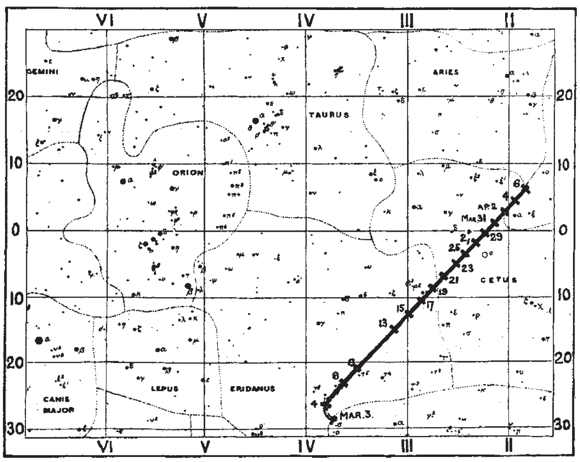
OUR ASTRONOMICAL COLUMN.

COMET 1899 *a* (SWIFT).—The following positions of the comet are taken from a circular received from the Centralstelle at Kiel:—

Ephemeris for 12h. Berlin M.T.

1899.	R.A. h. m. s.	Decl. ° ′	Br.
March 23	2 33 25	−5 7·4	
25	1 27 23	3 26·4	1·40
27	1 21 19	1 50·2	
29	1 15 8	−0 18·3	1·68
31	1 8 44	+1 10·1	
April 2	2 2 1	2 35·5	2·11
4	1 54 54	3 58·6	
6	1 47 19	+5 20·1	2·73

As will be seen from the table, the brightness is rapidly increasing as perihelion is approached; the possibility of observing the comet will depend on the local conditions of the sky near the horizon. It sets now about an hour after sunset. As a



guide for its recognition the accompanying chart of the region is given, which shows the path of the comet from the time of its discovery.

TUTTLE'S COMET.—Mr. J. Rahts continues his ephemeris of this comet in *Ast. Nach.*, Bd. 148, No. 3552. He also gives the elements for the epoch 1899 May 14·0 Berlin mean time.

Elements.

$$M = 359^\circ\ 59'\ 46''\!\cdot\!7 \qquad \phi = 55^\circ\ 15'\ 23''\!\cdot\!7$$

$$\left.\begin{array}{l}\pi = 116\ 29\ \ 3\cdot0 \\ \Omega = 269\ 49\ 53\cdot6 \\ i = \ \ 54\ 29\ 16\cdot3\end{array}\right\}1900\cdot0 \qquad \begin{array}{l}\mu = 259''\cdot6234 \\ \log a = 0\cdot7571085\end{array}$$

It may be interesting to many to recall the past history of this comet. It was discovered by Tuttle at Cambridge, U.S.A., on January 4, 1858 (*Ast. Nach.*, No. 1125). Some time after it was recognised to be identical with the comet 1790 II., and its period determined to be about 13·7 years. Confirmation of this was provided by its return in 1871 and again in 1885, passing perihelion in the latter year on September 11 (J. Rahts, *Ast. Nach.*, No. 2700). It has again this year been observed in a position closely agreeing with that computed from the data obtained in 1885, so that the new values for its elements are probably very nearly correct.

VARIABLE STARS.—*Harvard College Observatory Circular* No. 41 deals with the results of the photometric measurement of the stars + 20° 4200 (U Vulpeculæ) and + 28° 3460 (S.T. Cygni), which were announced to be variable by Müller and Kempf (*Ast. Nach.*, Bd. 146, No. 37). The measures were made by Prof. O. C. Wendell with the photometer with achromatic prisms attached to the 15-inch equatorial. In his case the stars were directly compared with stars of known magnitude in their immediate vicinity, while at Potsdam each was compared with the standard by means of an artificial star, and this fact probably accounts for the greater accordance among the Harvard figures. Apart from this the smoothed curves of both observers agree fairly closely, as is shown in the plotted light curves given in the article.

The period of + 20° 4200 is 7·98 days, during which the magnitude varies from 6·9 to 7·6. The star + 28° 3460 has a period of 3·8 days, its magnitude changing from 6·55 to 7·36.

