

THE

# AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]



HUBERT ANSON NEWTON.

[Read before the National Academy of Sciences, in April, 1897.—The portrait accompanying this notice is a reproduction of a photograph taken by a member of the family in the spring of 1894.]

HUBERT ANSON NEWTON was born on March 19th, 1830, at Sherburne, N. Y., and died at New Haven, Conn., on the 12th day of August, 1896. He was the fifth son of a family of seven sons and four daughters, children of William and Lois (Butler) Newton. The parents traced their ancestry back to the first settlers of Massachusetts and Connecticut,\* and had migrated from the latter to Sherburne, when many parts of central New York were still a wilderness. They both belonged to families remarkable for longevity, and lived themselves to the ages of ninety-three and ninety-four years. Of the children, all the sons and two daughters were living as recently as the year 1889, the youngest being then fifty-three years of age. William Newton was a man of considerable enterprise, and undertook the construction of the Buffalo section of the Erie canal, as well as other work in canal and railroad construction in New York and Pennsylvania. In these constructions he is said to have relied on his native abilities to think out for himself the solution of problems which are generally a matter of technical training. His wife was remarkable for great strength of character united with a quiet temperament and well-balanced mind, and was noted among her neighbors for her mathematical powers.

\* Richard Butler, the great-grandfather of Lois Butler, came over from England before 1633, and was one of those who removed from Cambridge to Hartford. An ancestor of William Newton came directly from England to the New Haven colony about the middle of the same century.

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Young Newton, whose mental endowments were thus evidently inherited, and whose controlling tastes were manifested at a very early age, fitted for college at the schools of Sherburne, and at the age of sixteen entered Yale College in the class graduating in 1850. After graduation he pursued his mathematical studies at New Haven and at home, and became tutor at Yale in January, 1853, when on account of the sickness and death of Professor Stanley the whole charge of the mathematical department devolved on him from the first.

In 1855, he was appointed professor of mathematics at the early age of twenty-five. This appointment testifies to the confidence which was felt in his abilities, and is almost the only instance in which the Yale Corporation has conferred the dignity of a full professorship on so young a man.

This appointment being accompanied with a leave of absence for a year, in order to give him the opportunity to study in Europe, it was but natural that he should be attracted to Paris, where Chasles was expounding at the Sorbonne that modern higher geometry of which he was to so large an extent the creator, and which appeals so strongly to the sense of the beautiful. And it was inevitable that the student should be profoundly impressed by the genius of his teacher, and by the fruitfulness and elegance of the methods which he was introducing. The effect of this year's study under the inspiring influence of such a master is seen in several contributions to the *Mathematical Monthly* during its brief existence in the years 1858-61. One of these was a problem which attracted at once the attention of Cayley, who sent a solution. Another was a discussion of the problem "to draw a circle tangent to three given circles," remarkable for his use of the principle of inversion. A third was a very elaborate memoir on the construction of curves by the straight edge and compasses, and by the straight edge alone. These early essays in geometry show a mind thoroughly imbued with the spirit of modern geometry, skilful in the use of its methods, and eager to extend the bounds of our knowledge.

Nevertheless, although for many years the higher geometry was with him a favorite subject of instruction for his more advanced students, either his own preferences, or perhaps rather the influence of his environment, was destined to lead him into a very different field of research. In the attention which has been paid to astronomy in this country we may recognize the history of the world repeating itself in a new country in respect to the order of the development of the sciences, or it may be enough to say that the questions which nature forces on us are likely to get more attention in a new country and a bustling age, than those which a reflective mind

puts to itself, and that the love of abstract truth which prompts to the construction of a system of doctrine, and the refined taste which is a critic of methods of demonstration, are matters of slow growth. At all events, when Professor Newton was entering upon his professorship, the study of the higher geometry was less consonant with the spirit of the age in this country than the pursuit of astronomical knowledge, and the latter sphere of activity soon engrossed his best efforts.

Yet it was not in any of the beaten paths of astronomers that Professor Newton was to move. It was rather in the wilds of a *terra incognita*, which astronomers had hardly troubled themselves to claim as belonging to their domain, that he first labored to establish law and order. It was doubtless not by chance that he turned his attention to the subject of shooting stars. The interest awakened in this country by the stupendous spectacle of 1833, which was not seen in Europe, had not died out, as is abundantly shown by inspection of the indexes of this Journal. This was especially true at New Haven, where Mr. Edward C. Herrick was distinguished for his indefatigable industry both in personal observation and in the search for records of former showers. A rich accumulation of material was thus awaiting development. In 1861, the Connecticut Academy of Arts and Sciences appointed a committee "to communicate with observers in various localities for combined and systematic observations upon the August and November meteors." In this committee Professor Newton was preëminently active. He entered zealously upon the work of collecting material by personal observation and correspondence and by organizing corps of observers of students and others, and at the same time set himself to utilize the material thus obtained by the most careful study. The value of the observations collected was greatly increased by a map of the heavens for plotting meteor-paths, which was prepared by Professor Newton and printed at the expense of the Connecticut Academy for distribution among observers.

