SUGGESTIONS ON THE CLASSIFICATION OF THE VARIOUS SPECIES OF HEAVENLY BODIES.[1]

III.

III.—SUB-GROUPS AND SPECIES OF GROUP I.

I. SUB-GROUP. NEBULÆ.

HAVING, in the preceding part of this memoir, attempted to give a general idea of that grouping of celestial bodies which in my opinion best accords with our present knowledge, and which has been based upon the assumed meteoric origin of all of them, I now proceed to test the hypothesis further by showing how it bears the strain put upon it when, in addition to furnishing us with a general grouping, it is used to indicate how the groups should be still further divided, and what specific differences may be expected.

The presence or absence of carbon will divide this group into two main sub-groups.

The first will contain the nebulæ, in which only the spectrum of the meteoric constituents is observed with or without the spectrum of hydrogen added.

It will also contain those bodies in which the nebula spectrum gets almost masked by a continuous one, such as Comets 1866 and 1867, and the great nebula in Andromeda.

In the second sub groups will be more condensed swarms still, in which, one by one, new lines are added to the spectra, and carbon makes its appearance; while probably the last species in this sub group would be bodies represented by γ Cassiopeiæ.

Species of Nebulæ.

I have elsewhere referred to the extreme difficulty of the spectroscopic discrimination in the case of the meteor-swarms which are just passing from the first stage of condensation, and it may well be that we shall have to wait for many years before a true spectroscopic classification of the various aggregations which I have indicated, can be made.

It is clear, then, from what has gone before that in each stage of evolution there will be very various surfaces and loci of collisions in certain parts of all the swarms, and we have already seen that even in the nebulosities discovered by Sir Wm. Herschel, which represent possibly a very inchoate condition, there are bright portions here and there.

If the conditions are such in the highly elaborated swarms and in the nebulosity that the number of collisions in any region per cubic million miles is identical, the spectroscope will give us the same result. In the classification of the nebulæ, therefore, the spectroscope must cede to the telescope when the dynamical laws, which must influence the interior movements of meteoric swarms, have been fully worked out. The spectroscope, however, is certainly at one with the telescope in pointing out that so-called planetary nebulæ are among the very earliest forms—those in which the collisions are most restricted in the colliding regions. The colour of these bodies is blue tinged with green; they do not appear to have that milkiness which generally attaches to nebulæ, and the bright nebulous lines are seen in some cases absolutely without any trace of continuous spectrum. In higher stages the continuous spectrum comes in, and in higher stages still possibly also the bands of carbon; for in many cases Dr. Huggins in his important observations has recorded the weakness of the spectrum in the red, or in other words the strengthening of the spectrum in the green and blue exactly where the carbon bands lie.

But in all the bodies of Group I. which possess forms visible to us in the telescope, it would seem proper that their classification should depend mainly—at present at all events—upon their telescopic appearance, and there is very little doubt that a few years' labour with the new point of view in the mind of observers armed with sufficient optical power, will enable us to make a tremendous stride in this direction; but it seems already that this must not be done without spectroscopic aid. For instance, if what I have previously suggested as to the possible origin of the planetary nebulæ be accepted, it is clear that in those which give us the purest spectrum of lines, one in which there is the minimum of continuous spectrum, we find the starting-point of the combined telescopic and spectroscopic classification, and the line to be followed will be that in which, *cæteris paribus*, we get proofs of more and more condensation, and therefore more and more collisions, and therefore higher and higher temperatures, and therefore greater complexity in the spectrum until at length true stars are reached.

When true stars are reached those of the cluster appear nebulous in the telescope in consequence of its distance; the spectroscope must give us indications by absorption.

It is not necessary in this connection, therefore, to refer to undoubted star clusters, as the presence of absorption will place them in another group; but the remark may be made that it is not likely that future research will indicate that new groupings of stars, such as Sir Wm. Herschel suggests in his paper on the breaking up of the Milky Way, will differ in any essential particular from the successive groupings of meteorites which are watched in the nebulæ. Space and gravitation being as they are, it is not necessary to assume that any difference of kind need exist in the method of grouping formed stars and meteoric dust; indeed there is much evidence to the contrary.