In the remaining part of the *Circular*, dealing with the variable S Antliæ, the remarkable accuracy attainable with the apparatus is well shown. This star has a period of 7h. 46·8m. (the shortest known except in the case of variables in clusters), and it was doubted whether its period ought to be doubled as was the case with U Pegasi. The differences in magnitude of S Antliæ at minimum and its comparison star for widely differing epochs only varied by ·004 of a magnitude, so that the period of variation as taken is correct, and the star is not of the same type as β Lyræ or U Pegasi.

RELATION OF EROS TO MARS.—In a short article in the *Astronomische Nachrichten*, Bd. 148, No. 3542, Herr J. Bauschinger, of the Berlin Observatory, points out the importance of the discovery of the minor planet Eros with reference to the relationship of Mars to the other planets. Hitherto Mars has been regarded as a major planet, and the asteroids as the remnant of a former planet existing between it and Jupiter. Since the recent observation of the new asteroid it is possible to regard Mars itself as having been included in the original planet which filled the gap, this view being supported by the facts of Mars having so small a mass and the great eccentricity of its orbit. If this turn out to be true, we shall in future have to speak of the "Planetoid-ring between the Earth and Jupiter" in discussing the asteroids.

MEASURING EXTREME TEMPERATURES.[1]

THE measurement of extreme temperatures is a subject of great theoretical interest, especially in connection with the determination of the laws of radiation and of chemical dissociation and combination. The temperature in each case is the factor of paramount importance, and without means of measuring the temperature there is no possibility of formulating any rational theories. The subject possesses, in addition, a powerful fascination for the experimentalist, on account of the difficulty of the observations involved, and of the extremely conflicting nature of the results obtained by different observers and different methods of research.

Temperature of the Sun.

Attempts have frequently been made to estimate the temperatures of the electric arc and of the sun, which may be taken as examples of the most extreme temperatures known to science, and afford an illustration of the difficulties to be encountered, and of the methods available for attacking these problems. A brief consideration and comparison of the results will also serve to explain the causes of the remarkable discrepancies existing in the estimates of such temperatures by different observers and different methods.

In the case of the sun it is at once obvious that no terrestrial thermometer can possibly be directly applied. The only available method is (1) to measure the intensity of the solar radiation, and (2) to endeavour to deduce the temperature by determining the law of radiation at high temperatures. The measurement of the intensity of the solar radiation is in itself a sufficiently intricate problem, containing many elements of doubt and difficulty; but by far the greatest source of uncertainty lies in the solution of the second part of the investigation, the determination of the law of radiation. The origin of the discrepancies thus imported into the results may be summed up in the word "Extrapolation."

The method of investigation necessarily consists in taking a series of observations at temperatures within the laboratory range of thermometry, from which to calculate an empirical

[1] Discourse delivered at the Royal Institution, on March 10, by Prof. H. L. Callendar, F.R.S.

formula representing as closely as possible the results of experiment. It is then assumed that the formula may be "extrapolated," or used to estimate the temperature of a radiating source of known intensity *beyond the range* of the observations on which it was founded. This is a perfectly justifiable method, and may lead to very good results if the empirical law happens to be correct; but if the formula happens to be unsuitable, it may lead to the most remarkable conclusions.

Law of Radiation.

The curves shown in Fig. 1 illustrate some of the typical formulæ which have either been proposed for the law of radiation, or been deduced from the results of modern experiments over the experimental range of the gas thermometer, extending to 1200° C., to which trustworthy determinations of temperature on the theoretical scale are at present restricted. In order to obtain a comparison of the formulæ themselves, apart from other issues, the results of different observers are reduced to a common hypothetical value, 10 watts per square centimetre, for the radiation from a black body at 1000° C.

