have seen ill-effects follow its use. In some cases it is said to cause vomiting. Non-irritating diuretics have also been freely used, and recoveries have been numerous.

The simplest form is, perhaps, that of taking large amounts of fluid —plain water, soda water, lemonade, &c.

A treatment frequently practised in the past year was Sternberg's treatment for yellow fever; this was introduced by Dr. Hearsay. Frequent doses of bicarbonate of soda, with minute doses of perchloride of mercury, are given. In some eleven cases so treated there has been little vomiting and no suppression.

It is, in my opinion, worthy of a fuller trial, and is quite harmless. It has not yet been fully tested by a suppression case. It can only be considered as a symptomatic treatment.

In cases where the vomiting has been persistent, morphia has been used hypodermically.

Sulphonal checks the restlessness so common in the disease. No ill-effects have been observed.

Most practitioners make a strong point of "feeding up" the patients, particularly with various meat extracts; they are not necessary, and, considering the large amount of waste products to be excreted, may be injurious. One patient, who recovered from a severe attack, treated himself on lime juice and soda water in large quantities, but had no food at all, "not even milk." In a severe case, stimulants are required later on; too early a resort to them is to be deprecated.

Prophylaxis.—Till the origin of the disease be known it is useless to discuss the question. If the views I hold be correct, it would be bound up with the prophylaxis of malaria. Comparisons between "blackwater fever" and various other diseases have been made.

Yellow fever resembles it in that there is a similar racial susceptibility and immunity, in the variability of the severity and duration of the disease, in the unfavourable prognosis with excessive vomiting, and the fatal augury of suppression.

Apart from bacteriological grounds, blackwater fever is distinctly separated from yellow fever by not being contagious or occurring in an epidemic form.

Paroxysmal hæmoglobinuria has merely the resemblance that hæmoglobin is present in the urine in both. Any attempt to otherwise compare the two fails.

For etiological purposes it is unimportant, as paroxysmal hæmoglobinuria is a disease of great rarity, not markedly more common in the tropics than elsewhere, whilst "blackwater fever" affects a *considerable percentage* of the European population under varied climatic conditions in malarial districts of Africa alone. It occurs but only rarely in other malarial countries, India, British Guiana, West Indies, &c.

With anæmias, including malarial anæmia and cachexias, it has the differences of its short duration, rapid course, and uniform tendency to speedy recovery, unless complications terminating fatally arise.

If kala azar be taken as the type of the malarial cachexia, it would be a secondary fever due to, or accompanied by, chronic visceral nges persisting after the malarial invasions had subsided. Blackwater fever, if a malarial origin were admitted, would have to be considered as a secondary disease characterised by acute temporary hæmolysis, not associated with causative visceral changes, but originating with an abrupt subsidence of a malarial invasion.

With ordinary forms of malaria, including the comatose one, there are no analogies at all.

The nearest perhaps is the “algide” form. In exceptional cases of blackwater fever the onset has been with marked collapse and continued prostration, whilst the urine has not contained large amounts of hæmoglobin. Such a case might be considered as an intermediate form.

In the present state of our knowledge of the disease opinions are of little or no value. The weight of evidence is in favour of a malarial origin. The character and parasitology of the prodromal stage appears to me to be the important period, and is not likely to be worked out till blood examinations in cases of malaria become a routine.

In conclusion, I consider that the balance of evidence is in favour of the view that “blackwater fever” commences in individuals suffering at the time from an invasion by the malaria parasites; but that there is no evidence to show that the attack actually depends on an exceptionally large number of these parasites, an exceptional degree of anæmia or visceral alteration, or on climatic influences or the exhibition of drugs.

What actually determines an attack of “blackwater fever” I am not in a position to state. Before the problem can be solved much more information is required regarding the period immediately preceding the onset of the attack, especially in connection with the parasitology and condition of the blood at that period.

Such data are peculiarly difficult to ascertain, as there is no known means of diagnosing the disease in the prodromal period.

The whole question of malarial sequelæ, including secondary fevers and the causation of visceral changes, requires more investigation, as it has been comparatively neglected since the knowledge of malarial parasitology became general.

The mode of production of immunity, temporary and persistent, is as yet unknown, and also requires much more study.

“Blackwater fever” may be due to some derangement or interruption of such processes, and therefore in our present state of knowledge it is futile to theorise.

Certain manifestations of malaria appear to be more common in some malarial countries than in others, though the parasites appear to be indistinguishable.

It is *possible that* these differences may depend on the different *definitive hosts of the* malaria parasites.

Several species of Anopheles have been proved to carry the malaria parasites. Mr. F. V. Theobald has identified three of the Anopheles found in British Central Africa as three found on the West Coast of Africa; but one, *A. paludis* (Theobald), is in the form of a distinct variety. These mosquitoes have not been found in other countries.

If the prevalence of "blackwater fever" in Africa is due to one or all of these hosts, *Anopheles funestus* must be one of those implicated.

A knowledge of the exact geographical distributions of the various species of malaria-bearing Anopheles is required in this connection, as well as the geographical distribution of "blackwater fever" and of special manifestations of malaria.

Notes.

1. The natives of British Central Africa have the woolly hair of the negro. The features are coarse but not typically negroid, and there are considerable tribal and individual variations in this respect. They are of various shades of colour from brown to black.

The tribes I have had most dealings with are the Yao, Manganja, and Angoni. There is a slight Arab admixture in some districts, and a larger Zulu in others. As a whole they belong to the Bantu division of the African races.

2. Two cases of "blackwater fever" have occurred in persons after arrival in England who had never had blackwater fever during their residence in British Central Africa. They had both had ordinary "fever" in Africa.

3. In early "suppression cases" the anæmia and icterus continue to increase although little or no hæmoglobinuric urine is excreted. The case (Chart 12) under the care of Dr. Gray is the only one I know of in which the number of corpuscles was estimated. Suppression set in within twenty-four hours of the onset of the disease. The number of corpuscles, as determined by Dr. Gray was 3,170,000 on the first day, 2,360,000 on the second, 2,180,000 on the third, and 1,740,000 on the fourth day. During the second, third, and fourth days a total of 4 ounces of urine was passed. The estimates for the next two days were 1,800,000 and 1,630,000 respectively. Suppression continued till death on the tenth day.

4. There appears to be considerable variation in the symptoms associated with suppression in "blackwater fever." In occasional cases, as in some of the suppression cases in yellow fever, the patient is perfectly rational and conscious just before death. The cerebral symptoms that occur are drowsiness, irritability, and sometimes mental weakness or confusion. Delirium during sleep is common. Convulsions are very rare. Coma only occurs, and not always even then, shortly before death. Life is usually prolonged for three or four ys after the onset of suppression, but may be as long as nine days.

There is, as a rule, little disturbance of the special senses, though loss of vision has been complained of. The pupils are in some cases dilated. Deafness is common only in cases treated by quinine.

There is steady loss of muscular strength in most cases, but not in all. Muscular twitchings are usually absent, even to the last. As a rule there is much vomiting, and often hiccough.

Occasionally a “uræmic smell” has been noted, but this is not usual. Anasarca does not occur. The urine may be free from albumin towards the end.

ILLUSTRATIVE TEMPERATURE CHARTS (pp. 64–77).

Chart 1.—“Blackwater fever.” Mild attack. Prodromal period taken for ordinary malarial attack, and parasites found.

Onset without rigor.

Post-hæmoglobinuric pyrexia.

The charts in three previous attacks of malaria and one subsequent attack attached.

„ 2.—“Blackwater fever.” Severe attack. This followed repeated attacks of fever for a period of three months.

The day before the attack “fever” taken to be ordinary malaria. Parasites found in fair numbers.

No complications. Post-hæmoglobinuric pyrexia very slight.

„ 3.—“Blackwater fever.” Severe attack.

Prolonged and severe post-hæmoglobinuric pyrexia not markedly affected by quinine in considerable doses.

„ 4.—“Blackwater fever.” Severe attack.