II. SUB-GROUP. BRIGHT-LINE STARS.

It might appear at first sight that the distribution of bright-line stars among various species should be very easy, since a constant rise of temperature should bring out more and more lines, so that the species might be based upon complexity of spectrum merely.

But this is not so, for the reason that the few observations already recorded, although they point to the existence of carbon bands, do not enable us to say exactly how far the masking process is valid. Hence in the present communication I content myself by giving some details relating to maskings, and the results of the discussions, so far as they have gone, in the case of each star. I shall return to the line of evolution in a later paper.

Masking of Radiation Effects produced by Variations of Interspacing.

I have already stated that carbon bands are apt to mask the appearance of other spectral phenomena in the region of the spectrum in which they lie. In this way we can not only account for the apparent absence of the first manganese fluting, while the second one is visible, but it is even possible to use this method to determine which bands of carbon are actually present. There is another kind of masking effect produced in a different way, and this shows itself in connection with sodium. It is well known that when the temperature is low, D is seen alone, and if seen in connection with continuous spectrum the continuous spectrum is crossed by either dark or bright D, according to the existing circumstances.

I showed some years ago that the green line of sodium, not the red one, is really visible when sodium is burned in the bunsen burner. It is, however, very much brighter when higher temperatures are used, although when bright it does not absorb in the way the line D does.

Now, if we imagine a swarm of meteorites such that in the line of sight the areas of meteorite and interspace are

[1] The Bakerian Lecture, delivered at the Royal Society on April 12, by J. Norman Lockyer, F.R.S. Continued from vol. xxxvii. p. 609.

equal, half the area will show D absorbed, and the other half D bright; and in the resulting spectrum D will have disappeared, on account of the equality, or nearly equality, of the radiation added to the absorption of the continuous spectrum. The light from the interspace just fills up and obliterates the absorption.

But if the temperature is such that the green line is seen as well as D; in consequence of its poor absorbing effect there will be no dark line corresponding to it in the resulting spectrum, but the bright green line from the interspace will be superposed on the continuous spectrum, and we shall get the apparently paradoxical result of the green line of sodium visible while D is absent. This condition can easily be reproduced in the laboratory by volatilizing a small piece of sodium—between the poles of an electric lamp. The green line will be seen bright, while D is very dark.

In the bodies in which these phenomena apparently occur—for so far I have found no other origin for the lines recorded 569, 570, and 571—the wave-length of the green sodium line being 5687, such as Wolf and Rayet's three stars in Cygnus and in γ Argûs, the continuous variability of D is one of the facts most clearly demonstrated by the observations, and it is obvious that this should follow if from any cause any variation takes place in the distance between the meteorites.

In all meteoric glows which have been observed in the laboratory, not only D but the green line have been seen constantly bright, while we know in Comet Wells most of the luminosity at a certain stage of the comet's history was produced by sodium. It is therefore extremely probable that the view above put forward must be taken as an explanation of the absence of D when not seen, rather than an abnormal chemical constitution of the meteorites—that is to say, one in which sodium is absent. This may even explain the fact that up to the present time the D line of sodium has not been recorded in the spectrum of any nebula.[1]

Detailed Discussion of the Spectra of some Bright-Line Stars.

These things then being premised, I now submit some maps illustrating this part of the inquiry, although it will be some time before my investigations on the bright-line stars are finished. These maps will indicate the way in which the problem is being attacked, and the results already obtained. To help us in the work we have first of all those lines of substances known to exist in meteorites which are visible at the lowest temperatures which we can command in the laboratory. We have also the results of the carbon work to which reference was made in the previous paper; and then we have the lines which have been seen, although their wave-lengths have in no case been absolutely determined, in consequence of the extreme difficulty of the observation, both in stars and in comets, which I hold to be almost identical in structure.

