THE PAST CENTURY.

Its Progress in Great Subjects.

A SET OF REMARKABLE ARTICLES

Fourth Paper of the Series, by Sir Norman Lockyer.

"ASTRONOMY."

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Sir Joseph Norman Lockyer, K. C. B., is probably the best known among living English astronomers, not only from his daring speculations, but from the fact that he has told of his discoveries in language that was intelligible to the general public. For thirty years he has been associated with British government institutions for the advancement of science, after distinguished work in the reform of the War Office. He was made a Fellow of the Royal Astronomical Society in 1866, his first contributions being on the planet Mars, and of the Royal Society nine years later. In 1868 he invented a means of observing the solar bombs without an eclipse, a discovery commemorated by the Prussian Government by the striking of a special medal. In 1869 he became Professor of Astronomical Physics in the Royal College of Science and he has been chief of the Government eclipse expeditions in 1870, 1871, 1875, 1878, 1882, 1886 and 1898. In 1878 he observed the total eclipse of the sun in the United States. He has received the Rumford Medal from the Royal Society and the Janssen Medal from the Institute of France, of which he is a corresponding member. On the occasion of the Queen's jubilee he was made a Knight Commander of the Bath.

Sir Norman Lockyer has busied himself with many branches of astronomy, but more especially with the sun, with spectroscopic work and with the philosophic deductions from the results of astronomical observations. He has been a leading advocate from astronomical grounds of the theory that all the chemical elements can ultimately be reduced to one, and is the originator of the meteoric hypothesis of the universe as a substitute for the nebular hypothesis of Laplace and Herschel, which is perhaps the most elaborate attempt to explain our cosmogony that has been made so far. From the beginning Sir Norman Lockyer has been editor of Nature.

In looking back over a century's work in the oldest of the sciences one is struck not only by the enormous advance that has been made in those branches of the science dealing with the motions of the heavenly bodies which were cultivated at least some years ago by early dwellers in the valleys of the Nile, Tigris and Euphrates, but with the fact that during the century that is passing away a perfectly new science of astronomy has arisen. By annexing physics and chemistry astronomers now study the motions of the particles of which all celestial bodies are composed; a new molecular astronomy has now been firmly established side by side with the old molar astronomy which formerly alone occupied the thoughts of star gazers.

Along this new line our knowledge has advanced by leaps and bounds, and the results already obtained in expanding and perfecting man's views of nature in all her beauty and immensity are second to none which have been garnered during the last hundred years.

THE POSITION AT THE BEGINNING OF THE CENTURY.

It may be well before attempting to obtain a glimpse of recent progress that we should try to grasp the state of the science at the time when the nineteenth century was about to dawn, and this, perhaps, can be best accomplished by seeing what men were working at this period, at which the greatest activity was to be found in Germany; there was no permanent observatory in the southern hemisphere or in the United States.

First and foremost among the workers—he has, in fact, been described as "the greatest of modern astronomers"—was William Herschel, a German domiciled in England. In the year 1773 he hired a telescope, and with this small instrument he obtained his first glimpses of the rich fields of exploration open in the skies. From that time onward he had one fixed purpose in his mind which was to obtain as intimate knowledge as possible of the construction of the heavens.

To do this, of course, great optical power was necessary, and such was his energy that, as large instruments were not to be obtained at any price, he set to work and made them himself.

Herschel presented the beginning of the nineteenth century not only with a definite idea of the constitution of the solar system, based on a connected body of facts and deductions from facts, as gleaned through his telescopes, but observations without number in many fields. He discovered a new planet, Uranus, and several satellites of the planets, published catalogues of nebulæ, established the gravitational bond between many "double stars" and carried on observations of the sun, then supposed to be a habitable globe. What Herschel did for observational astronomy and deductions therefrom, Laplace did for the furtherance of our knowledge concerning the exact motions of the bodies comprising the solar system. Newton had long before announced that gravitation was universal, and Laplace brought together investigations undertaken to determine the validity of this law. These were given to the world in his wonderful book on "Celestial Mechanics," the first volumes of which appeared in 1799.

A survey of the work of these two great astronomers gives one an idea of what was going on in observational and mathematical astronomy at the beginning of the century.