By these organized efforts, in a great number of cases, observations were obtained on the same meteor as seen from different places, and the actual path in the atmosphere was computed by Professor Newton. In a paper published in 1865\* the vertical height of the beginning and the end of the visible part of the path is given for more than one hundred meteors observed on the nights of August 10th and November 13th, 1863. It was shown that the average height of the November meteors is fifteen or twenty miles higher than that of the August meteors, the former beginning in the mean at a height of ninety-six miles and ending at sixty-one, the latter beginning at seventy and ending at fifty-six.

\* This Journal, II, vol. xl, p. 250.

We mention this paper first, because it seems to represent the culmination of a line of activity into which Professor Newton had entered much earlier. We must go back to consider other papers which he had published in the mean time.

His first papers on this subject, 1860-62,\* were principally devoted to the determination of the paths and velocities of certain brilliant meteors or fireballs, which had attracted the attention of observers in different localities. Three of these appeared to have velocities much greater than is possible for permanent members of the solar system. To another a particular interest attached as belonging to the August shower, although exceptional in size. For this he calculated the elements of the orbit which would give the observed path and velocity. But the determination of the velocity in such cases, which depends upon the estimation by the observers of the time of flight, is necessarily very uncertain, and at best affords only a lower limit for the value of the original velocity of the body before it encountered the resistance of the earth's atmosphere. This would seem to constitute an insuperable difficulty in the determination of the orbits of meteoroids, to use the term which Professor Newton applied to these bodies, before they enter the earth's atmosphere to appear for a moment as luminous meteors. Yet it has been completely overcome in the case of the November meteors or Leonids, as they are called from the constellation from which they appear to radiate. This achievement constitutes one of the most interesting chapters in the history of meteoric science, and gives the subject an honorable place among the exact sciences.

In the first place, by a careful study of the records, Professor Newton showed that the connection of early showers with those of 1799 and 1833 had been masked by a progressive change in the time of the year in which the shower occurs. This change had amounted to a full month between A. D. 902, when the shower occurred on October 13, and 1833, when it occurred on November 13. It is in part due to the precession of the equinoxes, and in part to the motion of the node where the earth's orbit meets that of the meteoroids. This motion must be attributed to the perturbations of the orbits of the meteoroids which are produced by the attractions of the planets, and being in the direction opposite to that of the equinoxes, Professor Newton inferred that the motion of the meteoroids must be retrograde.

The showers do not, however, occur whenever the earth passes the node, but only when the passage occurs within a year or two before or after the termination of a cycle of 33.25 years. This number is obtained by dividing the interval between the

\* This Journal, II, xxx, p. 186; xxxii, p. 448; and xxxiii, p. 338.

showers of 902 and 1833 by 28, the number of cycles between these dates, and must therefore be a very close approximation. For if these showers did not mark the precise end of cycles, the resultant error would be divided by 28. Professor Newton showed that this value of the cycle requires that the number of revolutions performed by the meteoroids in one year should be either  $2 \pm \frac{1}{33.25}$  or  $1 \pm \frac{1}{33.25}$  or  $\frac{1}{33.25}$ . In other words, the periodic time of the meteoroids must be either 180.0 or 185.4 or 354.6 or 376.6 days, or 33.25 years. Now the velocity of any body in the solar system has a simple relation to its periodic time and its distance from the sun. Assuming, therefore, any one of these five values of the periodic time, we have the velocities of the Leonids at the node very sharply determined. From this velocity, with the position of the apparent radiant, which gives the direction of the relative motion, and with the knowledge that the heliocentric motion is retrograde, we may easily determine the orbit.

We have, therefore, five orbits from which to choose. The calculation of the secular motion of the node due to the disturbing action of the planets, would enable us to decide between these orbits.

Such are the most important conclusions which Professor Newton derived from the study of these remarkable showers, interesting not only from the magnificence of the spectacle occasionally exhibited, but in a much higher degree from the peculiarity in the periodic character of their occurrence, which affords the means of the determination of the orbit of the meteoroids with a precision which would at first sight appear impossible.