Prolonged and severe post-hæmoglobinuric pyrexia.

Treatment mainly by phenacetin. Temporary effect of this drug followed in some instances by a higher rise.

In this case there was an intermission in the hæmoglobinuria, during this intermission parasites were found.

Quinine *not* given during the intermission; if it had been it would, according to custom, have been given when the temperature was down only (*), *i.e.*, in this case about five hours before the relapse.

„ 5.—“Blackwater fever.” More continuous form of post-hæmoglobinuric pyrexia.

„ 6.—“Blackwater fever.” Mild attack.

No post-hæmoglobinuric pyrexia.

„ 7.—(Indian) “Blackwater fever.” Patient was under treatment for enlarged spleen, anæmia, and chronic “fever,” secondary malarial fever (?).

Unusually slight pyrexial disturbance, either before, during, or after the hæmoglubinuric period. I can find no record of a case similar in these respects.

„ 8.—“Blackwater fever.” Medium severity. Prodromal period not marked by definite illness, as patient was able to live an ordinary life. Temperature was taken night before the attack and found to be raised, 105° F.

Post-hæmoglobinuric pyrexia moderate. Very little treatment. Good effect of an occasional dose of phenacetin (?).

Chart 9.—"Blackwater fever." Two attacks in same person at an interval of four months. Good health in between.

Last attack came on about eight days after last dose of quinine.

Second attack came on about twelve hours after last dose of quinine.

Charts 10 & 11.—"Blackwater fever." Attacks not severe, but *hyperpyrexia* in post-hæmoglobinuric period.

Chart 12.—"Blackwater fever." Suppression of urine. Fatal.

Followed untreated malaria. No quinine taken for a fortnight.

Post-hæmoglobinuric pyrexia appears to be rare in suppression cases.

„ 13.—"Blackwater fever." Severe case followed by acute lobar pneumonia.

No definite marked prodromal period. Malaise only. Temperature not taken. Post-mortem showed pigment disposed as in recent malaria.

„ 14.—"Blackwater fever." Relapse occurring on the third day before the urine had quite cleared.

According to the usual local rule for the administration of quinine, it might have been taken on the morning of the second day, but more probably would not have been taken till the third day, in which case the relapse would have been attributed to the quinine. None was taken.

„ 15.—"Blackwater fever." Series of relapses. The early ones of short duration and methæmoglobin only in the urine. The final attack was hæmoglobinuric and came on before the urine was quite free from methæmoglobin. Hepatic pain a marked feature, both of the early attacks and also in the rises of temperature in the post-hæmoglobinuric period.

Quinine, according to usage, would have been taken on the second and third days (*), and the relapses then would have been attributed to it. None was taken.

Probably the patient's temperature was also down on the first day of the chart, as he was out.

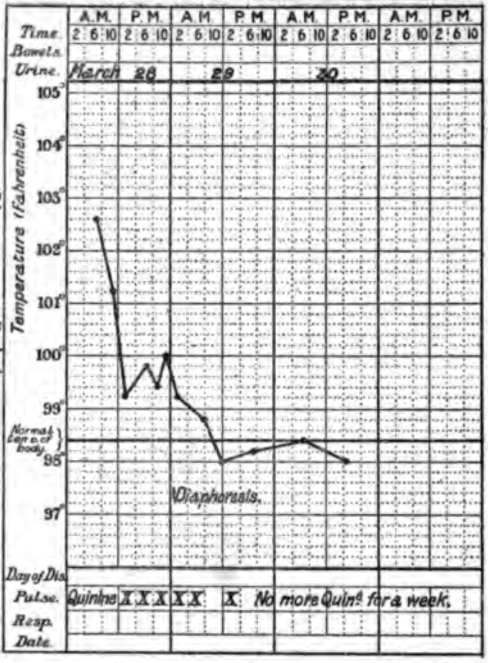
In this case there was hardly any vomiting.

(a) DISEASE
Malarial Fev

NOTES OF CA

Chart I.

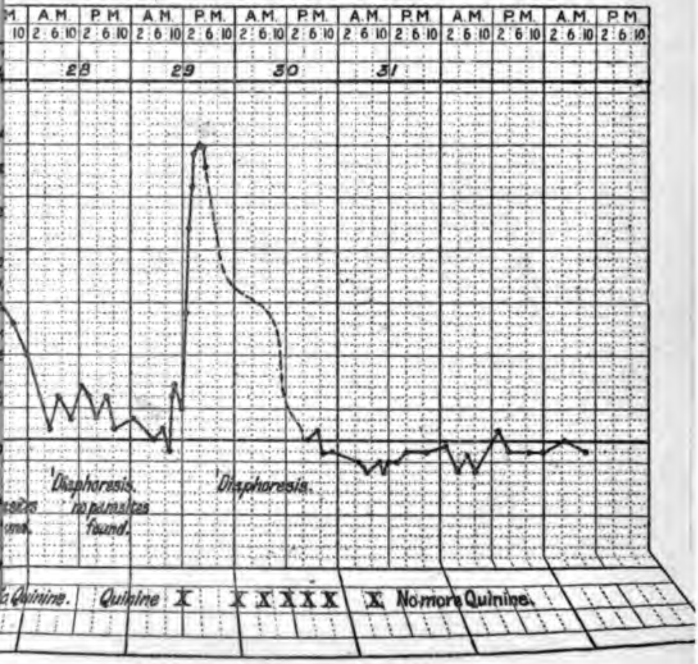
10th, 11th, & 12th, a
Malarial Fever, t
in recovery withou
symptoms.
13th attack & du
course "Blackwat
A subsequent P
Fever non-mal
14th attack of M
Fever, one cycle
the second trea
Quinine.
No definite subs
attacks in next



(c) DISEASE
Blackwater F
1st attack
Name D.
NOTES OF C

Frequent short a
fever in previous
all treated ene
with Quinine.
Last attack of "F
28th. An interval o
the longest sinc
Health in interv
considerable la
want of appetite,
never found to b
normal.
Quinine gr. X. two
before onset of
Onset of "Blackw
severe abdominal,
pain. Relieved by
vomiting. No rigo

RESULT Reco



DISEASE.

Blackwater Fever
1st attack.
Under care of Dr. Hearsay.
Name. W.
Age. 27.

NOTES OF CASE.

Chart 2.

First had fever three months ago, since then has had it about every other week.

Had 3 days fever 12 days before, and the 2 days before this attack.

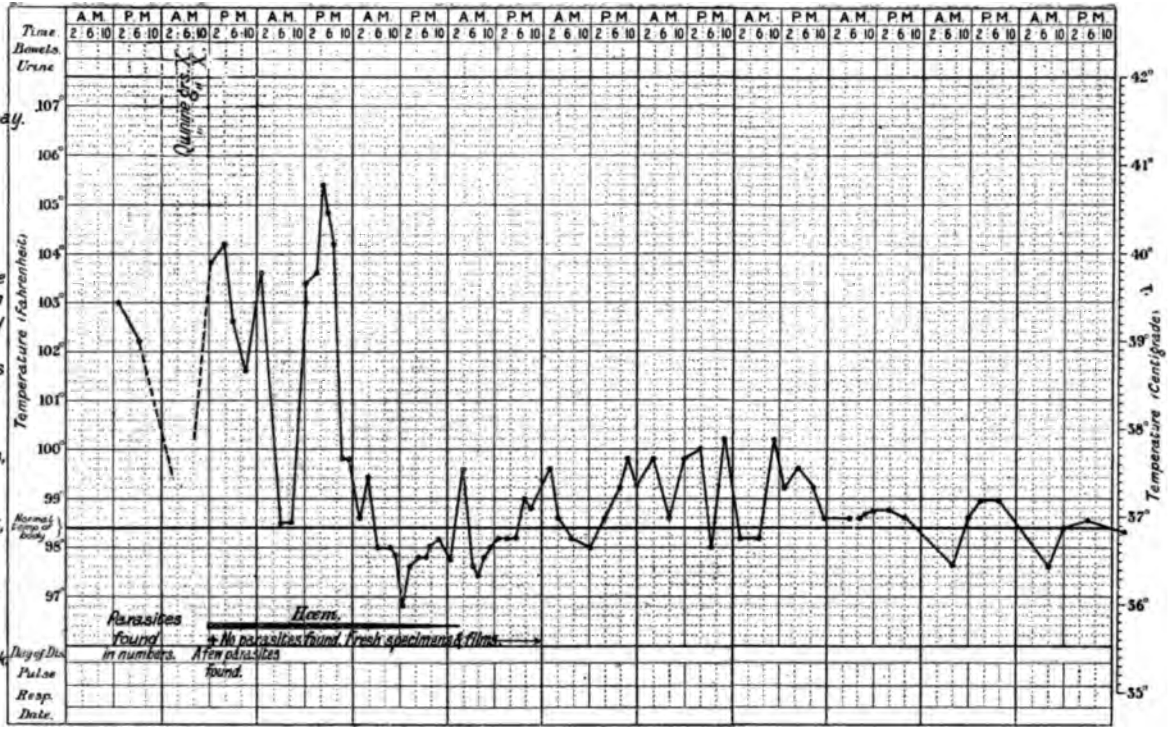
Has taken 250 grs. of quinine in the 3 months, but never as much as 20 grs. in a day.

