Salomons, Sir David, M.A.
Saunders, Edward.
Schlich, Professor William, C.I.E.
Sell, William James, M.A.
Shaw, Professor Henry S. Hele, M.Inst.C.E.
Sidgreaves, Rev. Walter, S.J.
Smith, James Lorrain, M.D.
Smith, Professor William Robert, M.D.
Smithells, Professor Arthur, B.Sc.
Spencer, Professor W. Baldwin, B.A.
Starling, Ernest Henry, M.D.
Swinton, Alan Archibald Campbell, Assoc. M.Inst.C.E.
Tanner, Professor Henry William Lloyd, M.A.
Tatham, John F. W., F.R.C.P.
Thomas, Michael Rogers Oldfield, F.Z.S.
Threlfall, Professor Richard.
Tutton, Alfred E., B.Sc.
Ulrich, Professor George Henry Frederic, F.G.S.
Walker, James, M.A.
Walker, Professor James, D.Sc.
Watson, William, B.Sc.
Whitehead, Charles, F.L.S.
Whymper, Edward, F.R.G.S.
Windle, Bertram Coghill Allen, M.D.
Woodward, Arthur Smith, F.G.S.
Wright, Professor Edward Perceval, M.A.

The following Papers were read:—

I. "Perturbations of the Leonids." By Dr. G. J. STONEY, F.R.S. and Dr. DOWNING, F.R.S.

II. "On Flapping Flight of Aëroplanes." By Professor M. F. FITZGERALD. Communicated by Professor G. F. FITZGERALD, F.R.S.

III. "On Hydrogen Peroxide as the Active Agent in producing Pictures on a Photographic Plate in the Dark." By Dr. J. W. RUSSELL, F.R.S.

"Perturbations 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.

Received February 8,—Read March 2, 1899.

When the present investigation was undertaken, our knowledge of the perturbations of the Leonids was due to an investigation carried on thirty years ago by Professor J. C. Adams.*

His object was to compute the shift in the nodes of the meteoric orbit due to perturbations, and to compare the calculated amount with the amount which had been deduced by Professor Hubert A. Newton from observations made at intervals during the last 1000 years.†

For Professor Adams's purpose the perturbations to be computed

* 'Comptes Rendus,' March 25, 1867, p. 651; and for a fuller account see 'Monthly Notices of the Roy. Astron. Soc.,' April, 1867, p. 247; or 'Monthly Notices,' March, 1897, p. 387, where the last-mentioned paper is reprinted.

† 'Silliman's Journal,' 1864, vol. **37**, p. 377; and vol. 38, p. 53.

were the average perturbations; and he accordingly employed Gauss's method, in which the mass of the disturbing planet is supposed to be distributed round its orbit in quantities proportional to the time that the planet occupies in travelling over each portion of its course. This elegant method furnishes the average amount of each perturbation on the supposition that the periodic times of the disturbed body and of the disturbing planet are incommensurable, so that in the course of time the two bodies present themselves in every possible position to one another.

This condition, however, has been but imperfectly fulfilled within the limited period of 1000 years over which the recorded observations extend, especially in the case of the three planets which influence the Leonids most, and indeed are almost the only planets whose attraction needs to be taken into account. These are Jupiter, Saturn, and Uranus. A comparison of the periodic times shows that fourteen revolutions of Jupiter approximate in duration within about one-fifth of a year, to five revolutions of the meteors; two revolutions of Uranus occupy about one and three-quarters of a year more than this same time, and nine revolutions of Saturn correspond within a fraction of a year to eight revolutions of the meteors.

These cycles have been several times repeated within the period over which the observations extend; and one consequence of these cycles is that there have been oscillations in the rate of the advance of the node about its mean value, so that the times for the showers assigned by applying to the orbit the average shift of its node, have usually differed by several hours from the actual times. On one occasion—in A.D. 1533—the shower anticipated the computed time by about twenty-six hours, and, as the present investigation shows, a deviation of comparable amount and in the opposite direction is to be expected this year. Accordingly, even if our sole object were to enable astronomers in future to predict more satisfactorily the times of the greater Leonid showers, it would be necessary to prepare for the task by first studying the actual amount of the perturbations in each revolution, and moreover, for meteors occupying various stations along the stream.