Professor Newton anticipated a notable return of the shower in 1866, with some precursors in the years immediately preceding, a prediction which was amply verified. In the mean time he turned his attention to the properties which belong to shooting stars in general, and especially to those average values which relate to large numbers of these bodies not belonging to any particular swarm.

This kind of investigation Maxwell has called *statistical*, and has in more than one passage signalized its difficulties. The writer recollects a passage of Maxwell which was pointed out to him by Professor Newton, in which the author says that serious errors have been made in such inquiries by men whose competency in other branches of mathematics was unquestioned. Doubtless Professor Newton was very conscious of the necessity of caution in these inquiries, as is indeed abundantly evident from the manner in which he expressed his conclusions; but the writer is not aware of any passage in which he has afforded an illustration of Maxwell's remark.

The results of these investigations appeared in an elaborate memoir "On Shooting Stars," which was read to the National Academy in 1864, and appeared two years later in the *Memoirs of the Academy*.\* An abstract was given in this *Journal* in 1865.† The following are some of the subjects treated, with some of the more interesting results :

The distribution of the apparent paths of shooting stars in azimuth and altitude.

The vertical distribution of the luminous part of the real paths. The value found for the mean height of the middle point of the luminous path was a trifle less than sixty miles.

The mean length of apparent paths.

The mean distance of paths from the observer.

The mean foreshortening of paths.

The mean length of the visible part of the real paths.

The mean time of flight as estimated by observers.

The distribution of the orbits of meteoroids in the solar system.

The daily number of shooting stars, and the density of the meteoroides in the space which the earth traverses. The average number of shooting stars which enter the atmosphere daily, and which are large enough to be visible to the naked eye, if the sun, moon and clouds would permit it, is more than seven and a half millions. Certain observations with instruments seem to indicate that this number should be increased to more than four hundred millions, to include telescopic shooting stars, and there is no reason to doubt that an increase of optical power beyond that employed in these observations would reveal still larger numbers of these small bodies. In each volume of the size of the earth, of the space which the earth is traversing in its orbit about the sun, there are as many as thirteen thousand small bodies, each of which is such as would furnish a shooting star visible under favorable circumstances to the naked eye.

These conclusions are certainly of a startling character, but not of greater interest than those relating to the velocity of meteoroids. There are two velocities to be considered, which are evidently connected, the velocity relative to the earth, and the velocity of the meteoroids in the solar system. To the latter, great interest attaches from the fact that it determines the nature of the orbit of the meteoroid. A velocity equal to that of the earth, indicates an orbit like that of the earth ; a velocity  $\sqrt{2}$  times as great, a parabolic orbit like that of most comets, while a velocity greater than this indicates a hyperbolic orbit.

Professor Newton sought to form an estimate of this critical quantity in more than one way. That on which he placed

\* Vol. i, 3d memoir.

† II, xxxix, 193.

most reliance was based on a comparison of the numbers of shooting stars seen in the different hours of the night. It is evident that in the morning, when we are in front of the earth in its motion about the sun, we should see more shooting stars than in the evening, when we are behind the earth; but the greater the velocity of the meteoroids compared with that of the earth, the less the difference would be in the numbers of evening and morning stars.\*

After a careful discussion of the evidence Professor Newton reached the conclusion that "we must regard as almost certain (on the hypothesis of an equable distribution of the directions of absolute motions), that the mean velocity of the meteoroids exceeds considerably that of the earth; that the orbits are not approximately circular, but resemble more the orbits of comets."

This last sentence, which is taken from the abstract published in this Journal in 1865, and is a little more definitely and positively expressed than the corresponding passage in the original memoir, indicating apparently that the author's conviction had been growing more positive in the interval, or at least that the importance of the conclusion had been growing upon him, embodies what is perhaps the most important result of the memoir, and derives a curious significance from the discoveries which were to astonish astronomers in the immediate future.

The return of the November or Leonid shower in 1865, and especially in 1866, when the display was very brilliant in Europe, gave an immense stimulus to meteoric study, and an especial prominence to this group of meteoroids. "Not since the year 1759," says Schiaparelli, "when the predicted return of a comet first took place, had the verified prediction of a periodic phenomenon made a greater impression than the magnificent spectacle of November, 1866. The study of cosmic meteors thereby gained the dignity of a science, and took finally an honorable place among the other branches of astronomy."† Professor J. C. Adams, of Cambridge, England, then took up the calculation of the perturbations determining the motion of the node. We have seen that Professor Newton had shown that the periodic time was limited to five sharply determined values, each of which with the other data would

\* It may not be out of place to notice here an erratum which occurs both in the *Memoirs of the National Academy* and in the abstract in this Journal, and which the writer finds marked in a private copy of Professor Newton's. In the table on page 20 of the memoir and page 206 of the abstract, the column of numbers under the head "hour of the night" should be inverted. There is another displacement in the table in the memoir, which is, however, corrected in the abstract.