Treatment after onset, Sodium Bicarbonate & Liq. Hydrarg. Perchlor.

Herpes Preputialis during convalescence.

Was free from "fever" for some weeks after the attack.

RESULT Recovery.



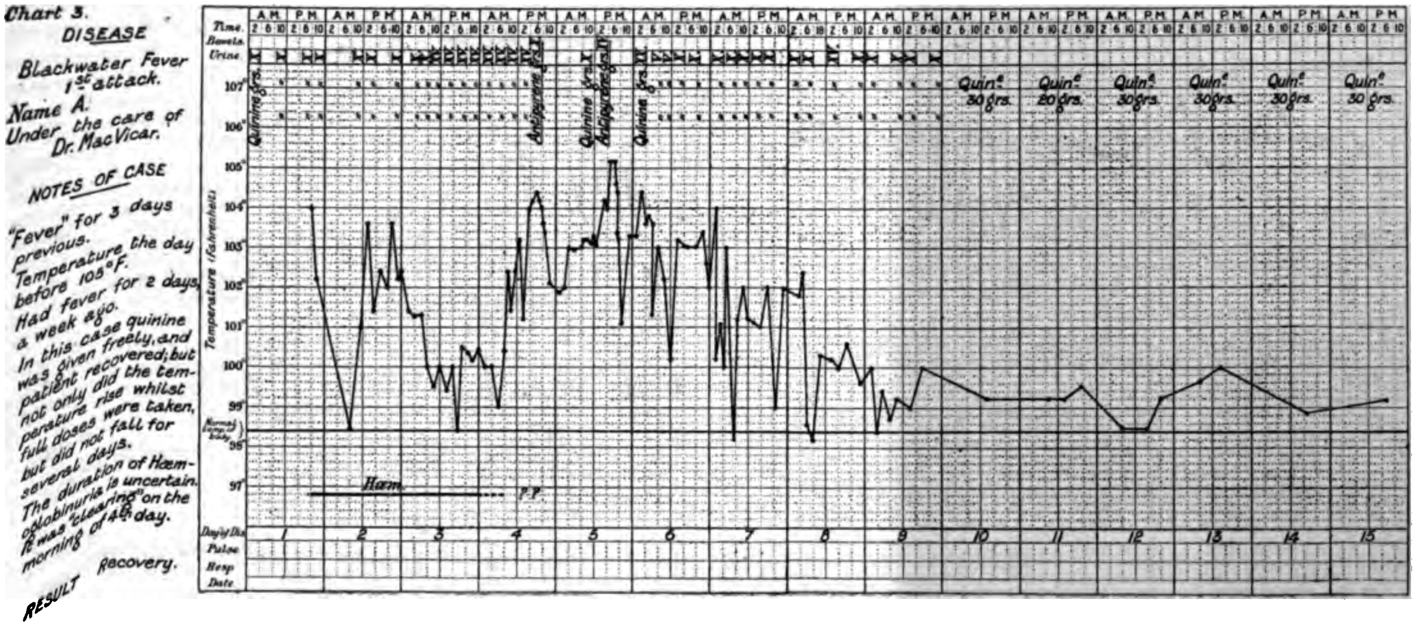


Chart 3.
DISEASE
Blackwater Fever
1st attack.
Name A.
Under the care of
Dr. MacVicar.
NOTES OF CASE
"Fever" for 3 days previous.
Temperature the day before 105°F.
Had fever for 2 days a week ago.
In this case quinine was given freely, and patient recovered; but not only did the temperature rise whilst full doses were taken, but did not fall for several days.
The duration of Hæmoglobinuria is uncertain. It was "clearing" on the morning of 4th day.
RESULT Recovery.
Time.
Bowels.
Urine.
A.M.
P.M.
2 6 10
Temperature (Fahrenheit)
107°
106°
105°
104°
103°
102°
101°
100°
99°
Normal
98°
97°
Day of Dis.
Pulse
Resp
Date
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Quinine grs.
Antipyrene grs. X
Quinine grs. X
Antipyrene grs. XV
Quinine grs. XV
Hæm.
P.P.
Quin.e 30 grs.
Quin.e 20 grs.
Quin.e 30 grs.
Quin.e 30 grs.
Quin.e 30 grs.
Quin.e 30 grs.

[redacted]

DISEASE.

Blackwater Fever
1st attack.
Under care of Dr. Hearsay.
Name. W.
Age. 27.

NOTES OF CASE.

Chart 2.

First had fever three months ago, since then has had it about every other week.

Had 3 days fever 12 days before, and the 2 days before this attack.

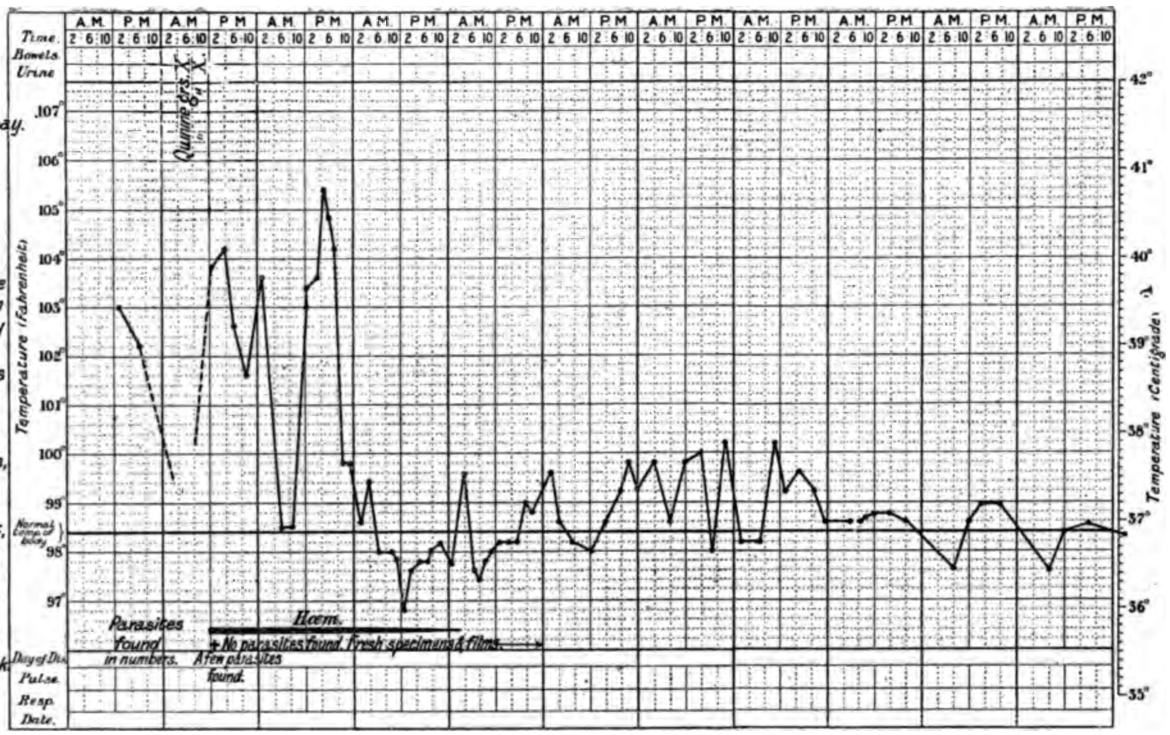
Has taken 250 grs. of quinine in the 3 months, but never as much as 20 grs. in a day.

