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*SOME ADVANCES MADE IN ASTRONOMICAL SCIENCE DURING THE NINETEENTH CENTURY.**

IN glancing over the field of astronomical achievement during the century recently closed, the most striking feature is undoubtedly the rise and growth during the past fifty years of an entirely new department, one totally unknown and almost undreamed of before the first half of the century had passed, that called by Professor Langley the new astronomy, more technically known as astrophysics. In considering the restrictions which must be regarded in case this address is to be kept within manageable limit, perhaps it would be well to confine my remarks to this new branch of the science. I shall, however, give the chief place to the older astronomy, touching briefly upon the newer phase.

Near the close of the seventeenth century appeared Newton's immortal work, called by him 'The Mathematical Principles of Natural Philosophy.' In this treatise the law of universal gravitation as the controlling and governing principle of the planetary system was established by a rigorous course of mathematical reasoning. It was many years, however, before these conclusions were universally accepted. On the continent of Europe particularly, the

* Annual address delivered before the University of Pennsylvania Chapters of the Society of Sigma Xi, June 13, 1901, by C. L. Doolittle.

field was already occupied by the philosophy of Descartes. The glittering generalities found here in place of the severe mathematical reasoning of Newton proved too attractive to be at once overthrown.

Fifty years elapsed before anything material was added to the science of Newton, then came a galaxy of distinguished men, including Euler, Clairaut, D'Alembert, Lagrange and Laplace, who, by a series of most brilliant and exhaustive researches, made possible by the development of much more powerful mathematical instruments than those possessed by Newton, practically disposed of every objection which the opponents of Newton's theory could discover.

Their last stronghold and one which proved extremely difficult to carry was the explanation of the secular acceleration of the moon's motion. Halley, one of Newton's disciples, had found by a comparison of ancient and medieval eclipses with those of modern times, that the lunar month is now shorter than was the case 2,000 years ago. How this could be if the motion of this body were governed by the law of gravity only proved an extremely difficult question. It was finally shown by Laplace to be one of the consequences of this law, that what is now an acceleration will in the future become a retardation, thus preserving the system essentially as we see it to-day. This took place near the beginning of the nineteenth century. We may, therefore, say that this century began its course with the law of universal gravitation firmly established. In fact no one was hereafter found to seriously call it in question whose opinion was worthy of notice.

It is not to be supposed, however, that the science of celestial mechanics was now finished. In fact we can hardly say that any branch of physical science ever has been or ever will be finished. Results depending for their value upon observations of any kind must share the inevitable imperfections of the observer and of his instrument.

The problems of celestial mechanics have accordingly occupied the attention of a large number of distinguished men during the century past. With the discovery of new planets and comets and stellar systems, new applications are constantly appearing calling for the most refined skill and active perseverance of its votaries. Refinements in observation and improvements in method also call for frequent revision of the old investigations. This is particularly true of the lunar theory.

The study of the moon's motions was one of the first problems to attract the attention of the ancient astronomers. Since their day we are probably safe in saying that no problem in the entire range of science has called out anything approaching the labor and ingenuity bestowed upon this one. Yet the theory is hardly in a satisfactory condition to-day. Such a statement may seem to those who have never looked into the intricacies of the problem like a confession of failure.

So far as it concerns a purely mathematical statement of the conditions the problem offers no difficulties. The relations between the coordinates of a body like the moon, acted on by any system of forces, are very readily expressed by a series of three differential equations of the second order. The forces here are the mutual attractions exerted by the sun, moon and planets. If only two bodies are present the solution offers no difficulty. If there is a third, we have the famous problem of the three bodies. In spite of all that has been done during the century in the way of mathematical advancement this problem still defies its most powerful resources. Recourse must be had to methods of approximation, expansion in the form of series being one of the most obvious. No one can form an idea of the intricacy and complexity of the resulting expressions who has not himself looked into the problem. Delaunay, at one time director of the Paris Observatory, carried this investigation farther than any of his predecessors had done, but though it had occupied his almost undivided attention for twenty years, it was still unfinished at the time of his death. (He was unfortunately drowned at Cherbourg in 1872 by the capsizing of a pleasure boat.) We have in this country to-day three investigators who are perhaps the greatest living authorities on this subject—Professors Newcomb, Hill of New York, and Brown of Haverford.