In the case of each star the lines which have been recorded in its spectrum are plotted in the way indicated in the maps. The general result is that when we take into account the low temperature radiation, which we learn from the laboratory work, not only can we account for the existence of the lines which have been observed, but apparent absorptions in many cases are shown to be coincident with the part of the spectrum in front of a bright carbon fluting.

[1] In the lecture the author here referred to the spectrum of o Ceti, as photographed by Prof. Pickering for the Henry Draper Memorial, the slide having been kindly placed at his disposal by the Council of the Royal Astronomical Society. All the bright hydrogen lines in the violet and ultra-violet are shown in the photograph; with the exception of the one which is nearly coincident with H. The apparent absence of this line is in all probability due to the masking effect of the absorption-line of calcium. In this case, then, it appears that the calcium vapour is outside the hot hydrogen, and this therefore was being given off by the meteorites at the time.

A continuation of this line of thought shows us also that, when in these stars the spectrum is seen far into the blue, the luminosity really proceeds first from the carbon fluting, and in the hotter stars, from the hydrocarbon one in addition, which is still more refrangible. In the stars which have been examined so far, the dark parts of the spectrum, which at first sight appear due to absorption, are shown to be most likely caused by the gap in the radiation in that part of the spectrum where there is no continuous spectrum from the meteorites, and no bright band of carbon.

All the observations, it would appear, can be explained on the assumption of low temperature.

Notes on the Maps.

Lalande 13412.—Both Vogel and Pickering have observed the spectrum of this star and have measured the wave-lengths of the bright lines.

Vogel gives a sketch of the spectrum as well as a list of wave-lengths.

Vogel mentions a dark band at the blue end of the spectrum, and gives the wave-length in his sketch as from 486 to 473.

Both observers measure the bright 486 hydrogen (F) line.

Vogel measures a bright line at 540, while Pickering's measure is 545; but Pickering in another star, Arg.-Oeltzen 17681, has measured this line at 540, so there can be little doubt that is the correct wave-length.

Vogel measures a line at 581, but this has not been noticed by Pickering.

The bright part of the spectrum extending from 473 towards the blue with its maximum at 468 is, I would suggest, the carbon band appearing beyond the continuous spectrum, the rest of the carbon being cut out by the continuous spectrum, although 564 asserts itself by a brightening of the spectrum at that wave-length in Vogel's sketch, and by a rise in his light-curve.

The line at 540 is the only line of manganese visible at the temperature of the bunsen burner, while the 581 measurement of Vogel is in all probability the 579 line, the strongest line of iron visible at low temperatures.

In this star therefore we have continuous spectrum from the meteorites, and carbon bands, one of them appearing beyond the continuous spectrum in the blue as a bright band; bright lines of hydrogen, manganese, and iron being superposed on both. There is no absorption of any kind, the apparent dark band being due to defect of radiation.

Vogel's results are given in the *Publicationen des Astrophysikalischen Observatoriums zu Potsdam*, vol. iv. No. 14, p. 17.

Pickering's are published in the *Astronomische Nachrichten*, No. 2376; *Science*, No. 41; and quoted in *Copernicus*, vol. i. p. 140.

2nd Cygnus.—B.D. + 35°, No. 4013.—Messrs. Wolf and Rayet, in 1867, first observed the spectrum of this star, and measured the positions of the bright lines. Micrometer readings and reference lines are given by them from which a wave-length curve has been constructed. The wave-lengths of the bright lines in the star thus ascertained are: 581 (γ), 573 (β), 540 (δ), and 470 (α); the relative intensities being shown by the Greek letters.

"La ligne β est suivie d'un espace obscur; un autre espace très-sombre précède α."

Vogel afterwards examined the spectrum, measured the positions and ascertained the wave-lengths of the bright lines, drew a sketch of the spectrum as it appeared to him, and a curve showing the variation of intensity of the light throughout the spectrum.