The study was now destined to make rapid strides, as not only were new optical instruments, some designed for special purposes, introduced, new mathematical processes applied, fresh fields for research opened up, but the number of workers was considerably augmented by the increased means available so much so, indeed, that the first astronomical periodical was founded by Von Zach in 1800 to facilitate intercommunications between the observers.

The first evening of the nineteenth century (Jan. 1, 1801) augured well for progress. It had long been thought that all the members of the solar system had not as yet been discovered, and there was a considerable gap between the planets Mars and Jupiter, indicated by Bode's law. Observers were organized to make a thorough search for the missing planet, portions of the sky being divided between them for minute examination. It fell to the Italian observer, Piazzi, to discover a small body which was moving in an orbit between these two planets, on the date named. The century thus began with a sensation, and because the new body, which was named "Ceres," was not of sufficient size to be accepted as the "missing planet" the idea was suggested that perhaps it was a fragment of a larger planet that had once filled a vacuum in the past.

An opportunity here arose for mathematical astronomy to come to the help of the observer, for "Ceres" soon was lost in the solar rays and it was left to rediscover it, after it had passed behind the sun, an approximate knowledge of its path and future position was necessary.

With the then existing methods of computation of orbits it was impossible to have numerous observations to use as data for the calculation. The necessary data available in the case of Ceres were not sufficient for the application of the method. The occasion then called for a man of the greatest mathematical power of the nineteenth century, and Karl Friedrich Gauss, who, although only 24 years of age, undertook the solution of the problem by employing a system which he had devised, known as "the method of least squares," which enabled him to obtain a somewhat probable result from a given set of observations.

This, with a more general method of orbit computation, also originated by himself, was sufficient to enable him to calculate late future positions of Ceres, and on the anniversary of the original discovery, with a certain amount of anxiety, the equations found the planet in very close to the position assigned by Gauss. No great was the curiosity regarding the nature of the planet which was supposed to have been shattered, that numerous observers at once commenced to search after other fragments.

These were the *adventures* of Ceres and thereabouts, but the seed of much future work was sown. Kant and Laplace had already occupied themselves with theories as to the world formation, and spectrum analysis as applied to the heavenly bodies may be said to have been started by Wollaston's observations of dark lines in the solar spectrum in 1802. Fraunhofer was then a boy at school. In the same year the first photographic images were produced by Wedgewood and Davy.

OBSERVATORIES.

It has been stated that at the beginning of the century there were no permanent observatories either in the southern hemisphere or in the United States. The end of the century finds us with 200 observatories all told, of which fourteen are south of the equator and forty-seven in the United States, among which latter are the best equipped and most active in the world.

The observatory of Parramatta was the first established in 1820 in the southern hemisphere. This was followed by that at the Cape of Good Hope in 1829. Of the more modern southern observatories from which the best work has come we may mention Cordova, the seat of Gould's important investigations, established in 1885, and Arequipa, a dependency of Harvard, whence the spectra of the southern stars have been secured, under still more recently (1888).

I believe, but I do not know, that the large number of American observatories have radiated from Cincinnati, where, in consequence of eloquent appeals, both by voice and pen, from Mitchell, then professor of astronomy, an observatory was commenced in 1845. There can be no doubt that at the present moment, with the numerous well equipped and active observatories, and the careful and thorough teaching established side by side with them, which enables neophytes students to use the various instruments, the United States in matters astronomical fills the position accepted by Germany at the beginning of the century.

In Europe special observatories have been established at Meudon, Kensington and Potsdam, so that new astrophysical inquiries may be undertaken without interfering with the prosecution, or extension of the important meridional work carried on at Paris, Greenwich and Berlin. A large proportion of the observations made by the Lick and Yerkes observatories in the United States has been astrophysical.

One of the special inquiries committed to the charge of the Solar Physics Observatory at Kensington at its establishment by the British Government had relation to the possibility of running home meteorological changes on the earth, especially those followed by drought and famines in various parts of the Empire, to the varying changes in the sun indicated by the ebb and flow of spots on its surface. With this end in view observations of the sun were commenced in India and the Mauritius to supplement those taken at Greenwich. At the same time other daily observations of sun spots by a different method were commenced at Kensington.

This kind of work was at first considered ideally useless. We shall see later on what has become of it.