† Schiaparelli, *Entwurf einer astronomischen Theorie der Sternschnuppen*, p. 55.

give an orbit, and that the true orbit could be distinguished from the other four by the calculation of the secular motion of the node.

Professor Adams first calculated the motion of the node due to the attractions of Jupiter, Venus, and the Earth for the orbit having a period of 354·6 days. This amounted to a little less than 12' in 33·25 years. As Professor Newton had shown that the dates of the showers require a motion of 29' in 33·25 years, the period of 354·6 days must be rejected. The case would be nearly the same with a period of 376·6 days, while a period of 180 or 185·4 days would give a still smaller motion of the node. Hence, of the five possible periods indicated by Professor Newton, four were shown to be entirely incompatible with the motion of the node, and it only remained to examine whether the fifth period, viz: that of 33·25 years, would give a motion of the node in accordance with the observed value. As this period gives a very long ellipse for the orbit, extending a little beyond the orbit of Uranus, it was necessary to take account of the perturbations due to that planet and to Saturn. Professor Adams found 28' for the motion of the node. As this value must be regarded as sensibly identical with Professor Newton's 29' of observed motion, no doubt was left in regard to the period of revolution or the orbit of the meteoroids.\*

About this time, M. Schiaparelli was led by a course of reasoning similar to Professor Newton's to the same conclusion,—that the mean velocity of the meteoroids is not very different from that due to parabolic orbits. In the course of his speculations in regard to the manner in which such bodies might enter the solar system, the questions suggested themselves: whether meteoroids and comets may not have a similar origin; whether, in case a swarm of meteoroids should include a body of sufficient size, this would not appear as a comet; and whether some of the known comets may not belong to streams of meteoroids. Calculating the orbit of the Perseids, or August meteoroids, from the radiant point, with the assumption of a nearly parabolic velocity, he found an orbit very similar to that of the great comet of 1862, which may therefore be considered as one of the Perseids,—probably the largest of them all.†

At that time no known cometic orbit agreed with that of the Leonids, but a few months later, as soon as the definitive elements of the orbit of the first comet of 1866 were published, their resemblance to those of the Leonids, as calculated for the period of 33·25 years, which had been proved to be the correct

\* Monthly Notices Roy. Ast. Soc., vol. xxvii, p. 247.

† Entwurf, etc., pp. 49–54.



value, was strikingly manifested, attracting at once the notice of several astronomers.

Other relations of the same kind have been discovered later, of which that of Biela's comet and the Andromeds is the most interesting, as we have seen the comet breaking up under the influence of the sun; but in no case is the coincidence so striking as in that of the Leonids, since in no other case is the orbit of the meteoroids completely known, independently of that of the comet, and without any arbitrary assumption in regard to their periodic time.

The first comet of 1866 is probably not the only one belonging to the Leonid stream of meteoroids. Professor Newton has remarked that the Chinese annals mention two comets which passed rapidly in succession across the sky in 1366, a few days after the passage of the earth through the node of the Leonid stream, which was marked in Europe by one of the most remarkable star-showers on record. The course of these comets, as described by the annalists, was in the line of the Leonid stream.\*

This identification of comets with meteors or shooting-stars marks an epoch in the study of the latter. Henceforth, they must be studied in connection with comets. It was presumably this discovery which led Professor Newton to those statistical investigations respecting comets, which we shall presently consider. At this point, however, at the close as it were of the first chapter in the history of meteoric science, it seems not unfitting to quote the words of an eminent foreign astronomer, written about this time, in regard to Professor Newton's contributions to this subject. In an elaborate memoir in the *Comptes Rendus*, M. Faye says, with reference to our knowledge of shooting-stars and their orbits, "we may find in the works of M. Newton, of the United States, the most advanced expression of the state of science on this subject, and even the germ, I think, of the very remarkable ideas brought forward in these last days by M. Schiaparelli and M. Le Verrier."†

The first fruit of Professor Newton's statistical studies on comets appeared in 1878 in a paper "On the Origin of Comets." In this paper he considers the distribution in the solar system of the known cometic orbits, and compares it with what we might expect on either of two hypotheses: that of Kant, that the comets were formed in the evolution of the solar system from the more distant portion of the solar nebula; and that of Laplace, that the comets have come from the stellar spaces and in their origin had no relation to the solar system.