For, in fact, the perturbations have not only differed in different revolutions, but even within a single revolution, the meteors which occupy successive positions in the procession are differently affected by the surrounding planets, as is confirmed by the definite results which Herr Berberich has obtained by assuming successively two epochs for the perihelion passage.* The dense part of the stream, with which we are chiefly concerned, and which we may call the ortho-stream,† is now so

* See his paper on the perturbations since 1890 of the orbit of the comet which is associated with the Leonids, 'Astr. Nach.,' No. 3526.

† In order to facilitate the study of the Leonids it is convenient to distinguish

long that it takes between two and three years to pass each point in its orbit, so that the configurations in which the several parts are presented to the disturbing planets are markedly different. Accordingly, perturbations must have produced in this long stream both sinuosities and an unequal distribution of density;* and the first step towards increasing our acquaintance with these and other kindred phenomena, as well as towards gaining a better insight into the past history of the swarm, is to aim first at securing a more intimate knowledge of the perturbations.

With this end in view it was decided, as a first step, to compute the actual perturbations of a definite part of the stream over the whole of one revolution, taking that part of the ortho-stream of which Adams had determined the orbit, and extending the computation over the revolution from the date of the great shower of November, 1866, until that day in January, 1900, when the same part of the stream will return to the earth's orbit.

Adams's calculation was based on determinations of the radiant point which were made in 1866, before photography had lent the aid to astronomy which it now yields. Moreover, the circumstance that the earth deflected the meteors which were then observed by an amount which varied as the shower progressed, was not at that time attended to by observers. Owing to these imperfections, there is a considerable probable error in the mean of the determinations which were made in 1866, and a corresponding uncertainty in the values of the elements computed from that mean. We are accordingly only justified in employing Adams's orbit as approximate. But, fortunately, an error in the orbit, of such an amount as is at all likely to exist, will not materially affect the perturbations of the orbit, which are what we have at present in view.

The main stream of Leonids—the ortho-stream—is narrow and very long, and it is convenient to divide it into segments, each of which

between a great body of them—the ortho-Leonids—which are travelling round the sun in nearly identical orbits, and another class of Leonids which we may call clino-Leonids, that are pursuing courses which differ in a more considerable degree from the ortho-orbit. By the ortho-orbit is to be understood the mean of the orbits of the ortho-Leonids.

The ortho-Leonids at present form a compact stream of such a length that it takes nearly three years to pass each point of its orbit, and so narrow that when the earth passes obliquely through it the transit occupies only some five or six hours; whereas the clino-Leonids form a less dense and wider stream, which has spread itself the whole way round the ring, and which produces in every November, when the earth passes through it, a feeble meteoric shower that lasts for several days.

* One consequence of the existence of irregularities in the stream of ortho-Leonids is that the ortho-orbit at one cross-section of the stream (*i.e.*, the mean of the orbits of the meteors occupying that situation in the stream) is in general not absolutely identical with the ortho-orbits at other cross-sections.

shall be of moderate length. Through one of these, which we may call segment A, the earth passed in November, 1866, and on that occasion there was withdrawn from it that small portion which consisted of meteors which either encountered or passed close to the earth. Those that actually plunged into the earth's atmosphere were destroyed: those that passed near were deflected, and were also either accelerated or retarded, and they thus became clino-Leonids. It is with the great majority of the meteors in segment A, which escaped both these fates and continued to be ortho-Leonids, that Adams's investigation is concerned. He ascertained their orbit; and starting from the elements of the orbit as determined by him, the actual perturbations which it has since undergone have been computed, and the main results thus arrived at are embodied in the following table.