Treatment after onset, Sodium Bicarbonate & Liq. Hydrarg. Perchlor.

Herpes Preputialis during convalescence.

Was free from "fever" for some weeks after the attack.

RESULT Recovery.



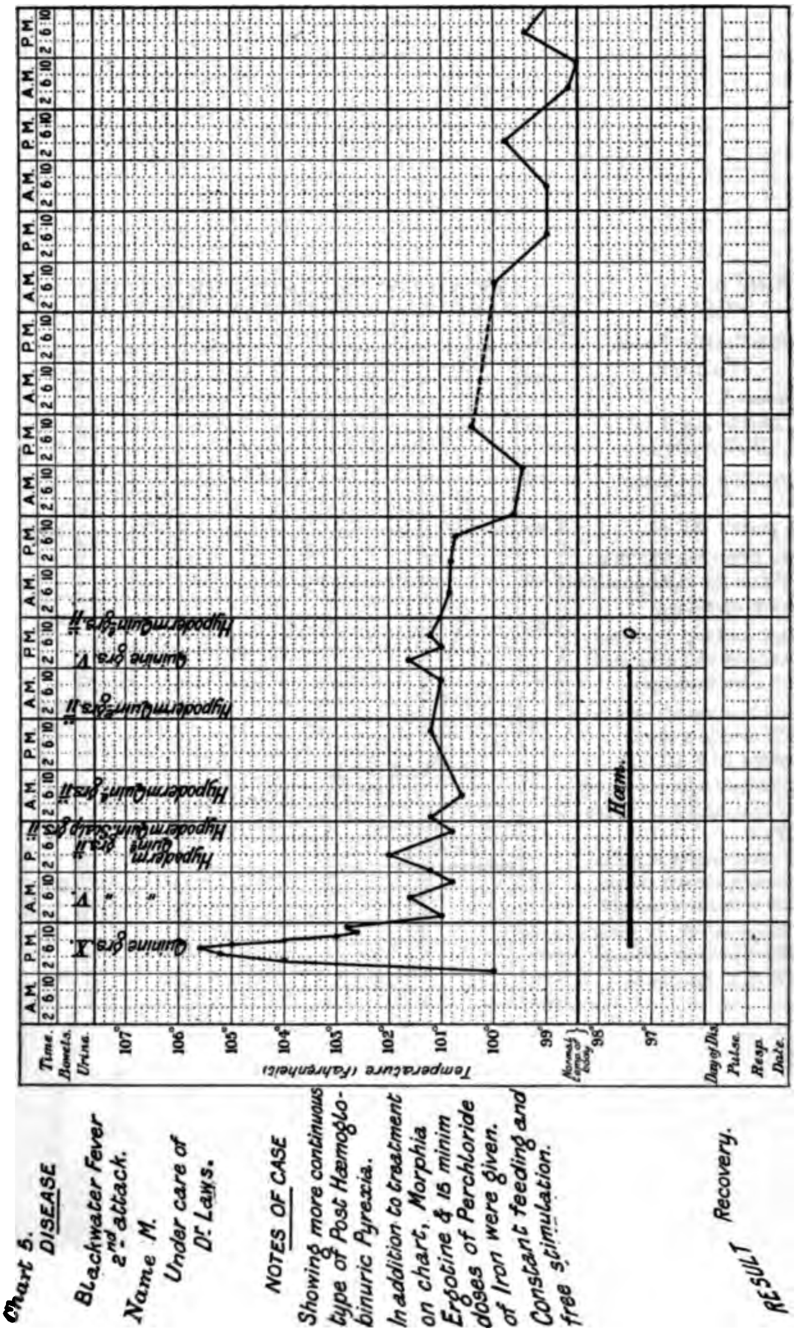


Chart 5.

DISEASE

Blackwater Fever 2nd attack.

Name M.

Under care of Dr Laws.

NOTES OF CASE

Showing more continuous type of Post Hæmoglobinuric Pyrexia.

In addition to treatment on chart, Morphia Ergotine & 15 minim doses of Perchloride of Iron were given. Constant feeding and free stimulation.

RESULT Recovery.

Chart 6.
DISEASE
Blackwater Fever
1st attack.
Name B.
Under care of
Dr. Kerr Cross.

NOTES OF CASE

2½ years B.C.A.
Had been having fever off & on for 10 days with much vomiting.
Was taking quinine 15-30 grs. in a day, but not continuously.
Had temperatures of 101°F. on the 2 days before the attack.
No definite rigor at onset but one about 10 hours after.
No complications but convalescence slow.
Had crescent about 12 days after. No parasites found in attack.
RESULT Recovery.

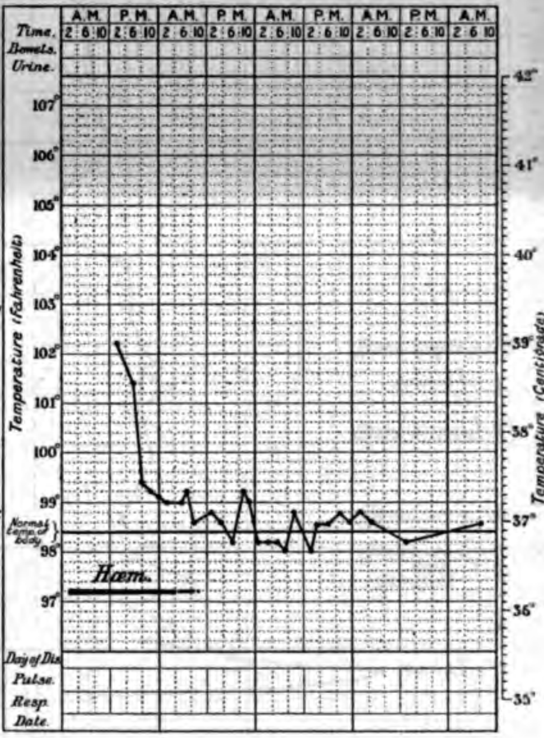


Chart 7.

DISEASE

"Blackwater Fever"

Name C.S.

Under the care of
Dr. Hearsay.