IMPROVEMENTS IN TELESCOPES.

The progress in astronomical science throughout the closing century has naturally to a great extent depended upon the advances made both in the optics of the telescope and the way in which they are mounted, either with circles to record exact times and positions, or made to move so as to keep a star or other celestial objects in the field of view while under observation. The perfection of definition and the magnitude of the lenses employed in the modern instrument have been responsible for many important discoveries.

Ever since the telescope was invented Galileo's lens was smaller than those used in spectacles, men's minds have been concentrated on producing instruments of larger and larger size to penetrate the cosmos to its innermost depths.

At the beginning of this century we were, as we have seen already, in the reign of reflectors of large dimensions. Herschel's forty-foot mirror, the instrument he was using in 1801, which had a focal length of forty feet, was capable of being employed with high magnifying powers, and it was the judicious use of these, on occasions when the finest of weather prevailed, that enabled him to enrich so extensively our knowledge of the stellar and planetary systems. For the ordinary work of astronomy, however, especially when circles are used, refractors are the more suitable instruments. This form suffers less from the vicissitudes of weather and temperature, and is therefore more suited where exact measurements are required.

Toward the end of the eighteenth century a Swiss artisan, Pierre Guinand, after many years of patient labor, succeeded in producing pure pieces of flint glass as large as six inches in diameter. The modern refracting telescope in Glasgow and elsewhere.

In this form was started at Munich the famous optical and mechanical work in which many men of genius took an active and astronomical world. Fortune is proverbially fickle, and many failures to found, and under the leadership of the great German astronomer Bessel, great strides were made in the measurement of parallaxes. Fraunhofer, who had been taught working under the direction of Schmid, and received various commissions in connection with glass, was unfortunate not to be dubbed. In each instance the artisan's work assisted of gradually increasing in size, ultimately reaching proportions in astronomical work is that dealing with spectrum analysis, which although suggested as early as the time of Kepler, did not receive any impetus as regards its application to celestial bodies until the beginning of the present century at the hands of Wollaston and Fraunhofer. Then, however, it still lacked the chemical touch supplied afterward by Kirchhoff and Bunsen. This showed us that the spectrum observed when the light from any heated body is passed through a prism is as much to the chemical composition of the light source, the constituents of a vapor which is in a condition to absorb light can be determined by an extension of the same principle. Kirchhoff assisted by Stokes, Angström and Balfour Stewart when the results were more fully considered.

The first celestial body toward which the spectroscope was turned was our own luminary, the sun.

Wollaston had discovered that on examination was crossed by a few dark lines, followed soon from Fraunhofer, who by 1814 mapped with instruments of greater power that the solar spectrum was crossed not with few dark lines, but by some hundreds. Subsequent with examining the spectra of the solar Fraunhofer noticed his instrument brought the stars, the light of which he also examined, so that he may be more exact the character of stellar spectra. It is now the credit of Sir John Herschel that from that time forward he knew that the stars did not be unique, but that they were, as before stated, the known in the solar spectrum were mapped with great diligence by Kirchhoff in 1861 in comparison with Angström and Thalén, and it is now generally agreed that the elements in the sun are the same as those in the earth.

The observations of the sun were carried to a great extent by means of the spectroscope, but as it was no longer a habitable globe, but one with the earth's temperature at a fierce heat, surrounded by an atmosphere of metallic vapors, chief among them iron, also in a state of dissociation. To these metallic vapors Angström added hydrogen, which after a time.

Hence there was established a firm link between the heavens and the earth, the first step to the problem of the chemistry of the universe.

It is not only that, but as Frauenhofer made the instrumental equipment should be complete, spectroscopes were made on a larger scale, prisms, which meant greater dispersion, were employed to render the nearer shades of the lines in spectra more accurate. The growth of our knowledge especially necessitated the making of maps of the lines in the solar spectrum, and in the spectra of the chemical elements which had been compared with it on a fixed scale. This was done by Angström, who utilized for this purpose the diffraction grating invented by Fraunhofer, and defined the position of all lines in spectra by their wave lengths, in tenths of millionths of millimetres.

In 1866 Sir Norman Lockyer began a work on the stars by a first attempt at classification. Two years later Huggins and Miller published maps of the spectra of some stars. Donati demonstrated that comets gave rich spectra and Huggins did the same for nebulæ.