\* This Journal II, xliii, p. 298, and xlv, p. 91, or *Encycl. Britann.*, article Meteor.

† *Comptes Rendus*. T. lxiv, p. 551.

In regard to the distribution of the aphelia, he shows that, except so far as modified by the perturbations due to the planets, the theory of internal origin would require all the aphelia to be in the vicinity of the ecliptic,—the theory of external origin would make all directions of the aphelia equally probable, *i. e.*, the distribution in latitude of the aphelia should be that in which the frequency is as the cosine of the latitude. The actual distribution comes very near to this, but as the effect of perturbations would tend to equalize the distribution of aphelia in all directions, Professor Newton does not regard this argument as entirely decisive. He remarks, however, that if Kant's hypothesis be true, the comets must have been revolving in their orbits a very long time, and the process of the disintegration of comets must be very slow.

In regard to the distribution of the orbits in inclination, the author shows that the theory of internal origin would make all inclinations equally probable,—the theory of external origin would make all directions of the normal to the plane of the orbit equally probable. On the first hypothesis, therefore, we should expect a uniform distribution in inclination; on the second, a frequency proportioned to the sine of the inclination. It was shown by a diagram in which the actual and the two theoretical distributions are represented graphically, that the actual distribution agrees pretty well with the theory of external origin and not at all with that of internal origin. It was also shown that the curve of actual distribution cannot be made to agree with Kant's hypothesis by any simple and reasonable allowances for perturbations. On the other hand, if we assume the external origin of comets, and ask how the curve of sines must be modified in order to take account of perturbations, it is shown that the principal effect will be to increase somewhat the number of inclinations between  $90^\circ$  and  $135^\circ$  at the expense of those between  $45^\circ$  and  $90^\circ$ . It is apparent at once from the diagram that such a change would make a very good agreement between the actual and theoretical curves, the only important difference remaining being due to comets of short periods, which mostly have small inclinations with direct motion. These should not weigh very much, the author observes, in the general question of the distribution of inclinations, because they return so frequently and are so easily detected that their number in a list of observed comets is out of all proportion to their number among existing comets. But this group of comets of short periods can easily be explained on the theory of an external origin. For such comets must have lost a large part of their velocity by the influence of a planet. This is only likely to happen when a comet overtakes the planet and passes in front of it. This implies that its orig-

inal motion was direct and in an orbit of small inclination to that of the planets, and although it may lose a large part of its velocity, its motion will generally remain direct and in a plane of small inclination. This very interesting case of the comets of short periods and small inclinations, which was treated rather briefly in this paper, was discussed more fully by Professor Newton at the meeting of the British Association in the following year.\*

Many years later, Professor Newton returned to the same general subject in a very interesting memoir "On the Capture of Comets by Planets; especially their Capture by Jupiter," which was read before the National Academy in 1891, and appeared in the *Memoirs of the Academy* two years later.† It also appeared in this *Journal* in the year in which it was read.‡ This contains the results of careful statistical calculations on the effect of perturbations on orbits of comets originally parabolic. It corroborates the more general statements of the paper "On the Origin of Comets," giving them a precise quantitative form. One or two quotations will give some idea of the nature of this very elaborate and curious memoir, in which, however, the results are largely presented in the form of diagrams.

On a certain hypothesis regarding an original equable distribution of comets in parabolic orbits about the sun, it is shown that "if in a given period of time a thousand million comets come in parabolic orbits nearer to the sun than Jupiter, 126 of them will have their orbits changed" by the action of that planet "into ellipses with periodic times less than one-half that of Jupiter; 839 of them will have their orbits changed into ellipses with periodic times less than that of Jupiter; 1701 of them will have their orbits changed into ellipses with periodic times less than once and a half that of Jupiter, and 2670 of them will have their orbits changed into ellipses with periodic times less than twice that of Jupiter." A little later, Professor Newton considers the question, which he characterizes as perhaps more important, of the direct or retrograde motion of the comets after such perturbations. It is shown that of the 839 comets which have periodic times less than Jupiter, 203 will have retrograde motions, and 636 will have direct motions. Of the 203 with retrograde motion, and of the 636 with direct motion, 51 and 257, respectively, will have orbits inclined less than  $30^\circ$  to that of Jupiter.