The general problem of three bodies has proved a very fascinating one. If, for instance, Mars and Jupiter were of approximately the same dimensions as the sun, the determination of their respective motions would be vastly more complex than it now is. Mr. G. H. Darwin has been giving much attention to this class of problems bringing out some interesting results. Although the problem does not confront us in this unmanageable form in our own system it will eventually find practical application in unraveling the intricacies of the stellar motions.

Probably no achievement in the domain of science ever produced so profound an impression upon the unprofessional public as the discovery of Neptune by a purely theoretical investigation undertaken independently by Leverier and Adams, predicting its place in the heavens before it had ever been seen, or at least recognized as a planet. It is unnecessary now to rehearse the familiar story of that brilliant discovery. It was somewhat like the egg of Columbus, but up to the present time the attempts to apply the process in other regions of the planetary system have not been attended with success. The first such attempt was by Leverier himself, followed in 1859 by his confident announcement of a planet between Mercury and the Sun. The prestige of Leverier's name, accompanied by a supposed view of the planet by Dr. Lescarbault, an amateur astronomer, proved sufficient to carry conviction generally; and Vulcan found a place with the other planets in many books written thirty or forty years ago. No one else, however, whose authority was worth much claimed to have seen the planet until the occurrence of the total eclipse of the sun July 29, 1878. At this time Professor Watson, of Ann Arbor, and Lewis Swift, of Rochester, believed they had each seen one and perhaps two planets near the sun. The reputation of both as skilled observers naturally gave great weight to their authority, but the planets were never seen again and a critical examination of the places assigned renders it practically certain that fixed stars were mistaken for planets. Vulcan as a single large planet within the orbit of Mercury is now by the unanimous verdict of the astronomical profession relegated to the realm of myths. It was very natural to attempt to apply the process to the discovery of planets beyond Neptune, but although some indications of one and possibly two such have been suspected, nothing of the kind has yet been seen.

The eighteenth century ended with a list of known planets numbering 7 not including satellites. The nineteenth began with eight, the first day of January, 1801, being distinguished by the addition to the list of Ceres, the first of the long line of asteroids to be detected. The fortunate discoverer was Gieuseppe Piazzi. The scene of Piazzi's activities was the University of Palermo, where he had been diligently engaged for nine years with the most perfect instrument which the skill of that day could produce in accumulating materials for a great stellar catalogue. At the time of which we are speaking his attention was directed to a place in the constellation Taurus on account of an error of Wollaston, one of his contemporaries, in assigning a place to a star where none existed. Piazzi found, however, an eighth magnitude star not before noted, and upon repeating the observation the following evening, it was found to be in motion. Piazzi carefully followed the planet until February 11, when he fell ill, and his activities were for some time suspended. Meanwhile letters had been sent to Oriani, at Milan, and Bode, at Berlin. About this time, however, it may be remembered that another individual, not wholly unknown to fame, was actively employed in this part of the world in the practical applications of military science. We refer to one Napoleon Bonaparte. This may explain the fact that Oriani's letter arrived at Milan two and one-half months after it was written. Olbers, however, received that directed to him at the end of two months. The planet was now lost in the sun's rays and it was greatly feared that it would not be recovered, for, with a body so minute, unless its position could be given with some approach to accuracy the attempt to find it was an almost hopeless task. This emergency brought to the front the great mathematician Gauss. At that time a young man unknown to fame, he attacked the problem, and as a result produced a method for determining an orbit from three observed positions which completely overcame the difficulty, at the same time showing its author's title to a place in the front rank of mathematicians.