NOTES OF CASE

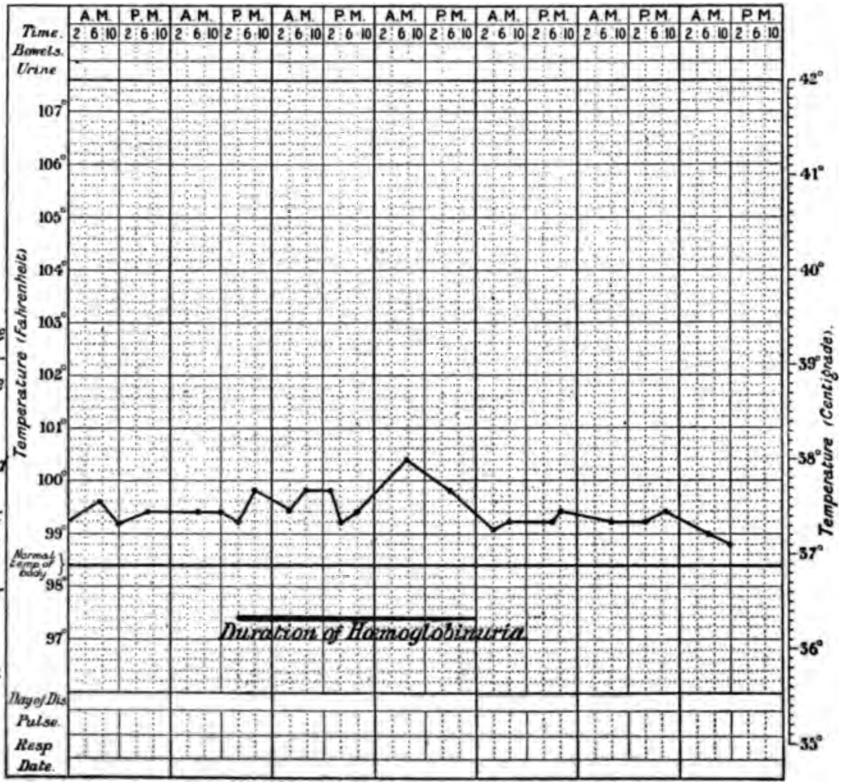
Sikh. Anæmia and
, enlarged Spleen.

The case is remarkable for the very slight disturbance in temperature during the period of Hæmoglobinuria.

There was low continued fever before, during, & after the Blackwater.

No parasites found in films taken during & after the Blackwater Period.

Treatment:-
Bicarbonate of Soda
& Liq. Hyd. Perchlor.



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rt 8.

DISEASE

Blackwater Fever
1st attack.

Name C.
Under the care of
Dr Hearsay.

NOTES OF CASE

Had been having "fever" off & on for some time. Resident in Shiré Highlands & only left there 2 days before attack. Appeared in fair health day before attack, but at night his temperature was up & he took X grs. quine. Rigor initial. Moderate vomiting.

Treatment:-
Sodium Bicarbonate,
& Liq. Hydrarg. Perchlor.
No parasites found.
Pigmented Leucocytes.

RESULT Recovery.

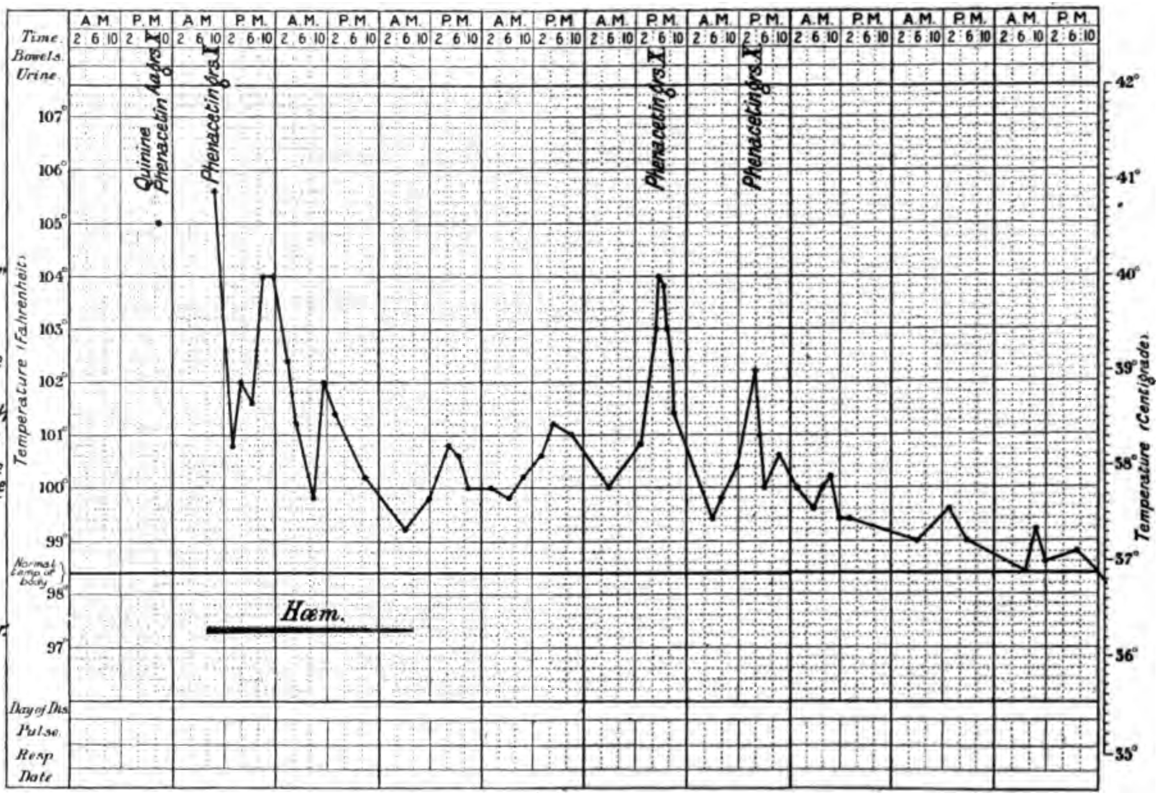


Chart 9.

DISEASE

Blackwater Fever
1st attack.

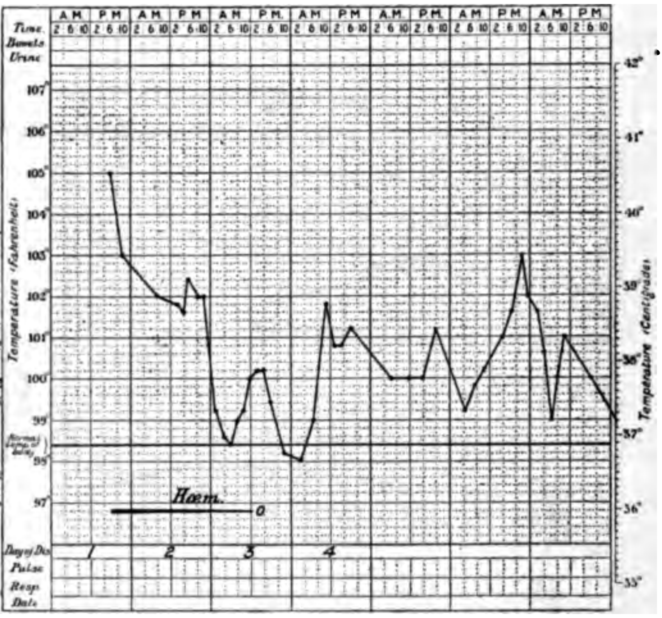
Name S.

Under care of
Dr Gray.

NOTES OF CASE

3 1/12 years in B.C.A. Had very little fever after 1st year, been most of the time in Angoni & Shire Highlands.
Not a quinine taker, but took 5 grs. rather more than a week ago.
"Fever" the day before the attack, as well as the same day.
Initial Rigor.
Treatment:-
Liq. Hydrarg. Perchlor. & Sodm. Bicarb. at first, & then Terebine.

RESULT Recovery.



DISEASE

Blackwater Fever
2nd attack.

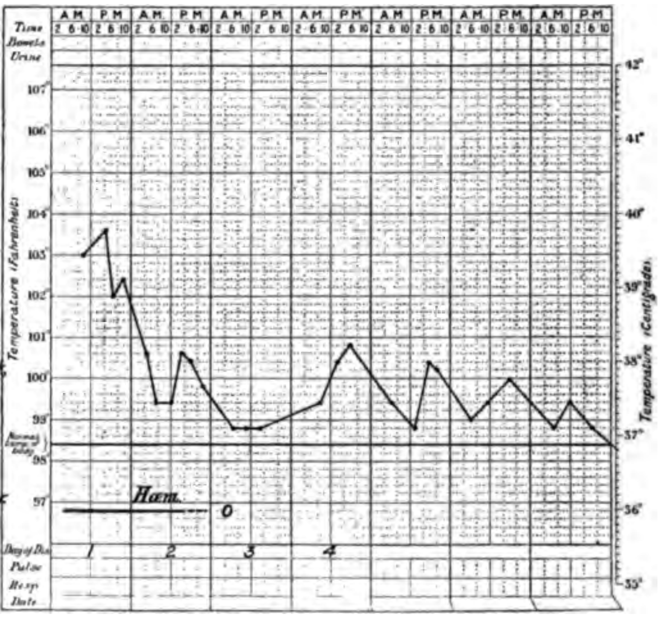
Name S.