We have seen that the earliest of Professor Newton's more important studies on meteors related to the Leonids, which at

\* Rep't Brit. Assoc. Adv. Sci. for 1879, p. 272.

† *Mem. Nat. Acad.*, vol. vi, 1st memoir.

‡ This *Journal*, III, xlii, pp. 183 and 482.

that time far surpassed all other meteoric streams in interest. One of his later studies related to another stream which in the mean time had acquired great importance. The identification of the orbit of the Andromed meteors with that of Biela's comet, which we have already mentioned, gave these bodies a unique interest, as the comet had been seen to break up under the influence of the sun. Here the evolution of meteoroids was taking place before our eyes; and this interest was heightened by the showers of 1872 and 1885, which in Europe seem to have been unsurpassed in brilliancy by any which have occurred in this century.

The phenomena of each of these showers were carefully discussed by Professor Newton. Among the principal results of his paper on the latter shower are the following:\*

The time of the maximum frequency of meteors was Nov. 27, 1885, 6<sup>h</sup> 15<sup>m</sup> Gr. m. t. The estimated number per hour visible at one place was then 75,000. This gives a density of the meteoroids in space represented by one to a cube of twenty miles edge. Three hours later the frequency had fallen to one-tenth of the maximum value. The really dense portion of the stream through which we passed was less than 100,000 miles in thickness, and nearly all would be included in a thickness of 200,000 miles.

A formula is given to express the effect of the earth's attraction on the approaching meteoroids in altering the position of the radiant. This is technically known as the zenithal attraction, and is quite important in the case of these meteors on account of their small relative velocity. The significance of the formula may be roughly expressed by saying that the earth's attraction changes the radiant of the Biela meteors, toward the vertical of the observer, one-tenth of the observed zenith distance of the radiant, or more briefly, that the zenithal attraction for these meteors is one-tenth of the observed zenith distance. The radiant even after the correction for zenithal attraction, and another for the rotation of the earth on its axis, is not a point but an area of several degrees diameter. The same has been observed in regard to other showers, but the result comes out more distinctly in the present case because the meteors were so numerous and the shower so carefully observed.

This implies a want of parallelism in the paths of the meteors, and it is a very important question whether it exists before the meteoroids enter our atmosphere, or whether it is due to the action of the atmosphere.

Professor Newton shows that it is difficult to account for so large a difference in the original motions of the meteoroids, and

\* This Journal, III, xxxi, p. 409.

thinks it reasonable to attribute a large part of the want of parallelism to the action of the atmosphere on bodies of an irregular form, such as we have every reason to believe that the meteoroids have, when they enter our atmosphere. The effect of the heat generated will be to round off the edges and prominent parts, and to reduce the meteor to a form more and more spherical. It is, therefore, quite natural that the greater portion of the curvature of the paths should be in the invisible portion and thus escape our notice. It is only in exceptional cases that the visible path is notably curved.

But the great interest of the paper centers in his discussion of the relation of this shower to preceding showers, and to the orbit of Biela's comet. The changes in the date of the shower (from Dec. 6 to Nov. 27) and in the position of the radiant are shown to be related to the great perturbations of Biela's comet in 1794, 1831, and 1841-2. The showers observed by Brandes, Dec. 6th, 1798, by Herrick, Dec. 7th, 1838, and by Heis, Dec. 8th and 10th, 1847, are related to the orbit of Biela's comet as it was in 1772; while the great showers of 1872 and 1885, as well as a trifling display in 1867, are related to the orbit of 1852.\*

Assuming, then, that the meteoroids which we met on the 27th of November, 1872, did not leave the immediate neighborhood of the Biela comet before 1841.5, we seem to have the data for a very precise determination of their orbit between those dates. The same is true of those which we met in 1885. The computation of these orbits, the author remarks, may possibly give evidence for or against the existence of a resisting medium in the solar system.

In his last public utterance on the subject of meteors, which was on the occasion of the recent sesquicentennial celebration of the American Philosophical Society, Professor Newton returns to the Biela meteoroids, and finds in the scattering which they show in the plane of their orbit the proof of a disturbing force in that plane, and therefore not due to the planets. The force exerted by the sun appears to be modified somewhat as we see it in the comet's tails, where indeed the attraction is changed into a repulsion. Something of the same sort on a smaller scale relatively to the mass of the bodies appears to modify the sun's action on the meteoroids.