The discovery of three more planets belonging to the asteroid group soon followed, Juno, Vesta and Pallas, then, after a long interval came Astræa in 1845. The discoverer was Hencke, an amateur astronomer, who had been watching the heavens during fifteen years in the hope of this reward. The number now known to exist is near five hundred, with no indication that the supply approaches exhaustion. About ten years ago the application of photography to this purpose by Wolf, of Heidelbegr, made possible what may be called a wholesale process. One plate, taken October 22, 1900, showed no less than five of these bodies. This is at present believed to be the maximum record. What is to become of this numerous family is one of the serious questions of this day. The complete investigation of the theory of one is almost the work of a lifetime.

Of satellites, or secondary planets, seven have been added to the list during the century, one of Saturn, by Bond of Cambridge, September, 1848; one of Neptune, by Lassell, soon after the discovery of the planet itself; two of Uranus, also by Lassell, 1851; two of Mars, by Hall, of Washington, August, 1877; one of Jupiter, by Barnard, of the Lick Observatory, September, 1892. We should perhaps include an eighth in this category, an additional satellite of Saturn having been announced by W. H. Pickering two years ago, but as it has not yet been confirmed, judgment must be suspended for the present.

The periods of rotation of Mercury and Venus were investigated by the German astronomer Schroeter, sometimes called the Herschel of Germany, near the beginning of the century. His conclusion was that the length of the day on both these planets differs but little from our own. These results kept their places in the text-books almost unchallenged until near the close of the century. The multiplicity of observers equipped with instruments greatly superior to those of Schroeter were apparently unable either to confirm or disprove his conclusions. In 1889, however, Schiaparelli found what he considered decisive evidence showing that the planet Mercury rotates on its axis in the same time required to complete a revolution about the sun, thus like our moon always keeping the same hemisphere presented to the primary body. Later Schiaparelli came to the same conclusion with regard to Venus. The results obtained at Flagstaff, Arizona, by Messrs. Lowell and Douglas are in perfect agreement with these conclusions. Although probably correct, the question is still regarded by many as an open one. The spectroscope will give the final verdict. Attempts in this direction have already been made by two experienced spectroscopists, Keeler, at the Lick Observatory, and Belopalski, at Pulkowa. Keeler's career was closed by death, leaving this and many other important researches unfinished. Such references to Belopalski's results as have come to our notice seem to throw but little additional light on the question. It may be that the instrument has not yet reached that degree of mechanical perfection which an investigation of such delicacy demands; but we may confidently predict its ultimate success.

With regard to the rotation periods of Uranus and Neptune, we know next to nothing. Such scanty bits of information as have been obtained, however, point to short periods in both cases, 8 to 12 hours; here again we may look to the spectroscope to give us a final answer.

As to the physical condition of the planets themselves, their adaptability to the support of animal and vegetable life, we certainly know a little more now than was known during the early part of the century. The author of the 'Positive Philosophy' expresses what seems to have been the prevailing sentiment regarding the orthodox science of that day as follows: "With regard to the heavenly bodies, we may obtain practical knowledge of their geometrical and mechanical phenomena, but all physical, chemical, physiological and social researches for which our powers fit us on our own earth are out of the question in regard to the planets. The only case in which this rule may be too severe is in that of the temperature."

There was, however, no dearth of philosophers whose speculations disregarded these modest limitations. To such the planets, like our own earth, were the abode of vegetable and animal life with, of course, intelligent beings, perhaps greatly superior to ourselves at the head. As no other use in the economy of the universe could be suggested for these neighboring worlds, and as God could not be supposed to create anything in vain, the conclusion was obvious. More exact knowledge has, however, dissipated most of these plausible theories. It seems at present unlikely that a single one of the other planets, with the possible exception of Venus can now be in a condition to support the higher forms of life.