By these observations comets and nebulæ were shown to be spectroscopically different from stars which at that time were studied by their dark lines only.

Chiefly by the labors of Pickering, the energetic head of the Harvard Observatory, science has been enriched during the later years by observations of thousands of stellar spectra, the study of which has brought about the most marvellous advance in our knowledge.

These priceless data have enabled us now to classify the stars not only by their brightness, or their color, but by their chemistry.

Next to be chronicled is the application of the so-called Doppler-Fizeau principle, which teaches us that when a light source is approaching or receding from us the light waves are crushed together or drawn out, so that the wave length is changed. The amount of change gives us the velocity of approach or recession, so that the rate of movement of stars toward or from the earth, or the uprush or downrush of the solar vapors on the sun's disk can be accurately determined. A further utilization of this principle is found when the stars are so close together that they appear as one if the plane of motion passes near the earth. A line common to the spectra of both stars will appear double twice in each revolution, when the motion to or from the earth, or, as it is termed, "in the line of sight," is greatest. "Spectroscopic doubles," as these stars are called, yield up many of their secrets which otherwise would elude us. Their line of revolution, the size of the orbit and the combined mass can be determined.

Coming from the stars to the sun.

By the device of throwing an image of the sun on the slit of the spectroscope the spectra of solar spots have been studied from 1891 onward, and a little later the brighter portions of the sun's outer envelopes, revealed till then only during eclipses, were brought within our ken spectroscopically so that they are now studied every day.

CELESTIAL PHOTOGRAPHY.

Wedgewood and Davy, in 1802, made prints on paper by means of silver salts, but it was not until 1830 that Niepce and Daguerre founded photography, which Arago, in an address to the French Chamber, at once suggested might subsequently be used to map of the positions of stars.

In spite of Sir John Herschel's carrying out a series of experiments so important for our correct knowledge of the sensitiveness of stars in the early stages of photography that I have no hesitation in quoting from one of Herschel's manuscripts relating to a deposit on a glass plate of "minute particles of silver from a mixed solution of the hyposulphites of silver and soda." The manuscript states: "After forty-eight hours time colors had just formed a film (microscopically) of gamboge, the white off were slowly by a second. Having stored it I found that it was very little affected by light, and by washing it with nitrate of silver, weak and drying it, it became highly sensitive. In this state I took a camera picture of the house opposite."

The original of the above-mentioned photograph, the first photograph ever taken on glass, is now in the science collection at Cape Victoria and Albert Museum, South Kensington.

In the early days of photography colored glasses were used in order to investigate the source of inference as from the photographic plate. Sir John Herschel was among the first to propose that such investigations should be made direct with a spectrum, and he, like Dr. J. W. Draper, stated that he had found a new kind of light beyond the blue end of the spectrum, as the photographic plate showed a portion of the spectrum there which was not visible to the eye. Alvanes followed advance and in 1847 Becquerel photographed the whole solar spectrum, in colors, with respect to the lines registered by the hand and eye of Fraunhofer, not only the blue, but the complete spectrum from Thomson's "actinic light" as he called the ultra violet, to the extreme red.

The first photograph of a celestial object was one of the moon secured by Dr. J. W. Draper in 1840, as he said he was in 1845, as I know, before a Daguerreotype was taken of the moon, this was done by Bond's and Fossey, while the first photographs of the sun were taken at Harvard in 1850. After the introduction of the wet collodion process regular photographs of the moon's surface were commenced at Mr. John Herschel's observatory at Kew in 1858 and the total solar eclipse of 1860 was made memorable by the photographs of Mr. De La Rue, who before that time had secured admirable photographs of the moon, as also had Rutherfurd.

Photography now began to be used in the data and to questions of science.

The first laboratory photographs of the spectra of the chemical elements was taken by Dr. W. A. Miller in 1862.

Rutherfurd was the first to secure a photograph of the solar spectrum with a suitable dispersion by means of prisms.

In 1863 Mascart undertook a comparison of the photographic investigation of the solar spectrum, in colors, with respect to the lines registered by the hand and eye of Fraunhofer, not only the line, but the complete spectrum from Thomson's "actinic light" as he called the ultra violet, to the extreme red.

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