Excluding the law of Newton, which applies only to small differences of temperature, and also the law of Dulong and Petit, which was founded on observations over a very limited range with mercury thermometers, and is obviously inapplicable at high temperatures, there is a certain family resemblance between the remaining curves; but the differences between them are still so considerable that, if sufficiently accurate measurements of temperature were available, it should be possible to decide with certainty which of the formulæ was the most correct. A fairly close agreement is seen to obtain between the formula proposed by Weber and the curves representing the results of the recent experiments of Bottomley, Paschen and Petavel. But, on the other hand, there is strong evidence, both experimental and theoretical, in favour of the fourth power law

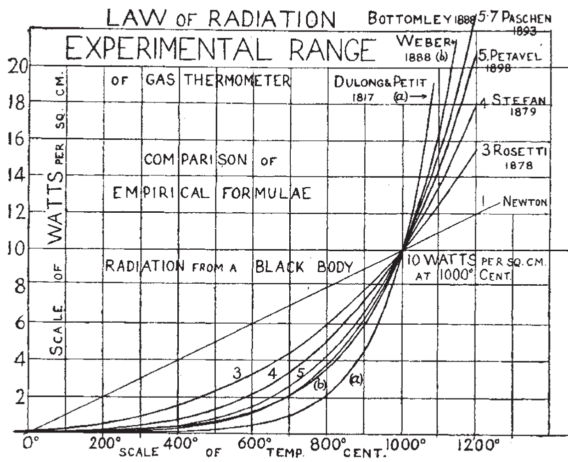


FIG. 1.—Formulæ of radiation. Experimental range.

proposed by Stefan, which differs materially from that of Weber; and many supporters may be found, especially among astronomers, for the very different formula of Rosetti.

Results of Extrapolation.

The importance of choosing a correct formula is most easily realised by reference to Fig. 2, which represents the results of extrapolation as applied to deducing the probable temperature of the sun. On the scale of Fig. 2, the dimensions of the experimental range of Fig. 1 are reduced to the thickness of the line at the lower left-hand corner of the diagram. The line at the top represents the intensity of solar radiation, which is taken at 10,000 watts per square centimetre in round numbers. The points at which the various curves meet this line show the corresponding values of the solar temperature.

The estimates of one million degrees and upwards, which were current in many of the older books on astronomy, were deduced from the law of Newton, and are obviously out of the question. The celebrated formula of Dulong and Petit gives results between 1500° and 2000° C., according to the data assumed, and evidently errs too much in the other direction. At the same time, it must be observed that the recent formula of Weber gives a result which is very little higher. Paschen considered that his results lent support to Weber's formula, and disagreed entirely with Bottomley's. But, according to the writer's reductions, they agree very closely with Bottomley's,

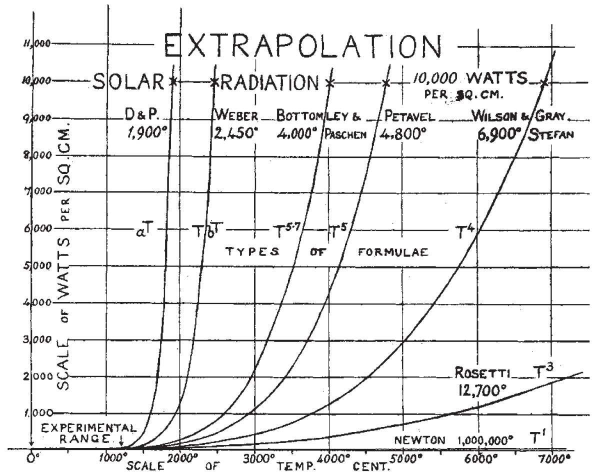


FIG. 2.—Temperature of the sun by extrapolation.

and are best represented by the formula $ET^{5\cdot7}$. The experiments of Petavel agree most nearly with a fifth power law. On the other hand, the experiments of Wilson and Gray, in which the temperature was measured by the *expansion* of a platinum strip, instead of by the increase of its electrical resistance, appear to be in exact confirmation of the fourth power law of Stefan, and give a much higher result for the solar temperature. The formula of Rosetti is approximately a third power law at high temperatures, and would not be admitted as probable, at least by physicists, at the present time.

The various formulæ above mentioned, together with the methods employed and the results deduced, are summarised in the following table.