Under the care of
Dr Hearsay.

NOTES OF CASE

Previous attack 4 months ago. Since then has had good health.
Fever for 3 hours every day.
Last quinine grs. X, 12 hours before attack, & Antipyrine grs. V, 4 hours before.
Initial Rigors.
Treatment:-
Sodm. Bicarb. & Liq. Hydrarg. Perchlor.

RESULT Recovery.



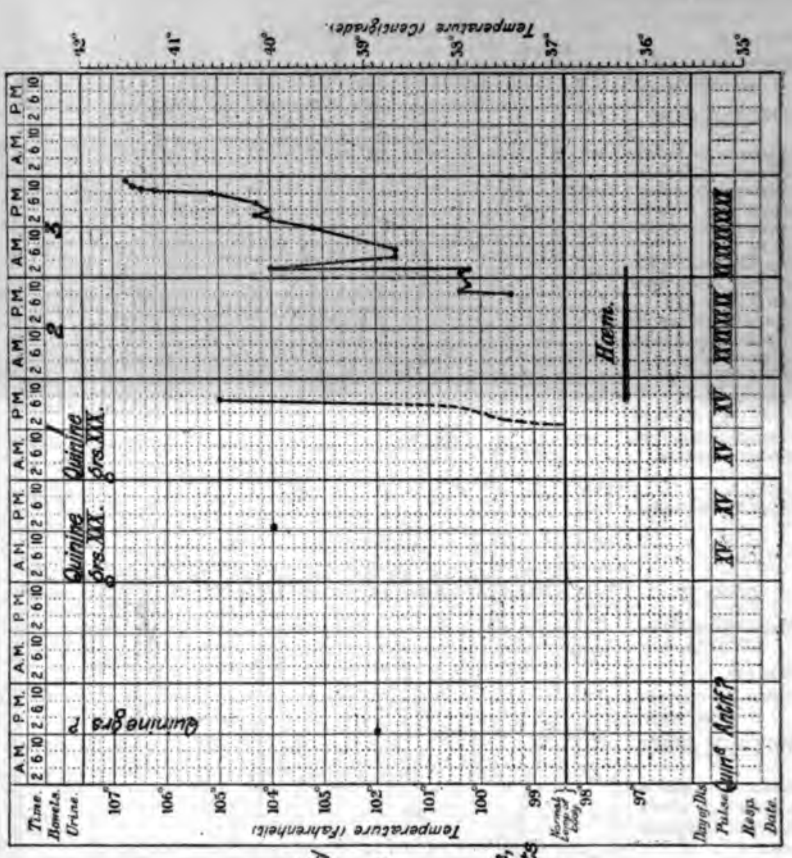


Chart 10.
DISEASE

Blackwater Fever
1st attack.
Hyperpyrexia.

Name R.B.

Under care of
Dr. Mac Vicar.

NOTES OF CASE

Nine years in B.C.A. Strong, full-blooded man.

Fever for 3 days, but felt better on 2nd day & was able to travel.

In addition to Quinine, digitalis & stimulants freely administered.

Chart II.

DISEASE

Blackwater Fever
Hyperpyrexia.
Name J.B.
Under care of
M.O. Blantyre Mission.

NOTES OF CASE

Had Blackwater Jan. 3rd & 4th under 48 hrs. Temperature 104°fell about a degree daily from 5th. On 10th (M) 99°F. Rigor in afternoon & again passed Blackwater. Urine cleared in about 24 hours. Temperature was never normal but fell gradually. From 14th-17th was treated with every available antipyretic. Cold bath alone had any success.

RESULT Died.

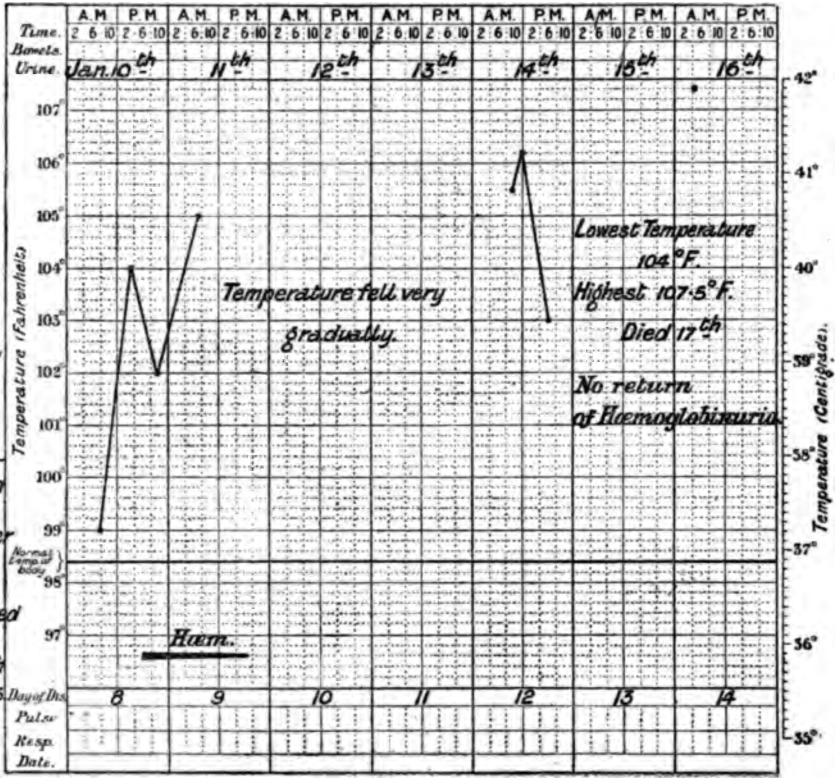
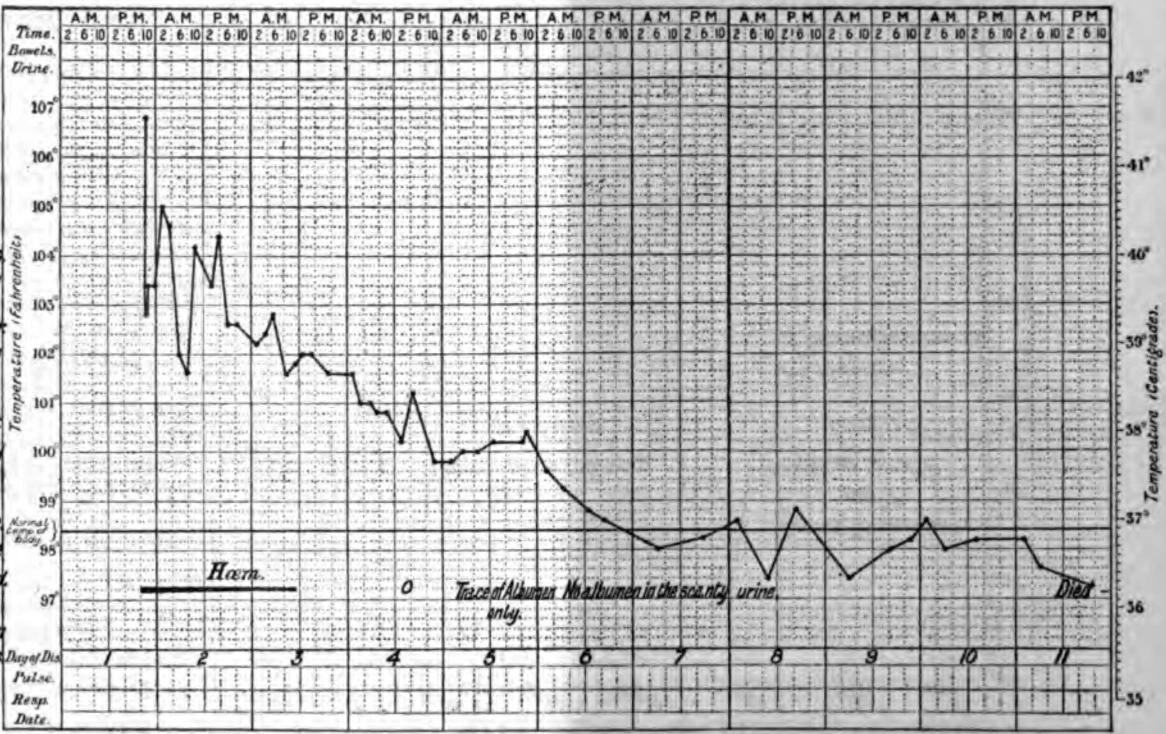


Chart 12.
DISEASE

Blackwater Fever.
Suppression.
Name C.M.
Under the care of
Dr. Gray P.M.O.