The wave-lengths given by Vogel are 582 and 570, and of a band with its brightest part at 464, fading off in both directions and according to the sketch having its red limit at 473. In the light curve Vogel not only shows the 582 and 570 lines, but al o bright lines in positions which by a curve have been found to correspond to wave-lengths 540 and 636. Vogel indicates in his sketch a dark band extending from 486 to the bright band 473, and an apparent absorption on the blue side of the 570 line, this absorption being ended at 564. These two bands agree in position with the dark spaces observed by Messrs. Wolf and Rayet. The bright band in the blue at 473 is most probably the carbon band appearing bright upon a faint continuous spectrum, this producing the apparent absorption from 486 to 473. If the bright carbon really

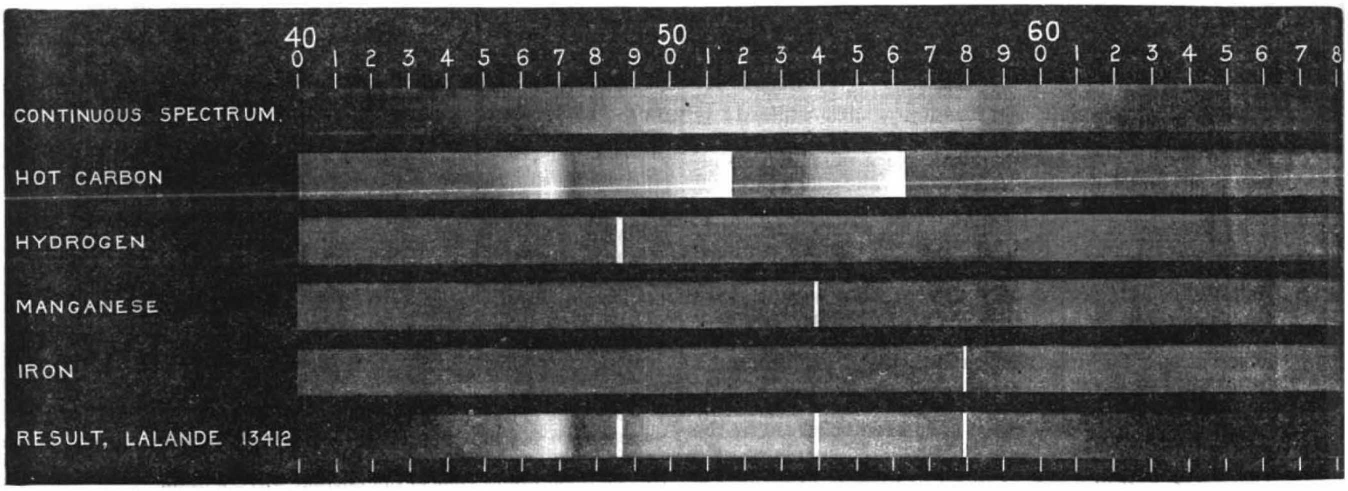

Fig. 4.—Map showing the probable origin of the spectrum of Lalande 13412.