TABLE I.—*Law of Radiation.*

Observers and date.	Temperature measured by	Radiation observed by	Formula proposed.	Solar temp. deduced.
				° C.
Dulong and Petit (1817)	Mercury thermometer	Rate of cooling in vac.	$E_1\ 1{\cdot}0077^T$	1900
Rosetti (1878)	Mercury thermometer	Thermopile Sb–Bi	E_3T^3 (nearly)	12,700
Stefan (1878)	No experiments made.		E_4T^4	6900
Schleiermacher (1885)	Platinum resistance	Heat loss C^2R in vac.	E_4T^4	6900
Weber (1888)	No experiments made.		$E_2T\ 1{\cdot}00043^T$	2450
Bottomley (1888)	Platinum resistance	Heat loss C^2R in vac.	$E_6T^{5\cdot7}$ *	4000
Paschen (1893)	Thermo-couple Pt–Pt Rh	Bolometer	$E_6T^{5\cdot7}$ *	4000
Wilson and Gray (1897)	Platinum expansion	Radio-micrometer	E_4T^4	6900
Petavel (1898)	Platinum resistance	Bolometer	E_5T^5 *	4800

* Formulæ deduced by the writer from the observations.

The above table is not intended to be exhaustive, but merely as a comparison of typical formulæ, reduced to a common standard. It does not contain the results of photometric investigations.

The Necessity of More Accurate Measurements of Temperature.

The conclusion to be derived from the above illustrations appears to be that in order to arrive at any certain knowledge with regard to the law of radiation, and the measurement of such extreme temperatures as those of the arc, and of the sun, the first step must be to secure a higher order of accuracy in the determination of the highest temperatures which can be observed and measured in the laboratory with material thermometers. There are other difficulties which are peculiar to the determination of the law of radiation, but we are at present concerned primarily with those relating to the measurement of temperature.

There are two comparatively independent lines along which research may proceed with advantage at the present time. (1) The direct comparison of different arbitrary methods; (2) the extension of the range of the gas-thermometer.

In order to secure consistency of statement and the reduction of the results of different observers to a common standard, it is in the first place desirable that the various methods available at the present time for the measurement of high temperatures in the laboratory should be *directly* compared *inter se*, through the greatest possible range. It is the custom at present for different observers to reduce their results *indirectly* to the scale of the gas-thermometer by reference to certain assumed values of the boiling and freezing points of various substances. They generally assume different values for these fixed points, and adopt different methods of calibration, which are undoubtedly responsible for many of the discrepancies at present existing.

To take an illustration from the experiments already quoted, the remarkable discrepancy between the experiments of Bottomley, Paschen and Petavel, on the one hand, and those of Wilson and Gray and Schleiermacher on the other, in the determination of the intensity of radiation from polished platinum, may be traced primarily to differences in the methods of measurement adopted. Bottomley and Petavel measured the electrical resistance of the radiating wire itself, and deduced the temperature by the usual formula for the platinum scale. Paschen calibrated his thermo-couple by reference to numerous fusing and boiling points. Wilson and Gray adopted the meldometer method based on the expansion of platinum, which they found to be uniform. The vacuum in Schleiermacher's experiments could not be measured, and was probably vitiated by gas evolved from the heated platinum.

"Platinum" Methods of Pyrometry.

These and similar discrepancies might be in a great measure removed, so far as they depend on the measurement of temperature, by the direct comparison of the various methods of measurement. The "platinum" methods are among the most important and the most easily comparable by direct experiment. These methods are founded on the characteristic stability and infusibility of the metals of the platinum group, properties which are accompanied by an even more remarkable degree of constancy in their less obvious electrical attributes. The two older methods, based on (1) the expansion and (2) the specific heat of platinum, are of comparatively limited application, but have given very good results in the able hands of Joly and Violle. The more modern electrical methods have the advantage of much wider applicability and convenience. They are of two distinct kinds: (3) the thermo-electric method, represented by the Pt-Pd. thermo-couple of Becquerel, the Pt-Ir. thermo-couple of Barus, and the Pt-Rh. thermocouple of Le Chatelier, and (4) the platinum resistance pyrometer of Siemens. The third method has been naturalised in this country, and brought to great perfection by the work of Sir William Roberts-Austen. The fourth method was that adopted by Bottomley, Schleiermacher, and Petavel in the experiments above mentioned, and has been applied with great success by Heycock and Neville at high temperatures, and by Dewar and Fleming at the other extremity of the scale.