In 1888 Professor Newton read a paper before the National Academy "Upon the relation which the former Orbits of those Meteorites that are in our collections, and that were seen

\*It is a curious coincidence that the original discoverer of the December shower as a periodic phenomenon, Mr. Edward C. Herrick, should have been (with a companion, Mr. Francis Bradley,) the first to observe that breaking up of the parent body which was destined to reinforce the meteoric stream in so remarkable a manner. See this Journal, III, xxxi, pp. 85 and 88.

to fall, had to the Earth's Orbit." This was based upon a very careful study of more than 116 cases for which we have statements indicating more or less definitely the direction of the path through the air, as well as 94 cases in which we only know the time of the fall. The results are expressed in the following three propositions :

1. The meteorites which we have in our cabinets and which were seen to fall were originally (as a class, and with a very small number of exceptions) moving about the sun in orbits that had inclinations less than  $90^\circ$  ; that is, their motions were direct, not retrograde.

2. The reason why we have only this class of stones in our collections is not one wholly or even mainly dependent on the habits of men ; nor on the times when men are out of doors ; nor on the places where men live ; nor on any other principle of selection acting at or after the arrival of the stones at the ground. Either the stones which are moving in the solar system across the earth's orbit move in general in direct orbits ; or else for some reason the stones which move in retrograde orbits do not in general come through the air to the ground in solid form.

3. The perihelion distances of nearly all the orbits in which these stones moved were not less than 0.5 nor more than 1.0, the earth's radius vector being unity.

Professor Newton adds, that it seems a natural and proper corollary to these propositions (unless it shall appear that stones meeting the earth are destroyed in the air) that the larger meteorites moving in our solar system are allied much more closely with the group of comets of short period than with comets whose orbits are nearly parabolic. All the known comets of shorter periods than 33 years move about the sun in direct orbits that have moderate inclinations to the ecliptic. On the contrary, of the nearly parabolic orbits that are known only a small proportion of the whole number have small inclinations with direct motion.

We have briefly mentioned those papers which seem to constitute the most important contributions to the science of meteors and comets. To fully appreciate Professor Newton's activity in this field, it would be necessary to take account of his minor contributions. These are given in the annexed bibliography, where it will be seen that more than half of the entries relate to these subjects.

Most interesting and instructive to the general reader are his utterances on occasions when he has given a résumé of our knowledge on these subjects or some branch of them, as in the address "On the Meteorites, the Meteors, and the Shooting

Stars," which he delivered in 1886 as retiring president of the American Association for the Advancement of Science, or in certain lectures in the public courses of the Sheffield Scientific School of Yale University, entitled "The story of Biela's Comet" (1874), "The relation of Meteorites to Comets" (1876), "The Worship of Meteorites" (1889), or in the articles on Meteors in the *Encyclopædia Britannica* and Johnson's *Cyclopædia*.

If we ask what traits of mind and character are indicated by these papers, the answer is not difficult. Professor Klein has divided mathematical minds into three leading classes: the logicians, whose pleasure and power lies in subtlety of definition and dialectic skill; the geometers, whose power lies in the use of the space-intuitions; and the formalists, who seek to find an algorithm for every operation.\* Professor Newton evidently belonged to the second of these classes, and his natural tastes seem to have found an equal gratification in the development of a system of abstract geometric truths, or in the investigation of the concrete phenomena of nature as they exist in space and time.

But these papers show more than the type of mind of the author; they give no uncertain testimony concerning the character of the man. In all these papers we see a love of honest work, an aversion to shams, a distrust of rash generalizations and speculations based on uncertain premises. He was never anxious to add one more guess on doubtful matters in the hope of hitting the truth, or what might pass as such for a time, but was always willing to take infinite pains in the most careful test of every theory. To these qualities was joined a modesty which forbade the pushing of his own claims, and desired no reputation except the unsought tribute of competent judges. At the close of his article on meteors in the *Encyclopædia Britannica*, which has not the least reference to himself as a contributor to the science, he remarks that "meteoric science is a structure built stone by stone by many builders." We may add that no one has done more than himself to establish the foundations of the science, and that the stones which he has laid are not likely to need relaying.

The value of Professor Newton's work has been recognized by learned societies and institutions both at home and abroad. He received the honorary degree of Doctor of Laws from the University of Michigan in 1868. He was president of the section of Mathematics and Astronomy in the American Association for the Advancement in Science in 1875, and president of the Association in 1885. On the first occasion he delivered an address entitled "A plea for the study of pure mathematics";

\* Lectures on Mathematics (Evanston), p. 2.

on the second the address on Meteorites, etc., which we have already mentioned. Of the American Mathematical Society he was vice-president at the time of his death. In 1888 the J. Lawrence Smith gold medal was awarded to him by the National Academy for his investigations on the orbits of meteoroids. We may quote a sentence or two from his reply to the address of presentation, so characteristic are they of the man that uttered them: "To discover some new truth in nature," he said, "even though it concerns the small things in the world, gives one of the purest pleasures in human experience. It gives joy to tell others of the treasure found."