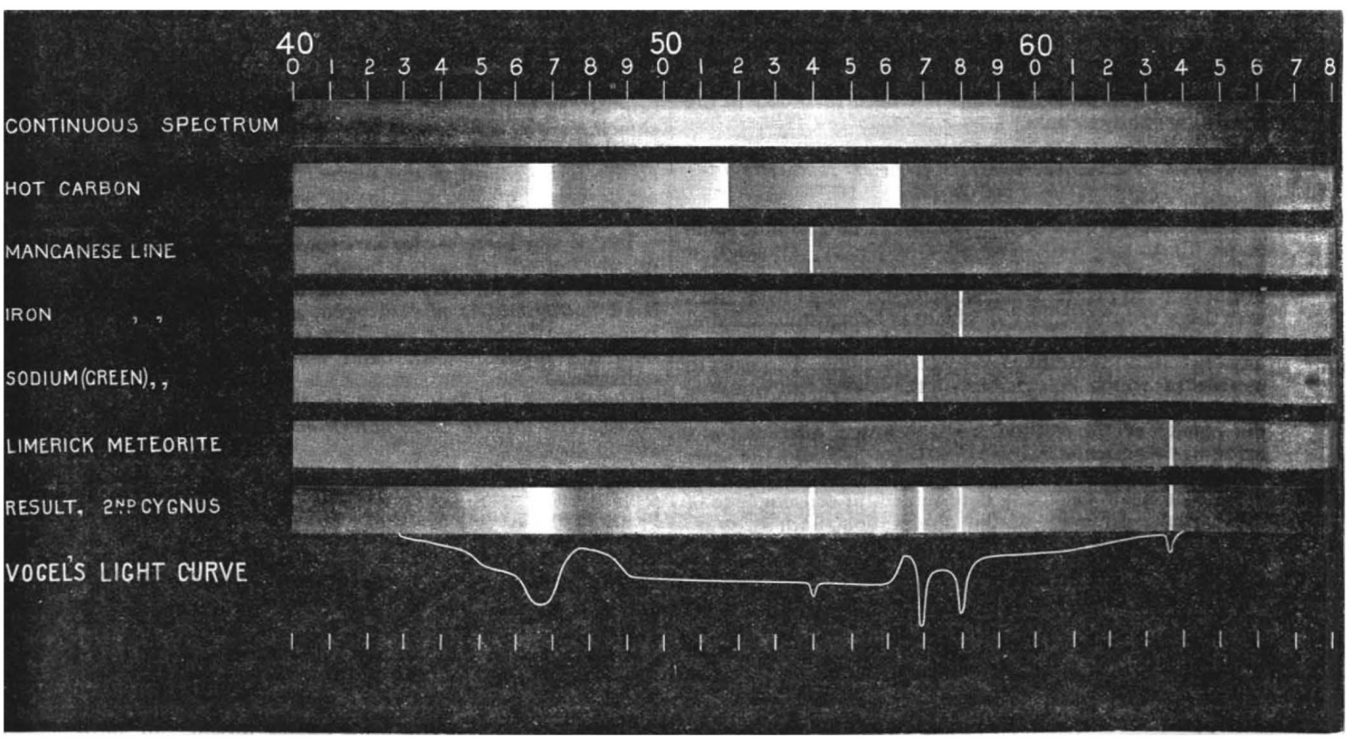

Fig. 5.—Map showing the probable origin of the spectrum of Wolf and Rayet's 2nd star in Cygnus.

accounts for the appearance of a dark band between the bright 570 and 564 in this star, all the apparent absorption is explained as due to contrast of bright bands on a fainter continuous spectrum due to red-hot meteorites.

The line at 540 is the only line of manganese visible in the bunsen burner, and the 580 line is the strongest low-temperature iron line. The 570 line is most probably the green sodium line 569, the absence of the yellow sodium being explained by the half-and-half absorption and radiation mentioned in the discussion of the causes which mask and prevent the appearance of the lines in a spectrum.

The line at 636 is in the red just at the end of the continuous spectrum, and as yet no origin has been found for it, although it has been observed as a bright line in the Limerick meteorite at the temperature of the oxyhydrogen blow-pipe.

This star therefore gives a continuous spectrum due to radiation from meteorites, and on this we get bright carbon (with one carbon band appearing separate in the blue), with bright lines of iron, manganese, sodium, and some as yet undetermined substance giving a line at 636 in the oxyhydrogen blow-pipe.

Wolf and Rayet's results are given in the *Comptes rendus*, vol. lxv. p. 292.

Dr. Vogel's are from the *Publicationen des Astrophysikalischen Observatoriums zu Potsdam*, vol. iv. No. 14, p. 19.

The above are only given as examples of the seven bright-line stars explained in the lecture.

(*To be continued.*)

THE ROYAL SOCIETY SELECTED CANDIDATES.

