one would expect to be strong, do not so appear; and *vice versa*. Images which would be strong for the right and left edges separately need not be so when the former are superimposed on the latter.

With these remarks I believe to have given a sufficient account of these interesting diffractions. I began the work since in all my reading in physics I had never seen a reference to these ubiquitous phenomena, and I hoped with the present paper to furnish at least one contribution of known whereabouts. In the course of the work I found much greater subtlety than I was prepared for, and some of the cases given are available for more rigorous treatment elsewhere.

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THE CROSSLEY REFLECTOR OF THE LICK OBSERVATORY.

THE leading article in the June number of *The Astrophysical Journal* has the above title and was written by Professor Keeler. It is a very full account of the instrument and of the work accomplished with this telescope since its installation on Mt. Hamilton. I am very glad to comply with the request of the editor to furnish an abstract for SCIENCE.

The frontispiece of the number is an excellent heliogravure plate of the 'Trifid' nebula in Sagittarius, from a negative made with the Crossley reflector. In this connection it ought to be said that no known method of reproduction gives all the detail to be seen on the original negatives of such subjects. There are also half-tone illustrations, from photographs, of the details of the telescope and its observatory.

This telescope was made by Dr. A. A. Common, of London, in 1879, and used by him until 1885, when he decided to build one of 5 feet aperture. He then sold the 3-foot instrument to Edward Crossley, Esq., of Halifax, England. For the construction of the instrument and for photographs obtained with it, Dr. Common was awarded the gold medal of the Royal Astronomical Society in 1884.

Mr. Crossley built a very complete observatory and dome for the telescope and used it for a number of years. The climate of Halifax was not adapted to the use of reflectors, however, and in 1895, at the request of Professor Holden, then director of the Lick Observatory, Mr. Crossley presented the telescope and its dome to this institution. The expenses incurred in transporting it from England and in erecting a suitable building on Mt. Hamilton were borne by friends of the Lick Observatory, principally residents of California. It was mounted here the same year. Its dome is situated on a spur of the mountain some 350 yards to the south of the main observatory and about 150 feet lower. The building contains, in addition to the dome and vestibule, a photographic dark-room, a study, a room for apparatus and storage, and a room for the hydraulic machinery which was used in England to revolve the dome. The present site is such that the hydraulic system which is used for the large refractor is not available for the Crossley reflector. The dome is turned by hand by means of an endless rope and a set of gears working in a cast-iron rack bolted to the inside of the sole plate of the dome. The dome is covered with sheet-iron, the framework being of iron girders. It is of the usual form, with a shutter in two parts which are rolled to each side, exposing a slit six feet wide. The slit extends well beyond the zenith. From the inside of the dome is swung a system of platforms around the telescope for the observer to stand upon. The cylindrical walls upon which the dome rests are double, 36¼ feet inside diameter. The dome itself is 38 feet 9 inches in diameter. The lower half of the observing slit was fitted with a screen of tarpaulin by Professor Keeler, which proved very useful against the winds which are so prevalent on Mt. Hamilton.

The telescope and its mounting are very completely described and figured by Dr. Common in Vol. 46 of the *Memoirs* of the Royal Astronomical Society. The telescope was designed especially for photographic work, in which it is very desirable to continue an exposure uninterrupted, across the meridian. This cannot be done in the usual form of mounting where the declination axis is attached to the middle of the tube of the telescope and to one end of a short polar axis. Dr. Common obviated this difficulty by placing the declination axis at the extreme lower end of the telescope tube, the axis of the telescope always being in the same meridian plane as the polar axis. The large mirror is *above* the declination axis, and hence requires to be counterbalanced. This counterbalancing of mirror and tube is effected by placing slabs of lead in two boxes which extend a short distance beyond the declination axis. Professor Keeler points out that the construction adopted by Dr. Common for his 5-foot reflector is a great improvement. In the latter instrument the tube is swung near its lower end between two large ears attached to the polar axis, the pivots forming the declination axis. The mirror is placed at the extreme end of the tube and thus acts as a counterbalance.

The construction of the mounting limits observations to 25° south declination. In London, for the latitude of which the mounting was constructed, this meant a zenith distance of 77° on the meridian, but at Mt. Hamilton it is only 62°. In our more southern latitude a considerable region is thus unfortunately out of reach of the telescope.