Besides the various learned societies in our own country of which he was a member, including the American Academy of Arts and Sciences from 1862, the National Academy of Sciences from its foundation in 1863, the American Philosophical Society from 1867, he was elected in 1872 Associate of the Royal Astronomical Society of London, in 1886 Foreign Fellow of the Royal Society of Edinburgh, and in 1892 Foreign Member of the Royal Society of London.

But the studies which have won for their author an honorable reputation among men of science of all countries, form only one side of the life of the man whom we are considering. Another side, probably the most important, is that in which he was identified with the organic life of the College and University with which he had been connected from a very early age. In fact, we might almost call the studies which we have been considering, the recreations of a busy life of one whose serious occupation has been that of an instructor. If from all those who have come under his instruction we should seek to learn their personal recollections of Professor Newton, we should probably find that the most universal impression made on his students was his enthusiastic love of the subject which he was teaching.

A department of the University in which he took an especial interest was the Observatory. This was placed under his direction at its organization, and although he subsequently resigned the nominal directorship, the institution remained virtually under his charge, and may be said to owe its existence in large measure to his untiring efforts and personal sacrifice in its behalf.

One sphere of activity in the Observatory was suggested by a happy accident which Professor Newton has described in this *Journal*, September, 1893. An amateur astronomer in a neighboring town, Mr. John Lewis, accidentally obtained on a stellar photograph the track of a large meteor. He announced in the newspapers that he had secured such a photograph, and requested observations from those who had seen its flight. The



photographic plate, with letters received from various observers, were placed in Professor Newton's hands, and were discussed in the paper mentioned. The advantages of photographic observations were so conspicuous that Professor Newton was anxious that the Observatory should employ this method of securing the tracks of meteors. With the aid of an appropriation granted by the National Academy from the income of the J. Lawrence Smith fund, a battery of cameras was mounted on an equatorial axis. By this means, a number of meteor-tracks have been obtained of the August meteors, and in one case, through a simultaneous observation by Mr. Lewis in Ansonia, Professor Newton was able to calculate the course of the meteor in the atmosphere with a probable error which he estimated at less than a mile. The results which may be expected at the now near return of the Leonids will be of especial interest, but it will be for others to utilize them.

Professor Newton was much interested in the collection of meteorites, and the fine collection of stones and irons in the Peabody Museum of Yale University owes much to his efforts in this direction.

Professor Newton was a member of the American Metrological Society from the first, and was conspicuously active in the agitation which resulted in the enactment of the law of 1866, legalizing the use of the metric system. He prepared the table of the metric equivalents of the customary units of weights and measures which was incorporated in the act, and by which the relations of the fundamental units were defined. But he did not stop here. Appreciating the weakness of legislative enactment compared with popular sentiment, and feeling that the real battle was to be won in familiarizing the people with the metric system, he took pains to interest the makers of scales and rulers and other devices for measurement in adopting the units and graduations of the metric system, and to have the proper tables introduced into school arithmetics.

He was also an active member of the Connecticut Academy of Arts and Sciences, serving several years both as secretary and president,—also as member of the council. He was associate editor of this Journal from 1864, having especial charge of the department of astronomy. His notes on observations of meteors and on the progress of meteoric science, often very brief, sometimes more extended, but always well considered, were especially valuable.

In spite of his studious tastes and love of a quiet life, he did not shirk the duties of citizenship, serving a term as alderman in the city council, being elected, we may observe, in a ward of politics strongly opposed to his own.

Professor Newton married, April 14th, 1859, Anna C., daughter of the Rev. Joseph C. Stiles, D. D., of Georgia, at one time pastor of the Mercer Street Presbyterian Church in New York City, and subsequently of the South Church in New Haven. She survived her husband but three months, leaving two daughters.

In all these relations of life, the subject of this sketch exhibited the same traits of character which are seen in his published papers, the same modesty, the same conscientiousness, the same devotion to high ideals. His life was the quiet life of the scholar, ennobled by the unselfish aims of the Christian gentleman; his memory will be cherished by many friends; and so long as astronomers, while they watch the return of the Leonids marking off the passage of the centuries, shall care to turn the earlier pages of this branch of astronomy, his name will have an honorable place in the history of the science.

J. WILLARD GIBBS.

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