It is not now proposed to enter into a discussion as to the indications of the existence of intelligent beings on the planet Mars. Though there are some who assert with great confidence that such is without doubt the case, there are others whose opinion is of equal value who are certain that the last Eskimo was frozen to death on the planet's equator many thousands of years ago. As to the large planets, Jupiter, Saturn, Uranus and Neptune, on account of their great size and consequently slower development, it is certain that they have not yet reached a condition adapted to the support of life, unless it be in its lowest forms. There is every indication that a very high temperature exists in the case of all four of these planets, that they are largely gaseous, consisting to a great extent of vapors floating in atmospheres whose depth must be reckoned in thousands of miles, and that certainly no part of the solid nucleus is ever seen by us.

We have every reason for believing that the sun with the attendant planets, our earth included, had a common origin, that they are composed of the same materials, that the same chemical and physical laws prevail throughout the system. We may feel very confident also that the same combinations of physical and chemical conditions which on this earth are associated with organic life will be similarly associated on other planets, that those conditions which prevent this development except in its lower forms above the line of perpetual snow will act in the same manner on Mars or Venus.

At the beginning of the century one comet was known to be a member of our system, more than one appearance having certainly been observed, viz., that of Halley. This comet is famous historically as the first whose return was successfully predicted, thus completely demolishing the vague and absurd notions which had been held regarding these bodies. At the close of the century something like a score have been observed at more than one appearance, one of which, that of Biele, has certainly gone to pieces, with many indications that a like fate is in store for all. Closely associated with the subject of comets is that of meteors, a subject to which the attention of all of us has been more or less directed within the past two years by the amount of space which the journals have given to the expected appearance of the November displays. This department of astronomy was quite unknown to science a hundred years ago. In the early part of the century writers who condescended to mention meteors at all spoke of them as atmospheric phenomena. As for meteoric stones, specimens of which are seen in all mineralogical collections, scientists would have none of them. Learned academicians ridiculed the idea that any one should be so absurdly credulous as to admit the possibility of a ponderous stone falling from heaven. When in 1790 an official statement signed by 300 eye witnesses of such an event was sent to the French Academy one of the distinguished physicists of that body wrote concerning it "How sad it is to see an entire municipality certifying in a formal official document to the truth of a fable which can only be regarded with pity." Finally in 1803 occurred a fall in France of so conspicuous a character and attested by such a host of credible witnesses that it could no longer be treated as a childish fable. The matter was investigated by the Academy with naturally only one possible verdict. Since then much attention has been given to this subject, but it does not appear that any part of it was shared by the minute shooting stars, with the appearance of which every one was so familiar, until the great display of 1833 had drawn attention to them. It soon began to be discovered that records of similar occurrences at various past times were to be found, and finally Professor Newton, of Yale, in 1864 brought together a series of such historic notices extending back to the year 902, October 15. It was found that these could be represented as successive recurrences of the same phenomenon at intervals of 33 years. Professor Newton, therefore, predicted with much confidence a repetition in 1866. This prediction was fully verified.

The details of the investigation, by which this was shown to be due to a swarm of meteoric bodies, of average dimensions, probably not much exceeding a grain of sand, moving in a long procession about the sun with a period of 33¼ years, we cannot enter into now. The length of the stream was found to be such that about three years were required to pass the point of intersection with the earth's orbit. n fact the particles are scattered—very thinly for the most part—over nearly the entire path.

Precisely how it came about that the display was so meager in 1899 is uncertain. Perhaps it was caused by the particles being very unequally distributed along the line and that the earth on that occasion passed through a comparatively thin region. Perhaps the perturbations of the planets have changed the course of the stream to such an extent that the earth no longer encounters it. The question will doubtless receive an answer in due time.

A large number of these meteoric streams have been recognized. A list of 695 radiants, as they are called, is to be found in the *Monthly Notices*, R. A. S., for 1875. Probably, however, a considerable number of these are fictitious.