NOTES OF CASE

Has been in B.C.A. 7 years.
Led an irregular life with much exposure.
Not had very much fever.
Had fever a fortnight ago following exposure.
Since then had several attacks. Was about, but not feeling well the day of the attack.
No quinine for a fortnight, & then only a small dose.
His attacks of "fever" since then have been untreated.
Terebine Treatment.
Much vomiting. Suppression (incomplete) within 24 hrs of the onset.
Severe Epistaxis.



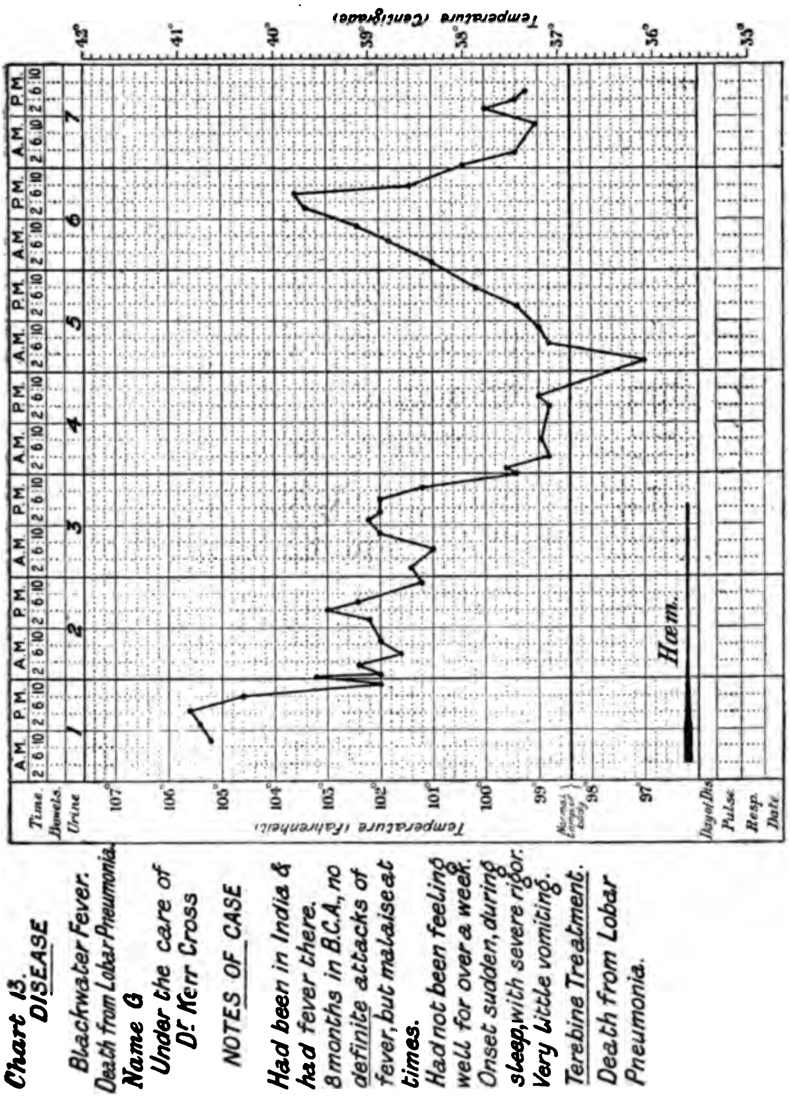


Chart 13.
DISEASE
Blackwater Fever.
Death from Lobar Pneumonia.
Name G
Under the care of Dr Kerr Cross
NOTES OF CASE
Had been in India & had fever there.
8 months in B.C.A., no definite attacks of fever, but malaise at times.
Had not been feeling well for over a week.
Onset sudden, during sleep, with severe rigor.
Very little vomiting.
Terebine Treatment.
Death from Lobar Pneumonia.
Time
Bowels
Urine
A.M.
P.M.
2 6 10
1
2
3
4
5
6
7
Temperature (Fahrenheit)
107°
106°
105°
104°
103°
102°
101°
100°
99°
Normal Temperature 98.4
98°
97°
Hæm.
Days of Dis.
Pulse
Resp.
Date
Temperature (Centigrade)
42°
41°
40°
39°
38°
37°
36°
35°

Chart 14.

DISEASE

Blackwater Fever
3rd attack.

Name R.

Under care of
Dr Hearsay.

NOTES OF CASE

Previous attacks 16 months & 32 months ago. Has had much fever. Parasitic invasions sometimes large. Day previous to Blackwater was up & about but felt ill in afternoon & went to bed. Took antifebrin & later a large dose of quinine ? 25 grs. Rigor initial. Vomiting slight.

Urine was clearing rapidly on the 3rd day but again became quite dark in evening.

No parasites found, but pigd leucocytes in films on 3rd day.

Treatment:–
Bicarbonate of Soda, & Lig. Hydrarg. Perchlor.

ESULT Recovery.