THE following fifteen candidates were selected on Thursday last by the Council of the Royal Society to be recommended for election into the Society. The ballot will take place on June 7, at 4 p.m. We print with the name of each candidate the statement of his qualifications:—

THOMAS ANDREWS, F.R.S.E.,

F.C.S., Assoc.M.Inst.C.E. Ironmaster and Metallurgist. Awarded by the Institution of Civil Engineers, for original metallurgical and physical researches, a Telford Medal and a Telford Premium, Session 1884; again a Telford Premium, Session 1885; and another Telford Premium, Session 1886. Author of the following eighteen papers:—In Proc. Roy. Soc. Lond. (four papers), "Electromotive Force from difference of Salinity in Tidal Streams," "Action of Tidal Streams on Metals during diffusion of Salt and Fresh Water," "Reversals of Electromotive Force between Metals of High Temperatures in Fused Salts," "Observations on Pure Ice and Snow" (a determination of their relative conductivity for heat, and the great contraction of ice at extremely low temperatures, &c.); Trans. and Proc. Roy. Soc. Edin. (four papers), "On Relative Electro-chemical Positions of Iron, Steels, and Metals in Sea Water," "Apparent Lines of Force on passing a Current through Water," "Resistance of Fused Halogen Salts," "Electromotive Force between Metals at High Temperatures"; Proc. Inst. Civ. Eng. (four papers), "On Galvanic Action between Metals long exposed in Sea Water," "Corrosion of Metals long exposed in Sea Water." Author of an investigation on "Effects of Temperature on Strength of Railway Axles," Part I., II., and III., conducted by the author at a cost of nearly £800, to determine on a large scale the resistance of metals to a sudden concussion at varying temperatures down to zero F. Author also of papers "On Variations of Composition of River Waters" (Chem. Soc., 1875), and "On Curious Concretion Balls from Colliery Mineral Waters" (Brit. Assoc. Rep., Chemical Section, 1879), and "On Strength of Wrought Iron Railway Axles" (Trans. Soc. Eng., 1879; a premium of books awarded for this paper). At present engaged on a research "On some Novel Magneto-Chemical Effects on Magnetizing Iron," and "On the Construction of Iron, Steels, and Cast Metals at Low Temperatures, −50° F.," and "On the Viscosity of Pure Ice at −50° F., &c."

JAMES THOMSON BOTTOMLEY, M.A.,

Demonstrator of Experimental Physics in the University of Glasgow. After being several years with Dr. Andrews in Belfast, as pupil, and as assistant afterwards, he acted as Demonstrator in Chemistry in King's College, London, under Dr. W. A. Miller, and subsequently as Demonstrator and Lecturer in Natural Science, under Prof. W. G. Adams, till 1870, when he came to his present post in the University of Glasgow. Author of "Dynamics," for the Science and Art Department; "Hydrostatics," ditto; "Mathematical Tables for Physical Calculations;" Essay on the Progress of Science since 1833 ("Conversations-Lexicon"); all the articles on Electricity and Magnetism in Moxon's "Dictionary of Science." Also of many scientific articles describing his own experimental researches, including "Thermal Conductivity of Water" (Phil. Trans., 1881); "Permanent Temperature of Conductors, &c." (Proc. Roy. Soc. Edin.), &c.

CHARLES VERNON BOYS,

A.R.S.M. Demonstrator of Physics, Normal School of Science and Royal School of Mines. Author and joint-author of the following:—"Magneto-Electric Induction" (Proc. Phys. Soc., 1879 and 1880); "An Integrating Machine" (Proc. Phys. Soc., 1881); "Integrating and other Apparatus for the Measurement of Mechanical and Electrical Forces" (Proc. Phys. Soc., 1882); "Apparatus for Calculating Efficiency" (Proc. Phys. Soc., 1882); "Measurement of Curvature and Refractive Index" (Proc. Phys. Soc., 1882); "Vibrating Electric Meter" (Proc. Roy. Inst. 1883); "New Driving Gear" (Soc. Art. Lect., 1884); and other papers.