Method of Indirect Comparison.

The usual or indirect comparison of the foregoing methods by means of the fusing points of various metals is illustrated in the annexed table, which contains several of the most recent results. The numbers given in brackets are now published for the first time, and should be regarded as preliminary.

TABLE II.—*Fusing Points by "Platinum" Methods.*

Method.	Observers.	Silver.	Gold.	Copper.	Palladium.	Platinum.
(1) Expansion.	(C & E)	(945)	(1061)	(1085)	(1640)	(1980°)
(2) Spec. heat.	Violle (1879)	957°	1045°	1054°	1500°	1775°
(3) Thermo-couples.	Becquerel (1863)	960°	1092°	1224°		
	Barus (1892)	985°	1093°	1097°	1643°	1855°
	,, (1894)	986°	1091°	1096°	1585°	1757°
	Holborn & Wien (1895)	968°	1072°	1082°	1587°	1780°
(4) Resistance.	H. & N. (1895)	961°	1061°	1082°	(1550)	(1820)

The results above given for the expansion method (1) were obtained by assuming the expansion to be uniform, and taking the F.P. of gold as 1061°. The results of Violle by the specific heat method (2) were deduced by assuming a linear formula for the specific heat of platinum. The discrepancies of the various results obtained by the thermo-electric method (3) are partly due to errors of observation, and partly to extrapolation, *i.e.* to differences in the formulæ of reduction. The high value found by Becquerel for the F.P. of copper as compared with gold and silver is probably to be explained by the use of a much thicker wire in the case of copper. The very accurate and consistent experiments of Heycock and Neville leave little doubt that the F.P. of pure copper is at least 20° above that of gold. The much smaller difference of 4° to 5°, given by Barus, may possibly be explained by contamination with oxygen or other impurity. In the case of silver and gold, Messrs. Holborn and Wien adopted the Becquerel method of observing the fusion of fine wires. In the case of copper, they adopted the much more accurate method of observing the freezing point of a large mass of metal in a crucible, which had been employed by the writer in 1892, and was used by Heycock and Neville throughout their researches. The Becquerel method is very liable to give results which are too high.

The determination of the higher fusing points of palladium and platinum is necessarily attended with greater uncertainty because it involves extrapolation, and is therefore more dependent on the particular formula of reduction assumed, in addition to the experimental difficulties of the higher temperatures. Considering all the obstacles to be encountered, it would be unreasonable to expect such different methods to give any closer agreement at these points.

Advantages of Direct Comparison.

Whatever the origin of these discrepancies, there can be no question that they greatly retard the progress of research and discovery at high temperatures. With the object of helping to remove these obstacles, the writer has recently been engaged, in conjunction with Mr. Eumorfopoulos, in a direct comparison of methods (1), (3) and (4), which are the simplest and most generally applicable. The advantages of the direct method of comparison are very great. (1) The comparison may be extended continuously throughout the scale, and is not confined to a few arbitrarily selected points. (2) It is easy to apply the electric method of heating, which is of all methods the most easily regulated. (3) It is easy to arrange the experiments in such a way that there can be no question of difference of temperature between the thermometers under comparison, which is the most insidious source of error in high temperature measurement.

Comparison of the Expansion and Resistance Scales.