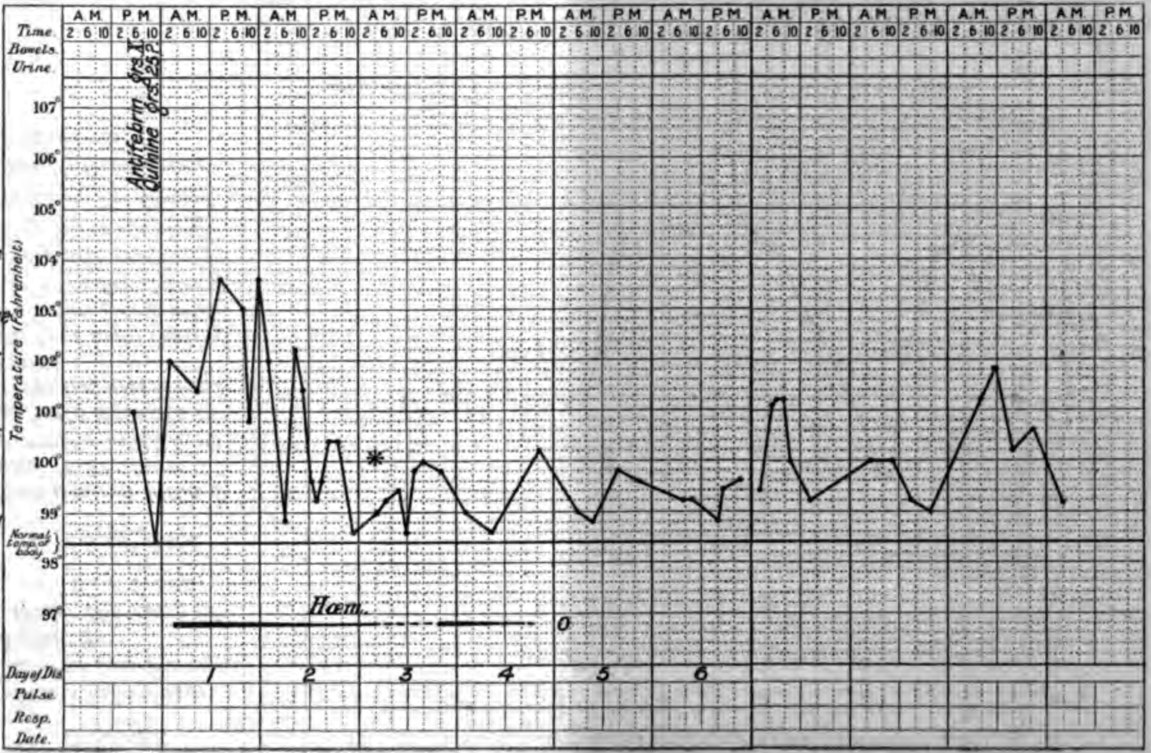


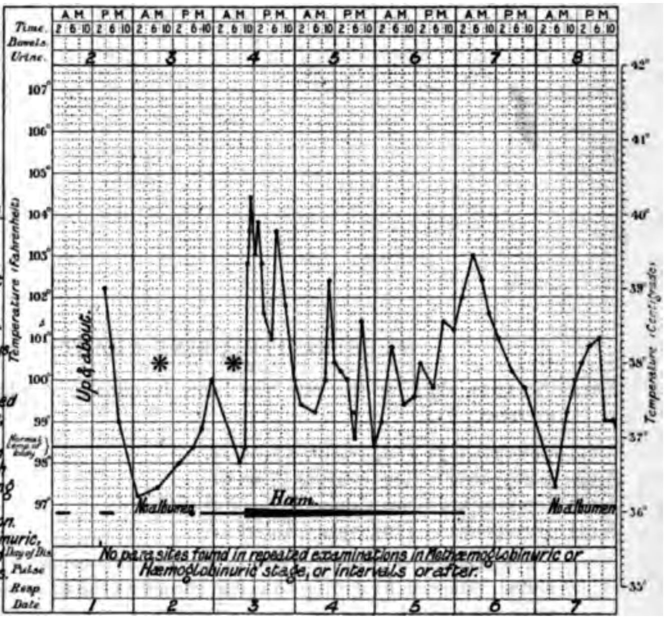
Chart 15.

DISEASE

"Blackwater Fever"
1st attack.
Name H.
Under the care of.
Dr Gray P.M.O.

NOTES OF CASE

Been 1 yr. 10 mths. in B.C.A. Had a good deal of fever & at one time took fair doses of Quinine. Of late has taken little, & the last time was 3 or 4 days before onset.
Passed "brown" urine in night having had fever for 2 days. Urine clear in morning & he went out but had to return. In afternoon passed "brown" urine, Methæmoglobin, it again cleared.
Following afternoon again passed Methæmoglobin which continued till the following morning when there was a sudden change in his condition. Next urine passed Hæmoglobinuric, so dark that it was estimated that it would persist 2½-3 days. Pain Hepatic not Renal.



No parasites found in repeated examinations in Methæmoglobinuric or Hæmoglobinuric stage, or intervals or after.

ILLUSTRATIVE URINE CHARTS.

URINE CHARTS, showing the rate per hour, in ounces, at which the urine is excreted.

A (1) corresponds to Temperature Chart 13.
A (2) corresponds to Temperature Chart 6.
A (3) Temperature Chart similar to 6. Not given.
A (4) corresponds to Temperature Chart 1.

These charts show an increase in the amount during the hæmoglobinuric period, followed by a drop to below normal as the urine clears, and a slow return to normal.

B. (Corresponding to Temperature Chart 8.) Merely slight increase in the rate during the hæmoglobinuric period. No marked drop as the urine cleared.

C. (Corresponding to Temperature Chart 2.) There is a decided fall in the amount passed in the first twenty-four hours; (?) indicating a tendency to early suppression, followed by a great increase in the second twenty-four hours, and a subsequent fall as the urine cleared.

The first fall was not due to *retention* of urine.

D. (Corresponding to Temperature Chart 12.) Suppression case. The amounts passed after the first twenty-four hours are too small to be indicated on this scale.

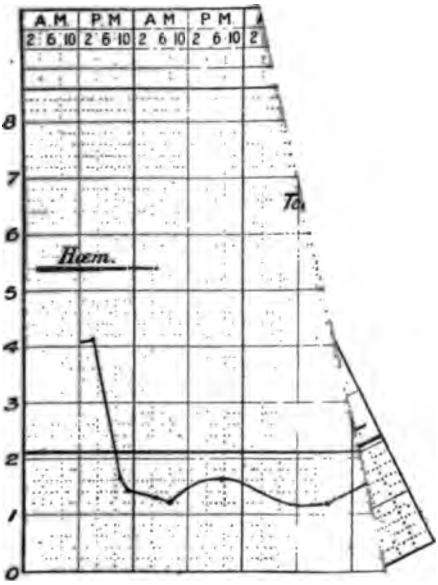
E. (Corresponding to Temperature Chart 15.)

Urine

Indicating
excretion
ounces per

The thick l
indicates th
the Hæmog

was
he

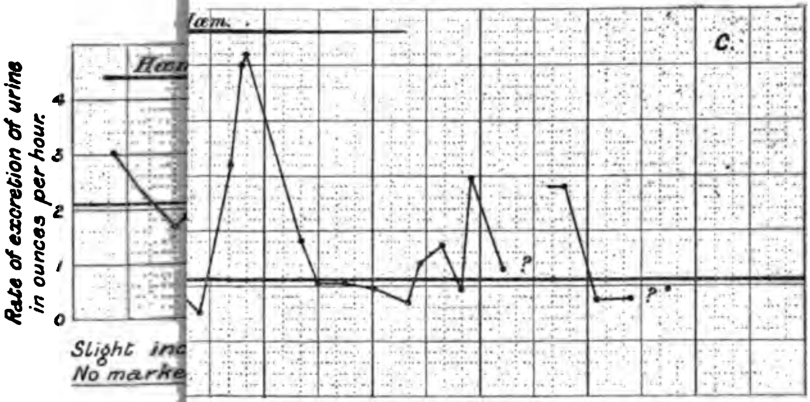


.t

:

e.

C. vide Temperature Chart 2.

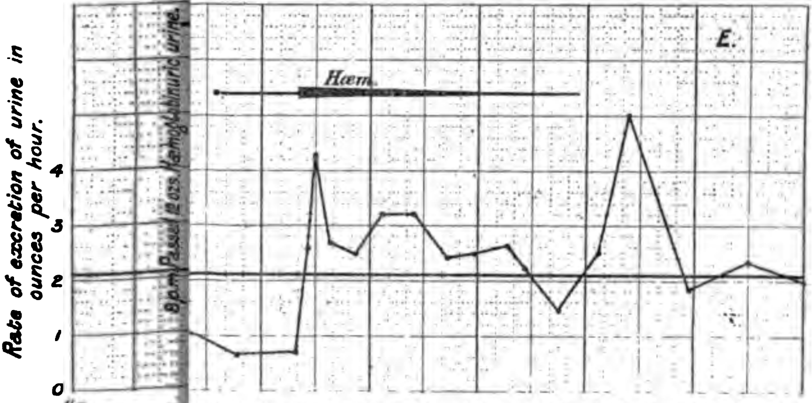


Slight inc

No marke

he amount of urine excreted. During the time that the rate was
very frequent micturition. No retention. Great increase in the
of excretion followed this period.
below normal as the urine cleared.
rease in the rate of excretion. From more imperfect notes of
gather that such a subsequent rise is common.

E. vide Temperature Chart 15.



"Suppress thick horizontal line the urine contained Methæmoglobin at
first sym sponding to the thinner horizontal lines.
the first cretion at first high, fell as the urine cleared; it did not rise
The pati of Methæmoglobin again, but did with the onset of
a.
the urine cleared, followed by a marked subsequent increase.