From his experience with the Crossley reflector, Professor Keeler came to the conclusion that the definition in the case of a reflector, as well as a refractor, depends almost wholly on external conditions, and that large masses of metal near the mirror have little effect, at least where the range of temperature is as small as at Mt. Hamilton.

The telescope is used as a Newtonian. It is provided with two large mirrors, each three feet in aperture, and of 17 feet 6.1 inches focal length. These mirrors were made by Mr. Calver. The one in use at present (mirror A) was refigured by Sir Howard Grubb, and is practically perfect for photographic work. It may be added that this mirror has so far been used with the same coating of silver which it had when received from England. Mirror B has not been used at Mt. Hamilton.

The diagonal mirror is round, its diameter being 8.9 inches. Its distance inside the focus is 29 inches.

The field of view after reflection is, therefore, elliptical. Its mounting is such, however, as to cut off an almost circular section of rays from the large mirror.

The tube of the telescope is a square framework of iron tubes braced by diagonal rods and is provided with curtains of black cloth to close the tube in. Professor Keeler found that any fogging of the plate was due to diffused skylight and the curtains have therefore been dispensed with. The outer end can be rotated about the axis of the telescope to bring the eyepiece into as comfortable a position as possible. This section carries the diagonal mirror and the eye end. The latter has the customary arrangement for focusing and is made to take the short tubes, one of which is arranged for visual and the other for photographic work. The photographic slide contains, in addition to the double motion device, an adjustable slide carrying an eye-piece with cross wires for guiding. This is placed very close to the plate-holder slide and clamped to it.

The image of a star is kept bisected by turning the proper screws attached to the movable frame.

Upon taking charge of the Lick Observatory in June, 1898, Professor Keeler decided to devote his own observing time to the Crossley reflector, notwithstanding that his previous experience had all been with refractors. Upon making a careful examination of the instrument, he found that a number of changes would be necessary before satisfactory results could be expected. Some of these were required on account of the change in latitude and the different climatic conditions existing at Mt. Hamilton. The brick pier upon which the telescope rested was found to be too high for the greatest convenience and usefulness and was lowered two feet. The polar axis was found to work hard, the plan of mercury flotation not being successful and the construction being such that the friction was increased in this lower latitude. This caused the driving clock to run irregularly, and a more powerful one was built at the observatory from designs by Professor Hussey. A further cause of irregularity was found in one of the wheels of the differential gearing for giving slow motion in right ascension. As long exposure photographs near the pole required a considerable degree of accuracy in the position of the polar axis, some time was spent in devising methods for adjusting a telescope of this design. The methods used for a telescope of the ordinary construction do not suffice. One very promising plan was to secure trails of the stars near the pole on the same plate in two positions of the telescope 180° apart. Consistent results were not obtained, however, owing to the instability of the large mirror. The axis was finally adjusted by using a long finder for observations of Polaris in the usual way, a watch telescope being fastened to the mounting in such a way that an object on the southern horizon could be observed during the process of shifting the iron pier.

The resolving power of the telescope was tested by visual observations of close double stars, with the result that stars of about the 8th magnitude and of nearly equal brightness could be separated with a magnifying power of 620, if as much as $0''.3$ apart. Stars of 5th magnitude and this distance could not be seen double owing to the increased amount of light. In connection with these observations Professor Keeler remarks: "Although the theoretical limit of resolution for a three-foot aperture is not reached in these observations, I do not think the mirror can do any better."

It is, however, in photographic work that the greatest field for the Crossley reflector appears to lie, and it is largely with respect to this line of work that any changes have been considered.

The ratio of aperture to focal length is so large in the instrument (a little greater than 1 to 6) that the field of view over which the star images are sufficiently free from distortion is only about 16′, or one inch, in diameter. The photographic equipment was designed to use plates $3\frac{1}{4}$x$4\frac{1}{4}$ inches in size. These are sufficiently large, for even with this size the star images show decided wings near the edges of the plates.

Several minor changes and improvements were made in the eye-end apparatus. Metal plate-holders were substituted for the wooden ones, as the latter could not be depended upon to keep their positions throughout the long exposures. Clamping screws were added to hold the plate-holder firmly in place. Spider threads were substituted for the coarse wires in the guiding eyepiece, and a system of mirrors added to illuminate the declination thread. A small electric lamp is used to illuminate the wires, current being supplied from the storage battery at the main observatory.