In the comparison of the scale of the expansion of platinum (1), with that of the platinum resistance thermometer (4), it is simply necessary to observe simultaneously the expansion and the electric resistance of a platinum strip, tube or wire maintained at a steady temperature by means of an electric current. The expansion may be measured, as in the meldometer of Joly, by means of a micrometer screw; but for lecture purposes it is preferable to adopt the method of the optical lever employed by Laplace in his experiments on expansion a century ago. By employing a direct reading ohmmeter to indicate the changes of electrical resistance, it is thus possible to exhibit the difference between the two methods by the simultaneous advance of two spots of light on a single scale. If the two instruments are adjusted to read correctly at 0° and 1000° C., the resistance thermometer will be in advance at temperatures below 1000°, but will lag behind at higher temperatures, because the rate of expansion increases as the temperature rises, whereas the rate of change of resistance diminishes. As the result of these experiments, it appears that the two scales (1) and (4) differ from that of the gas-thermometer to a nearly equal extent, but in opposite directions.

The resistance of platinum at its melting point is more than six times as great as at 0° C., whereas the whole expansion amounts to only one-fiftieth part of the length. The electrical method is for this reason by far the most accurate and sensitive. It also possesses in a very striking degree the merit of pliability and adaptability to the needs of each particular problem. For this reason the scale of the platinum resistance thermometer has come to be regarded as the platinum scale *par excellence*, and has been adopted as the standard of reference in many recent researches.

Fusing Point of Platinum.

As an illustration of the facility of applying this method, the determination of the fusing point of platinum on the platinum scale may be taken. This is a difficult experiment to perform by any other method. In performing the experiment by the measurement of the electrical resistance, it suffices to take a fine wire of which the electrical constants are accurately known, and to raise it gradually to its melting point by steadily increasing the current. The observation of the resistance of the central portions of the wire at the moment of fusion gives directly the temperature required on the platinum scale. In attempting to perform the same experiment by the expansion method, we are met by the difficulty that the platinum begins to soften and stretch at a temperature considerably below its melting point. Owing to the smallness of the expansion, a very slight viscous extension produces a relatively large error. In the resistance method it is not necessary to subject the wire to tension, and a small strain would in any case produce an inappreciable error on account of the very large increase of resistance with temperature. To obtain an equal degree of accuracy by the calorimetric method (2), or the thermo-electric method (3), it is necessary to use a furnace in which relatively large quantities of platinum can be melted. This has been done by Violle for method (2), and by Barus and Holborn and Wien for method (3). The latter used a linear formula for extrapolation, although their gas-thermometer experiments appeared to indicate a cubic formula for temperatures below 1200° C.

The temperature of the melting point of platinum on the platinum scale by the resistance method (4) is approximately $pt = 1350°$, and varies but slightly for different specimens of platinum. The result when reduced to the scale of the gas-thermometer by assuming that the rate of increase of resistance diminishes uniformly with rise of temperature (according to the usual formula of platinum thermometry, which has been verified with great care at moderate temperatures) gives a temperature of 1820° C. on the scale of the gas-thermometer. It is not improbable that platinum may deviate slightly from this formula at the extreme limit of the scale in the close neighbourhood of its melting point, but the evidence for this result is at least as good as that obtainable by any of the other methods. The observations are very easy and accurate as compared with the calorimetric method, and it is not necessary to make any arbitrary assumptions with regard to the formula of reduction, as in the case of the thermo-electric method.

As the accuracy of this formula has recently been called in question, on what appears to be insufficient grounds, by certain German and French observers, it is the more interesting at the present time to show that it leads to a result which cannot be regarded as improbable at the extreme limit of the scale. A different formula has recently been employed by Holborn and Wien, and supported by Dickson (*Phil. Mag.*, December 1897). The writer has already given reasons (*Phil. Mag.*, February 1899) for regarding this formula as inferior to the original, of which, however, it is a very close imitation. The above observations on the melting point of platinum, if reduced by Dickson's formula, would give a result $t = 1636°$ C., which appears to be undoubtedly too low as compared with the results of other methods, however great the margin of uncertainty we are prepared to admit in these difficult and debatable regions of temperature measurement.

It should be observed that the results of Violle by method (2) are consistently lower than those given by the resistance method in the case of silver, gold and copper. We should, therefore, expect a difference in the same direction at the F.P. of Pt. as found by method (4), and not a difference in the opposite direction as given by the thermo-electric method, on the arbitrary assumption of a different type of formula for extrapolation at high temperatures. It is a matter of some interest that the assumption of linear formulæ for both the specific heat and the rate of change of resistance should lead to results so nearly consistent over so wide a range of temperature in the case of platinum.