As already stated, the calculation has been extended over an entire revolution of that portion of the stream which we have called segment A; and in computing the perturbations, account has been taken of the attraction exercised upon these meteors by Mars, Jupiter, Saturn, and Uranus. At first Venus and the Earth were included, but as the influence of these planets was found to be insensible, they were omitted from the latter part of the calculation.

The expense of carrying on the work has been met partly out of the Government Grant administered by the Royal Society, and partly out of the Royal Society's Donation Fund. The computations have been made by Messrs. F. B. Cooper, J. H. Bell, and W. H. Walmsley, members of the staff of the Nautical Almanac office. We are also indebted to Mr. E. Roberts, the chief assistant, for his aid in various parts of the work. The method adopted was that by mechanical quadratures, the determinations of the variations of the elements being made at intervals of thirty-six days, except for the period from May, 1871, to December, 1894, during which time the perturbations were small and progressed so regularly that it was found sufficient to make the computations at intervals of 216 days.

The most noteworthy features are a near approach to Saturn in April, 1870, and a near approach to Jupiter in August, 1898, at which latter time the meteors in segment A of the stream were at a distance from the planet of only 0·9 of the mean radius of the earth's orbit. The consequences of these near approaches are brought out in the table. Uranus produced but little effect in this revolution. The planet was at a distance when the swarm crossed his orbit. And the influence of Mars was trifling. So that nearly the whole of the perturbations during this revolution have been caused by Jupiter and Saturn.

Perturbations of the Elements of the Orbit of Segment A of the Ortho-stream in certain Selected Intervals of Time. The Elements are referred to the mean Equinoxes of their respective epochs.

	Elements of the osculating ellipse on 1866, November, 13 d. 13 h., as found by Adams.	Perturbations of the elements in the selected intervals.					Computed values of the elements on 1900, January, 27 d. 15 h.
		I.	II.	III.	IV.	V.	
Mean longitude in orbit ϵ ...	58° 10′ ·2	− 4′ ·83	− 0′ ·32	−27′ ·98	−13′ ·99	−0′ ·70	58° 34′ ·4
Longitude of perihelion π ...	58° 19′	− 5′ ·37	+10′ ·70	− 6′ ·47	− 4′ ·75	−0′ ·60	58° 40′ ·6
Longitude of node (descending) ν ...	51° 28′	+29′ ·33	+ 7′ ·15	− 1′ ·69	+70′ ·83	+0′ ·09	53° 41′ ·8
Inclination i ...	16° 46′	+11′ ·92	− 1′ ·01	+ 1′ ·43	−28′ ·60	−0′ ·01	=16° 29′ ·7
Angle of eccentricity ϕ ...	64° 46′ ·8	− 3′ ·39	− 1′ ·70	+12′ ·06	+ 7′ ·65	+0′ ·32	=65° 1′ ·7
Mean distance a ...	10 ·3402	+0 ·015 660	−0 ·021 271	+0 ·033 726	+0 ·038 258	+0 ·001 747	=10 ·408 32
Daily motion of ϵ n ...	−1′ ·778 57	+0′ ·004 069	−0′ ·005 481	+0′ ·008 678	+0′ ·009 763	+0′ ·000 441	= −1′·761 10

I is the interval from 1866, November 13, to 1871, May 3. In this interval segment A of the ortho-stream crossed the orbits of Jupiter and Saturn.

II is the interval from 1871, May 3, to 1894, December 28. In this interval it crossed the orbit of Uranus, both on the outward and homeward journeys.

III is the interval from 1894, December 28, to 1897, December 30. In this interval it recrossed the orbit of Saturn.

IV is the interval from 1897, December 30, to 1899, May 18. In this interval it recrossed the orbit of Jupiter.

V is the interval from 1899, May 18, to 1900, January 27. This interval brings segment A of the stream back to its descending node.