ARTHUR HERBERT CHURCH, M.A. (Oxon.),

F.C.S., F.I.C. Professor of Chemistry in the Royal Academy of Arts. Sometime Professor of Chemistry in the Royal Agricultural College, Cirencester. Researches in Animal, Vegetable, and Mineral Chemistry, *e.g.* Turacin, an animal pigment containing copper (Phil. Trans., 1869); Colein, the pigment of *Coleus Verschaffeltii* (Journ. Chem. Soc, 1877); Aluminium in certain Cryptogams (*Chemical News*, 1874); Vegetable Albinism (Journ. Chem. Soc., 1879, 1880, 1886, Pts. I.-III.); New Mineral Species, Churchite, Tavistockite, Bayldonite (*ibid.*, 1865); Namaqualite (*ibid.*, 1870); Analysis of Mineral Phosphates and Arseniates (*ibid.*, 1868, 1870, 1873, 1875, &c., Proc. Roy. Irish Acad., 1882), &c.

ALFRED GEORGE GREENHILL, M.A.,

Professor of Mathematics for the Advanced Class of Artillery Officers at Woolwich. Was Second Wrangler and bracketed Smith's Prizeman in 1870. Has been Moderator and Examiner for the Mathematical Tripos, University of Cambridge, in 1875, '77, '78, '81, '83, '84. Author of "Differential and Integral Calculus" (1886); Article on Hydromechanics in the "Encyclopædia Britannica." Also of the following papers, in the Proceedings of the Royal Artillery Institute:—"Rotation required for Stability of Elongated Projectiles" (vol. x); "Motion in Resisting Medium" (*ibid.*); "Trajectory for Cubic Law of Resistance" (vol. xiv.); "Reduction of Bashforth's Experiments" (vol. xv.); "Siacci's Method for solving Ballistic Problems" (vol. xiv.). In the *Journal de Physique*:—"Sur le Magnétisme induit d'un Ellipsoide creux" (1881). *American Journal of Mathematics*:—"Wave Motion in Hydrodynamics" (vol. ix.). In the *Engineer*:—"Screw-propeller Efficiency" (1886). In the *Quarterly Journal of Mathematics*:—"Precession and Nutation" (vol. xiv.); "Plane Vortex Motion" (vol. xv.); "Motion of Top" (*ibid.*); "Motion of Water in Rotating Parallelopiped" (*ibid.*); "Fluid Motion between Confocal Ellipsoids" (vol. xvi.); "Solution by Elliptic Functions of Problems in Heat and Electricity" (vol. xvii.); "Functional Images in Cartesians" (vol. xviii.); "Complex Multiplication of Elliptic Functions" (vol. xxii.), and others. In *Messenger of Mathematics*:—"Fluid Motion" (vols. viii.-x.); "Lord Rayleigh's Theory of Tennis Ball" (vol. ix.); "Period Equation of Lateral Vibrations" (vol. xvi.); "Sumner lines on Mercator's Chart" (*ibid.*); "Solution of Cubic and Quartic" (vol. xvii.). In the Proceedings of the Cambridge Philosophical Society:—"Rotation of Liquid Ellipsoid" (vols. iii., iv.); "Green's Function for Rectangular Parallelopiped" (vol. iii.); "Integrals expressed by Inverse Elliptic Functions (*ibid.*); "Conjugate Functions of Cartesians" (vol. iv.); "Greatest Height a Tree can grow" (*ibid.*); "Complex Multiplication of Elliptic Functions" (vols. iv., v.). In Proceedings Institution Mechanical Engineers:—"Stability of Shafting" (1883).

LIEUT.-GENERAL SIR WILLIAM FRANCIS DRUMMOND JERVOIS, R.E., G.C.M.G.,

Governor and Commander-in-Chief of New Zealand. Distinguished as a Military Engineer. From 1841 to 1848 employed in South Africa, during which time he erected important military