One of the most remarkable discoveries connected with this subject was announced in 1866 by Schiaparelli, viz., that the well-known August swarm of meteors moves in practically the same orbit as a bright comet seen in 1862, known as Tuttle's comet. Shortly afterwards the orbit of the November swarm was identified with that of Temple's comet of 1866. A number of other such coincidences have been found, the most remarkable being that of a swarm known as Andromedes, which appears to have taken the place formerly occupied by Biele's Comet, in short to be nothing more or less than the shattered fragments of that body. Whether, on the one hand, those streams which have not been identified with any known comet are also the remnants of such a body long since disintegrated, and, on the other, whether those comets permanently attached to our system are undergoing a like process of dissolution, we can not say with certainty, but the theory looks very plausible. One such catastrophe has been carried to completion within the memory of many now living.

Another case in which this process was rapidly developing was that of the great comet of 1882, which many of us will remember. As this body receded from the sun its nucleus was broken into seven distinct fragments which gradually separated farther and farther from each other, until the body disappeared from view. According to the best determination of its period, this comet should return in seven or eight hundred years. When it does return, if this ever happens, undoubtedly it will be in the form of at least seven distinct comets, following each other at intervals of perhaps several years. Each of these will very likely be again subdivided, the operation continuing until nothing remains but minute fragments.

We may follow the process backward as regards this body. In 1843 appeared a splendid comet whose orbit was remarkable on account of the nearness of its approach to the sun. Again in 1880 a large body of this kind appeared whose path so closely resembled that of 1843 that it was generally believed to be the same body, though how such a conspicuous object could return to our neighborhood every thirty-seven years and never have been seen before 1843 was a puzzling question. Greatly to the surprise of astronomers, the great comet of 1882 was found to follow almost precisely the same path. The theory was at once advanced that on account of the close approach of this body to the sun, passing as it did through millions of miles of the solar corona, the resistance encountered was rapidly bringing it into the sun. A few years, possibly a few months, would suffice for completing the work. What effect this collision would produce upon the sun could only be conjectured. Would it bring disaster to our earth or not?

The comet, however, pursued its way after passing the sun, with no appreciable change in the character of its orbit. It was followed from September 3, the date of its discovery, until the following June, when its distance from the sun was 470,000,000 of miles. Abundant material therefore existed for investigating its movements. The result was that at least 650 years must elapse before its return, the time being more likely to be 800 years. It seems almost certain, therefore, that the three comets which appeared respectively in 1843, 1880 and 1882 originally constituted one gigantic body, which, on the occasion of a previous visit, perhaps about the time of the Norman conquest of England, had been torn in pieces by the sun's action precisely as was the case with the fragment which returned in 1882.

Whether the meteoric stones of which mention has been made are in any way related to the minute shooting stars, and whether or not they also at one time formed constituent parts of comets, we cannot say with certainty, but there seems to be no clear line of demarkation between the two classes of bodies. It appears to be simply a difference of dimension. A few of the fragments are massive enough to make their way through the air, and are known as meteoric stones. The great majority are so small that they are dissipated in the upper regions of the atmosphere.

On July 8, 1842, occurred a total eclipse of the sun, the line of totality passing over central and northern Europe. Great interest in this event had been aroused, largely due to the enthusiasm of the English astronomer Francis Baily. What we may call the first of the series of eclipse expeditions, since become such a conspicuous feature, were sent out at this time. Among those who made the long journey—long for those days—were the Astronomer Royal, Baily, Struve from Poulkova, Schumacher from Altona, and Arago from Paris. Though the corona and solar prominences had been frequently seen and described in a casual manner by previous witnesses of similar phenomena, such accounts had attracted little attention. Apparently most of the observers on the present occasion were totally unprepared for the spectacle which confronted them. So far as it concerns the cause of science, these now familiar appendages of the sun may be said to date their discovery from this occasion. Baily is particularly eloquent in his account of the corona, closing as follows: "Splendid and astonishing, however, as this remarkable phenomenon really was, and although it could not fail to call forth the admiration and applause of every beholder, yet I must confess that there was at the same time something in its singular and wonderful appearance that was appalling; and I can readily imagine that uncivilized nations may occasionally have become alarmed and terrified at such an object, more especially at times when the true cause of the occurrence may have been but faintly understood, and the phenomenon itself wholly unexpected.