Comparison of the Thermo-couple and the Platinum Thermometer, (3) and (4).

The chief difficulty and uncertainty encountered by Paschen in his experiments on radiation, was that of arranging the thermo couple so as to be at the same temperature as the radiating strip of platinum. It is better for this reason to measure the temperature of the strip itself by means of its electrical resistance, the method adopted by Schleiermacher, Bottomley and Petavel. The same difficulty occurs in the direct comparison of the scales of the thermo-couple and the platinum resistance thermometer. The simplest method of avoiding this objection appears to be that recently adopted by the writer, of enclosing the thermo-couple completely in a thin tube of platinum, which itself forms the resistance thermometer. There can then be no question of difference of temperature between the two, and the same tube may serve simultaneously for the expansion method, and as a radiating source for bolometric investigation of the law of radiation. The uniformity of temperature throughout the length of the tube can be tested at any time by means of potential leads, or by shifting the thermo-couple to different positions along its length. The method of electric heating is employed, and the central portion only of the tube is utilised in the comparison.

(*To be continued.*)

THE ORBIT OF THE LEONID METEOR SWARM.[1]

THE great Leonid swarm of meteors consists of ortho-Leonids which pursue nearly the same path round the sun, and clino-Leonids which move in orbits sensibly differing from the ortho-orbit. The present investigation is concerned with the ortho-Leonids. They form a dense stream extended along a portion of an immense orbit round which they travel in 33¼ years. This orbit has its perihelion a little inside the Earth's orbit, and its aphelion a little outside the orbit of Uranus. It intersects the orbits of these two planets, but lies in a plane inclined to the ecliptic, so that the meteors which traverse it pass under the intervening planets on their outward journey and over them on the homeward journey.

Accordingly, the orbits of the intervening planets—Mars, Jupiter and Saturn—pass through the orbit of the meteors; and they, as well as Uranus and the Earth, whose orbits intersect it, and Venus, which lies but little beyond, are well situated for exercising a perturbating control over the motions of the Leonids. But the influence of Mars and Venus is inconspicuous, and that of the Earth only sensible on the meteors which pass close to it; so that nearly the whole of the perturbating effect upon the greater part of the swarm is due to Jupiter, Saturn and Uranus.

The procession of ortho-Leonids is so long that it takes between two and three years to pass each point of its orbit; and accordingly when it streams across the earth's path, which it does three times in a century, the earth has time to come round to the point of intersection in at least two successive years, and on each such occasion receives one of the greater Leonid showers—a splendid spectacle, but of such brief duration, lasting only a few hours, that it is visible only from the side of the Earth, which happens at the time to be its advancing side.

The first of these great displays recorded in modern times was that witnessed by Humboldt and Bonpland on the morning of November 12, 1799, when travelling in South America. It was quite unexpected. So was the next great shower which visited Europe on the morning of November 13, 1832, and was followed by a still greater display which was seen from numberless stations in America in 1833. This recurrence of the phenomenon after an interval of 33 years led to its being expected in 1866, and diligent preparations were accordingly then made by astronomers to avail themselves of the opportunity of acquiring more information about the mysterious visitants. These meritorious efforts resulted in a great accession to our knowledge. Prof. Hubert A. Newton collected the records of several ancient observations which showed that the swarm returns to the Earth at intervals of 33¼ years, and that the date on which the meteors are seen had advanced by 3½ weeks since A.D. 902. From their periodic recurrence, he found that they must be moving in one or other of five orbits which he described, and from the advance in the date he inferred that the longitude of the node of the orbit has been advancing, an effect which must be due to perturbations. Prof. Adams ascertained which of Newton's five orbits is

[1] "Perturbation of the Leonids." By G. Johnstone Stoney, M.A., D.Sc., F.R.S., and A. M. W. Downing, M.A., D.Sc., F.R.S. (Abstract of a paper read before the Royal Society on March 2.)