The following were the adopted masses of the disturbing planets :—

Mars	$\frac{1}{3,093,500}$
Jupiter................................	$\frac{1}{1,047 \cdot 879}$
Saturn	$\frac{1}{3,501 \cdot 6}$
Uranus	$\frac{1}{22,756}$

In consulting the table, it has to be borne in mind that ϵ, which is there designated, in compliance with the usual convention amongst computers, the "mean longitude in the orbit," is in reality the sum of two angles lying in different planes, viz., the longitude of the node + the angle between the radii from the sun to the node and to an imaginary body starting from perihelion at the same epoch as segment A of the meteors, and thenceforward moving uniformly in a circular orbit round the sun in the same plane and with the same periodic time as the meteors. So again π, the so-called "longitude of perihelion," is the sum of two angles, viz., the longitude of the node measured along the ecliptic + the angle from the node to the perihelion measured in the plane of the orbit. The second angle in each case, that in the plane of the orbit, is measured in the direction of positive motion.

The perihelion distance in Adams's orbit, of which the elements are in the first column of the table, and which was the osculating ellipse on 1866, November 13, is 0·9855; that of the osculating ellipse on 1900, January 27, of which the elements are in the last column, is 0·97296. There is a corresponding difference in the distances of the node from the sun, a difference which would be enough to carry segment A of the meteoric stream inside the earth's orbit without intersecting it when it passes the earth's orbit on January 27, 1900, unless the depth of the stream towards the sun is greater than its width at right angles to that direction—a width which from observation has been estimated to be about 100,000 miles. We have, however, satisfied ourselves, from the dynamical conditions which must have prevailed when the Leonids joined the solar system, that the depth of the stream is much greater than its width.

The longitude of the node at the epoch 1900, January 27, would be 52° 25′, if computed in the way which has been hitherto usual, by applying to the longitude at the time of the shower of 1866 the average apparent shift of the node as determined from observation by Professor Newton, viz., 102″·6 annually; whereas in the orbit of our table it is 53° 42′. It thus appears that the amount of this perturbation upon segment A of the stream has been more than three and a half times its average amount, and, doubtless, the perturbations in this revolution of

the other elements have also been excessive as compared with their average amounts.

Thus, the mean distance of the meteors occupying segment A of the stream has been undergoing so much extension, that the meteors will at the end of the revolution find themselves with a periodic time longer by one-third of a year—an amount of change which must largely affect their future history, unless this great perturbation is compensated by what happens elsewhere or at other times.

At the epoch 1899, November 15, the longitude of the node will be 53° 41′·7, a position which the earth will reach on 1899, November 15d. 18h. It is probable, therefore, that the middle of the shower of the present year (1899) will occur nearly at this time, since segment A in the stream, for which our calculations have been made, is situated in the stream less than three months' journey of the meteors behind the segment which the earth will encounter next November, and which we may call segment B. This conclusion, however, rests on two assumptions: (1) That segments A and B were, in 1866, moving in orbits that did not much differ; (2) That the perturbations which segments A and B have since suffered have not much differed. Both assumptions are probable, but unfortunately neither is certain; so that the prediction can only be offered with reservation. If the shower occurs at the time anticipated, it will be visible from both Europe and America.

"On Hydrogen Peroxide as the active Agent in producing Pictures on a Photographic Plate in the Dark." By W. J. RUSSELL, Ph.D., V.P.R.S. Received February 18,—Read March 2, 1899.

In previous papers it has been shown that certain bodies are able, in the dark, to act on a photographic plate and produce a picture. The purpose of the present communication is to show that in all the cases which have been examined, and probably in all others of a similar kind, the action which occurs is due to the presence of hydrogen peroxide. As a sensitive plate always contains moisture, and probably would be inactive if quite dry, it does not seem possible to test the truth of this statement by the total exclusion of moisture; therefore more indirect means have to be adopted. In the following paper no attempt is made to explain the reactions which occur in the plate itself; that is a distinct question, and at present the object is to consider the means by which these changes, whatever they may be, are brought about. These changes are rendered visible by exactly the same processes as those adopted for the development of an ordinary light picture. Any of the ordinary photographic plates may be used in