"But the most remarkable circumstance attending the phenomenon was the appearance of three large protuberances, apparently emanating from the circumference of the moon, but evidently forming a portion of the corona. I never lost sight of them when looking in that direction, and when the first ray of light was admitted from the sun, they vanished with the corona altogether and daylight was instantaneously restored."

The importance of these phenomena was now for the first time brought home to astronomers, and the desirability of investigating their true character. A variety of theories were advanced, some old and some new, some not far from the truth and others very much so. Professor von Felitsch, of Griefwald, published a treatise in which he proved to his own satisfaction that corona, prominences and chromosphere were purely optical appearances.

Some of the mists and haze enveloping the subject were cleared away by the eclipse of 1851, which was successfully observed in Norway and Sweden, but it was not until 1860 that the true character of these phenomena, that of solar appendages, was firmly established. This occasion marked an important epoch in this class of investigations from the fact that photography was now for the first time generally applied. The photographs possessed the great advantage of freedom from personal bias and of forming a permanent record which could be studied at leisure. Although nothing was previously known of the character of the rays with which the impression must be taken, as it happened the results were eminently satisfactory. The comparison of plates taken hundreds of miles apart showed identically the same forms, thus disposing of the notion that they were due to personal or atmospheric causes, while those taken at the same place, in close succession, showed the moon to pass over them, gradually covering or uncovering them as the case might be.

The eclipse of 1868 was distinguished by another great advance in the practical application of the spectroscope. Now for the first time the true character of the so-called prominences was demonstrated, viz., that of glowing gases or vapors shooting up to heights of fifty or a hundred thousand miles above the sun's surface, and composed in great part of hydrogen. A conspicuous line was also seen near the D line of sodium. As this corresponded to no chemical element then known, it was called the helium line. In 1895 helium was discovered in a gas obtained from the mineral cleveite, an interesting case of a chemical element first discovered in the sun.

In connection with this eclipse it was found that these prominences could be observed at any time when the sun was visible by a proper use of the spectroscope. This important discovery was hit upon independently by M. Janssen and Mr. Norman Lockyer. Both discoverers communicated their methods to the French Academy, the letters reaching the Secretary within a few minutes of each other. In commemoration of this event a medal was prepared bearing the effigies of both Janssen and Lockyer.

The principle employed in obtaining the images of the prominences is as follows: The light of these objects is largely monochromatic. If such a ray is passed through a prism it is bent out of its course, losing a little of its brightness by the absorption of the glass but not otherwise. The light due to the glare of the atmosphere, however, which is the cause of our inability to see these features whenever the sun is visible, being composed of all the colors of the spectrum, is dispersed and rendered so faint as not to interfere with the image of the prominence. The higher the dispersion, the darker is the background against which this image is seen. It was at first thought necessary to employ a narrow slit, thus gradually building up the prominence by taking narrow slices in succession. It was soon found that the slit could be opened wide enough to show the entire image at once. This discovery made possible the careful and deliberate study of this feature of the sun, with the result that more is probably known of it than could ever have been ascertained, had it been necessary as at first to employ only the few moments during total eclipse.

The next step in advance would seem to be in the direction of accomplishing for the corona what had been done for the prominences and thus make possible the study of this feature of the sun's environment under the same leisurely and deliberate conditions. This problem has received a great amount of attention during the past twenty years. Various methods of attack have been suggested and tried, but so far without success.

In 1882 Professor Huggins believed that he had solved the problem. By the use of plates sensitive only to the most prominent rays of the corona, he obtained photographs which had every appearance of being genuine pictures of the solar appendage. The results were regarded by many as genuine, while others doubted. Much discussion followed, some of it slightly fervid in temperature.

However, the test was simple as soon as an opportunity could be had for applying it. The eclipse of 1886 gave the wished-for opportunity. Photographs taken during totality were compared with those taken by Huggins's process, but alas! the results were far from identical. The supposed coronal forms were therefore fictitious.