A piece of ruby glass between the lamp and wires prevents fogging of the plate.

As designed, the wires of the guiding eye-piece were in the same plane as the photographic plate, but as they were some three inches from the optical axis of the telescope a star's image was a crescent, and therefore unsuitable for purposes of accurate guiding. Outside this plane the star image, as seen in the guiding eye-piece, changes to an arrow-head whose point is directed to the optical axis of the telescope. As it was found that the focus of the telescope changed during long exposures, an image of the guiding star which was sensitive to changes of focus was highly desirable. Professor Keeler found that between the crescent and the arrow-head there was an image formed by the intersection, at an acute angle, of two well defined caustic curves in the aberration pattern. The intersection of these caustics offers a very satisfactory image on which to guide, and at the same time is very sensitive to changes of focus. The relation of the plane of the photographic plate and of the guiding threads was so altered that when the former was adjusted to accurate focus, by means of a high power positive eye-piece, a star's image assumed this particular form in the guiding eye-piece. By noting carefully at the commencement of the exposure the form of the star's image, the focus could be corrected by means of the focusing screw as changes were seen to occur. Photographs of four hours' duration were secured on which the star disks near the center of the plate were almost perfectly round, the smallest disks being from 2″ to 3″ in diameter.

In compensating for the variations of the motion of the telescope from that of the stars by moving the plate-holder, there is a limit which Professor Keeler has pointed out, to the amount which the plate-holder may be moved without causing distortions in some of the star images. This distortion arises from the fact that the motion of the plate-holder is in a straight line, while the stars describe small circles about the pole. Hence compensation by such a method of guiding is exact at the equator only. The amount which the plate-holder may be moved without causing an appreciable elongation of the star's image may be found from the formula,

$$d = \frac{e \cos \delta_1}{\cos \delta_2 - \cos \delta_1}$$

in which d is the displacement of the plate-holder; e the amount of elongation in the star's image which becomes perceptible; δ_1 the declination of the guiding star, and δ_2 the declination of the star on the plate farthest from the guiding star in declination. In the Crossley reflector it was found that at a declination of 70° (where many nebulæ were to be photographed) the plate-holder could not be moved in right ascension more than 1.0 mm. without causing an elongation of the fainter star images which were farthest from the guiding eye-piece in declination, of an amount equal to their own diameters. There is also a small distortion in declination, but on the scale of the Crossley photographs it is negligible.

To prevent halation in the long exposures, the plates are backed with a coating of Carbutt's 'Columbian Backing,' which has proved very satisfactory.

One of the earliest photographs obtained by Professor Keeler was a very successful one of the great nebula in Orion. This and similar photographs pointed to the great efficiency of the instrument for showing the structure in the nebulæ, and led to the systematic photographing of all the brighter ones within reach of the telescope. This program had been about half completed by Professor Keeler before his untimely death. In the prosecution of this work, great numbers of faint nebulæ were revealed; on one plate no less than *thirty-one* new ones were found. The accurate positions of these new nebulæ are now being measured by Mr. Palmer. He finds, on the average, about *ten* new nebulæ to the plate.

Professor Keeler summarizes the conclusions to be drawn from the work so far accomplished as follows:

"1. Many thousands of unrecorded nebulæ exist in the sky. A conservative estimate places the number within reach of the Crossley reflector at about 120,000. The number of nebulæ in our catalogues is but a small fraction of this.

"2. These nebulæ exhibit all gradations of apparent size, from the great nebula in Andromeda down to an object which is hardly distinguishable from a faint star disk.

"3. Most of these nebulæ have a spiral structure.

"To these conclusions I may add another, of more restricted significance, though the evidence in favor of it is not yet complete. Among the objects which have been photographed with the Crossley telescope are most of the 'double' nebulæ figured in Sir John Herschel's catalogue (*Phil. Trans.*, 1833, Plate XV.). The actual nebulæ, as photographed, have almost no resemblance to the figures. They are, in fact, spirals, sometimes of very beautiful and complex structure; and, in any one of the nebulæ, the secondary nucleus of Herschel's figure is either a part of the spiral approaching the main nucleus in brightness, or it cannot be identified with any real part of the object. The significance of this somewhat destructive conclusion lies in the fact that these figures of Herschel have sometimes been regarded as furnishing analogies for the figures which Poincaré has deduced, from theoretical considerations, as being among the possible forms assumed by a rotating fluid mass; in other words, they have been regarded as illustrating an early stage in the development of double star systems. The actual conditions of motion in these particular nebulæ, as indicated by the photographs, are obviously very much more complicated than those considered in the theoretical discussion."