Though much in the way of detail has been learned of the corona in connection with recent eclipses, it still remains very much of an enigma. Unless some new method may be found for attacking the problems which it presents, apparently their complete solution will be long delayed. Here too, as in other cases, the solution of one problem is likely to suggest a score of new ones, so that eclipse expeditions seem unlikely soon to be exclusively things of the past.

At the opening of the century, it can hardly be said that astronomers were in possession of more than two or three catalogues of stars which would be of any use whatever for the exact astronomy of today. Even these were of quite limited extent as regards the number of stars contained. There were, it is true, a number of such catalogues based upon the imperfect methods of the previous century, and a considerable amount of valuable material in the form of unreduced observations existed, but the latter was of little practical service so long as it remained in this form. Even if accessible, which was not always the case, very few could undertake the drudgery of searching through the records for the wished-for material, and when found, if found at all, to apply the reductions necessary to prepare it for practical use. It is to George Biddel Airy, who became Astronomer Royal in 1835, that astronomers owe the introduction of the present practice of reducing and publishing observations promptly, thus making them accessible to all.

The most valuable series thus buried out of sight at the beginning of the century was that of Bradley. The observations were made at Greenwich between the years 1750 and 1762. These were first rendered accessible by Bessel, who in 1818 published under the title 'Fundamenta Astronomiae,' a catalogue of 3112 stars constructed from all Bradley's observations. More recently a re-reduction has been published by Auwers, in which every refinement which the present state of science could suggest has been employed, in order to obtain from them the best possible results. This catalogue is of special value in such investigations as involve the stellar motions, the remoteness of the time of observation—140–150 years—being a great advantage in this respect. There was also a great mass of observed star places, the result of the untiring industry of LaCaille, D'Agelet and Lefrançais Lalande, nephew of the more widely celebrated astronomer. Most of this material was only placed in an accessible form after the nineteenth century was far advanced, the last contribution being the publication by our own Dr. Gould, in 1864, of the final reduction made under his direction of the observations of D'Agelet, all reduced to the epoch 1800.

The beginning of the century found Piazzi busily engaged at his observatory in Palermo accumulating material for his famous catalogue of 7646 stars, which finally appeared in 1814. As he possessed for this purpose an instrument superior to anything previously constructed, and was himself a careful and most industrious observer, this catalogue has been of very great value. A re-reduction of the observations is now in progress, based upon the more accurate values of the constants which we now possess, and with improvements in method unknown one hundred years ago, which cannot fail to add greatly to its usefulness.

As time went on observations were conducted with more or less regularity at various places, each observer or institution acting independently of what was done elsewhere. As a result, many stars were observed over and over again, and others, equally important, not at all. In 1866, however, the Astronomische Gesellschaft of Germany organized a systematic campaign, having for its object the accurate cataloguing of all stars of the northern heavens not fainter than the 9th or 9.5th magnitude. For this purpose the entire northern heavens were divided into zones of about 5° in width, and thirteen different observatories each undertook to observe one, or in some cases two, of these zones, the work all being done on a strictly uniform plan, so that the results shall be homogeneous throughout. This work has been in progress for more than thirty years—somewhat deliberately at some places, it must be said, but is now nearly completed. The plan has since been extended to include southern stars as far as the tropic of cancer. Meanwhile our own distinguished countryman, Dr. B. A. Gould, as the result of fifteen years' labor at Cordoba, Argentina, has given us a similar catalogue of 73,160 stars between the tropic of cancer and the south pole.

The great work, instituted by the Astronomische Gesellschaft in 1865, is still unfinished, yet an even more ambitious undertaking was inaugurated fourteen years ago by an international congress assembled at Paris for that purpose. This calls for a photographic survey of the heavens to be participated in by a number of observatories—eighteen have joined in the undertaking—two sets of plates being taken. The first set are to have sufficient length of exposure to give positions of all stars not fainter than the eleventh magnitude. These are to be measured and the resulting positions catalogued. When completed, this catalogue will include between two and three million stars. The second series of plates is to have a longer exposure, sufficient to show stars of the fourteenth magnitude and will furnish charts of the heavens. 22,154 plates are called for and many years will be required for its completion. The results already obtained show that star positions may be obtained in this way with an accuracy little if anything inferior to the results of meridian observation.

The problem of the past history and future destiny of the solar system has occupied much attention during the century. Near its beginning Laplace had announced his famous nebular hypothesis. For many years it seems to have been taken for granted that little if anything could be added to this theory. In a general way it may be said that it forms the foundation of whatever has been developed in this direction. Laplace began with the sun already existing, surrounded with an atmosphere of heated vapor extending beyond the farthest planet. This body revolved on its axis and gradually shrunk as its heat was radiated into space. The linear velocity of the outer parts remaining constant, the angular velocity would constantly increase until in time the centrifugal force became equal to the centripetal when the central part separated, leaving the equatorial part in the form of a ring. This ring contained the material out of which the outermost planet was formed. Successive repetitions of the process produced the different planets, and these in turn produced satellites in the same manner. The rings of Saturn were held to be almost an unanswerable piece of evidence in favor of the theory. Though, without doubt, the system was evolved in some way from a primitive nebula, we may say with certainty that it did not follow the orderly course marked out for it by Laplace. The subsequent discovery of the great principle of the conservation of energy dispensed with the original hypothesis which started with the mass in a heated condition, at the same time that it associated with it the important question as to the supply of heat and other forms of energy which are constantly being poured out with such prodigality by the sun. If we suppose the matter composing our system to have been at one time a nebulous mass, filling the present orbit of Neptune, the temperature may then have corresponded to the absolute zero so far as our purposes are concerned. The process of shrinking and condensation to the present condition would have evolved an amount of heat quite equal to that which the problem calls for, but, unless a constant supply is furnished from some source, the present process of radiation will soon come to an end. The explanation of this supply which is generally accepted was first announced by Helmholtz in 1854. He ascribed it to the shrinkage of the sun now going on. It is capable of mathematical proof that a body consisting of matter in the form of a gas, which is the case with the sun, by the process of condensation due to the pressure produced by its own attraction, will constantly grow hotter so long as it remains a gas. This operation must end when a considerable portion of its matter is reduced to a liquid or solid form. The system, then, had a beginning, and as a consequence it must come to an end. Or more properly speaking the present condition of things can not last forever. Thus Helmholtz concludes that if the intensity of radiation has been uniform from the beginning, the present order cannot have existed longer than 22,000,000 years. Others make the period less. Looking into the future, at the end of 5,000,000 years, the sun will have contracted to half its present volume, and at the end of another 5,000,000 years it will be mainly if not entirely solid, and must have ceased to be self-luminous much earlier. An interesting corollary to this subject is the principle of tidal evolution developed by Mr. G. H. Darwin. Supposing the moon to have been separated from the earth by some process at a time when the matter composing them was in a liquid condition, each body would produce enormous tides in the other. Consider those produced on the earth by the action of the moon: the effect would be on the one hand to retard the earth in its rate of rotation, and on the other to drive the moon farther from the earth. Without going further into detail, we may say that Mr. Darwin finds that if no other causes were at work not less than 50,000,000 years would be required for the evolution of the system of the earth and moon as it now exists.

It was not far from the beginning of the century that Herschel attempted the solution of the greatest of all problems—that of the structure of the universe. The problem proved, as may be supposed, quite impossible of solution by methods then available. Much has been learned during the century which was unknown to Herschel, but we seem to be as far as ever from the final solution. Instead of an orderly distribution of stars, clusters and systems, we find all apparently intermingled with vast cosmic clouds and huge dark bodies, possibly burned-out suns. For anything we know these latter may be as numerous or more so than the brilliant ones. Will the labor of another century bring order out of this seeming confusion or will it only disclose still greater complexities unknown to us? Time alone can tell.

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