As evidence of the power of the Crossley telescope it may be noted that a very faint image of the Ring Nebula in Lyra was obtained with an exposure of thirty seconds; with an exposure of two minutes a well marked impression of the nebula is obtained and a surprisingly strong image of the central star, which is a very faint object visually in the 36-inch refractor.

In the course of the work on the nebulæ, two new asteroids have been discovered, by means of their trails, one at least of which was so faint as not to be seen with certainty with the large refractor. Observations of these asteroids were made photographically, and were found to compare very favorably in accuracy with such observations made visually with a large refractor. These results point to the great value of this instrument for finding and giving the positions of asteriods, whose places are approximately known.

One of the most promising fields for the Crossley reflector is undoubtedly that of stellar spectroscopy. Two spectrographs have been designed and built at the observatory. One is due to the generosity of Miss C. W. Bruce, and contains three prisms of 60° and one of 30°, with an aperture of two inches; the other has a single quartz prism and is intended to give measurable, though small, spectra of some special objects nearly at the limit of vision of the telescope.

From what has been said, it will be seen that a large amount of work of great importance has already been accomplished with the Crossley reflector, besides opening up new fields for future investigation.

Professor Keeler clearly recognized the

necessity for attention to the small details as an element of success. He says:

"The foregoing account of the small changes which have been made in the Crossley telescope and its accessories may appear to be unnecessarily detailed, yet these small changes have greatly increased the practical efficiency of the instrument, and therefore, small as they are, they are important. Particularly with an instrument of this character, the difference between poor and good results lies in the observance of just such small details as I have described."

C. D. PERRINE.

LICK OBSERVATORY,
UNIVERSITY OF CALIFORNIA,
September 23, 1900.

ADDRESS OF THE PRESIDENT OF THE CHEMICAL SECTION OF THE BRITISH ASSOCIATION.

THE MODERN SYSTEM OF TEACHING PRACTICAL INORGANIC CHEMISTRY AND ITS DEVELOPMENT.

IN choosing for the subject of my Address to-day the development of the teaching of practical inorganic chemistry I do so, not only on account of the great importance of the subject, but also because it does not appear that this matter has been brought before this Section, in the President's Address at all events, during the last few years.

In dealing generally with the subject of the teaching of chemistry as a branch of science it may be well in the first place to consider the value of such teaching as a means of general education, and to turn our attention for a few minutes to the development of the teaching of science in schools.

There can be no doubt that there has been great progress in the teaching of science in schools during the last forty years, and this is very evident from the perusal of the essay, entitled 'Education: Intellectual, Moral, and Physical,' which Herbert Spencer wrote in 1859. After giving his reasons for considering the study of science of primary importance in education, Herbert Spencer continues: "While what we call civilization could never have arisen had it not been for science, science forms scarcely an appreciable element in our so-called civilized training."

From this it is apparent that science was not taught to any appreciable extent in schools at that date, though doubtless in some few schools occasional lectures were given on such scientific subjects as physiology, anatomy, astronomy and mechanics.

Herbert Spencer's pamphlet appears to have had only a very gradual effect towards the introduction of science into schemes of education. For many years chemical instruction was only given in schools at the schoolroom desk, or at the best from the lecture table, and many of the most modern of schools had no laboratories.

The first school to give any practical instruction in chemistry was apparently the City of London School, at which, in the year 1847, Mr. Hall was appointed teacher of chemistry, and there he continued to teach until 1869.* Besides the lecture theater and a room for storing apparatus, Mr. Hall's department contained a long room, or rather passage, leading into the lecture theater, and closed at each end with glass doors. In this room, which was fitted up as a laboratory, and used principally as a preparation room for the lectures, Mr. Hall performed experiments with the few boys who assisted him with his lectures. As accommodation was at that time strictly limited, he used to suggest simple experiments and

*Mr. A. T. Pollard, M.A., Head Master of the City of London School, has kindly instituted a search among the bound copies of the boys' terminal reports, and informs me that in the School form of Terminal Report a heading for Chemistry was introduced in the year 1847, the year of Mr. Hall's appointment.