SOME RECENT RESEARCHES ON THE GREAT NEBULA IN ORION.

Under the directorship of Prof. J. E. Keeler, the activities of the Lick Observatory at Mount Hamilton, Cal., with its magnificent 36-inch refractor, have been vastly increased. The wonderful nebula in Orion, one of the most distant and remarkable objects in the terrestrial universe, has been of late the subject of patient and protracted observation by Prof. Keeler, whose conclusions are embodied in the article below, written from information supplied by him and by him carefully revised.

Among the celestial objects which are regarded by astronomers with exceptional interest is the great nebula in the sword handle of Orion. Missed by the acute observer Al Sufi, to whom the nebula of Andromeda was known before A. D. 900, and, singularly enough, by Galileo, it seems to have been first discovered by Cysat, of Lucerne, in 1618. It was independently discovered thirty-eight years later by the eminent Dutch astronomer Huyghens, to whom we owe the earliest of the drawings that have come down to us. Since then it is safe to say that hardly a telescope has been made which has not, at one time or another, been directed to this wonderful object.

Until very recently, the only method of recording the shape of the nebula was that of drawing, by hand and eye, at the telescope. The first drawings were very rough. The positions of the stars in the nebula, as well as the outlines of the nebula itself, were merely sketched in by estimate. It is, moreover, sufficiently obvious that some of the early draughtsmen were by no means proficient in the use of the pencil, though we may concede that their drawings, in the form in which they have been published, owe some of their roughness to the engraver. Later observers conducted their work with more care. They plotted the stars from accurately observed positions, and drew the complex detail of the nebula with reference to the points so obtained. The great reflecting telescopes of Herschel, Lassell, and Lord Rosse were turned upon the nebula of Orion, and in considering the trustworthiness of the drawings made by these eminent observers, and by others with the large refracting telescopes of modern times, the elements of carelessness and lack of skill do not have to be taken into account.

But, in spite of all the care and skill bestowed upon them, these drawings differ greatly from one another. They agree well, it is true, with respect to the Huyghenian region—the bright, sharply defined central area of the nebula—but the faint, diffuse streamers which extend out from it are shown with widely various forms. These differences are due solely to the difficulty of perceiving and depicting such vague, dimly luminous shapes, and arising as they do from the limitations of human perception, they reflect no discredit on the skill of the artist. Of all the drawings that have been published, that which looks most like the actual nebula seen in the telescope is the beautiful picture by Prof. Bond, which forms the frontispiece of vol. v. of the Harvard College Observatory Annals, while the drawing which most accurately represents the forms of the dim, outlying streamers is one made by Lassell, in the pure air of Malta, in the year 1862.

No one would think of making such drawings now. The laborious methods of a few years ago have been superseded by the camera and the photographic plate.

The first photograph of the Orion nebula was taken by Dr. Henry Draper, of New York, on September 30, 1880. Another photograph taken by the same investigator, in 1882, is of great excellence, although it shows only the brighter parts of the nebula. A beginning having thus been made, progress became very rapid. A splendid photograph taken by Dr. Common in 1883, with a three-foot reflecting telescope of his own construction (now in the possession of the Lick Observatory), was awarded the gold medal of the Royal Astronomical Society. Still further advances were made by Pickering, Roberts, and others; and it would seem that the photographic method has now nearly reached its limit, since with still longer exposures the plate is blackened by the general illumination of the sky. By means of these photographs it has been shown that the great nebula is part of a vast nebulous system, which includes a large part of the constellation of Orion.

A photograph taken with moderate exposure is shown herewith, which is not, however, given as a specimen of modern work (since the method of reproduction is entirely unsuitable for such an object as a nebula), but is inserted for convenience of reference and to illustrate some of the remarks which follow. The detail in the central parts of the nebula is almost entirely lost in the process of reproduction.

NEBULA OF ORION PHOTOGRAPHED WITH THE CROSSLEY THREE-FOOT REFLECTOR.

On comparing such a photograph with celebrated drawings, we are struck by some remarkable differences. With respect to the Huyghenian region, photographs and drawings agree very well, but its intensity, as compared with the rest of the nebula, is very much greater in the drawings. This in itself means little, since the amount of contrast on a photograph depends upon the length of exposure, quickness of plate, manner of development, and other circumstances, as well as on the relative intensity of the images which produce the negative. It is easy to obtain a photograph with short exposure which shows the Huyghenian region and nothing else. With long exposures, as all photographers know, contrasts are reduced.

Other differences are, however, less easily explained. Some details (as, for instance, the beautiful curves of nebulosity on the left [west] of the Huyghenian region) are bright and distinct in the photographs, but do not appear at all in the drawings; yet in some cases they appear to be as bright as other features which are easily visible in even a small telescope. Why is this?

To answer this question it is necessary to consider the quality of the light of the nebula as revealed by the spectroscope.

In 1864 Dr. (now Sir William) Huggins, then first applying the spectroscope to the study of such celestial objects, found that the spectrum of the Orion nebula consists of isolated bright lines, among others one or two of the lines of hydrogen. The gaseous nature of the nebula was, therefore, established. Later investigations, chiefly by Sir William and Lady Huggins, Sir Norman Lockyer, and Prof. Campbell, have revealed the existence of a large number of lines, some of which have been identified with lines of hydrogen and helium, while others are of unknown origin. [Prof. Keeler kindly sent a diagram of a spectrum, which it was not possible to publish owing to lack of space. In this diagram the intensities of the lines are represented by varying widths.]

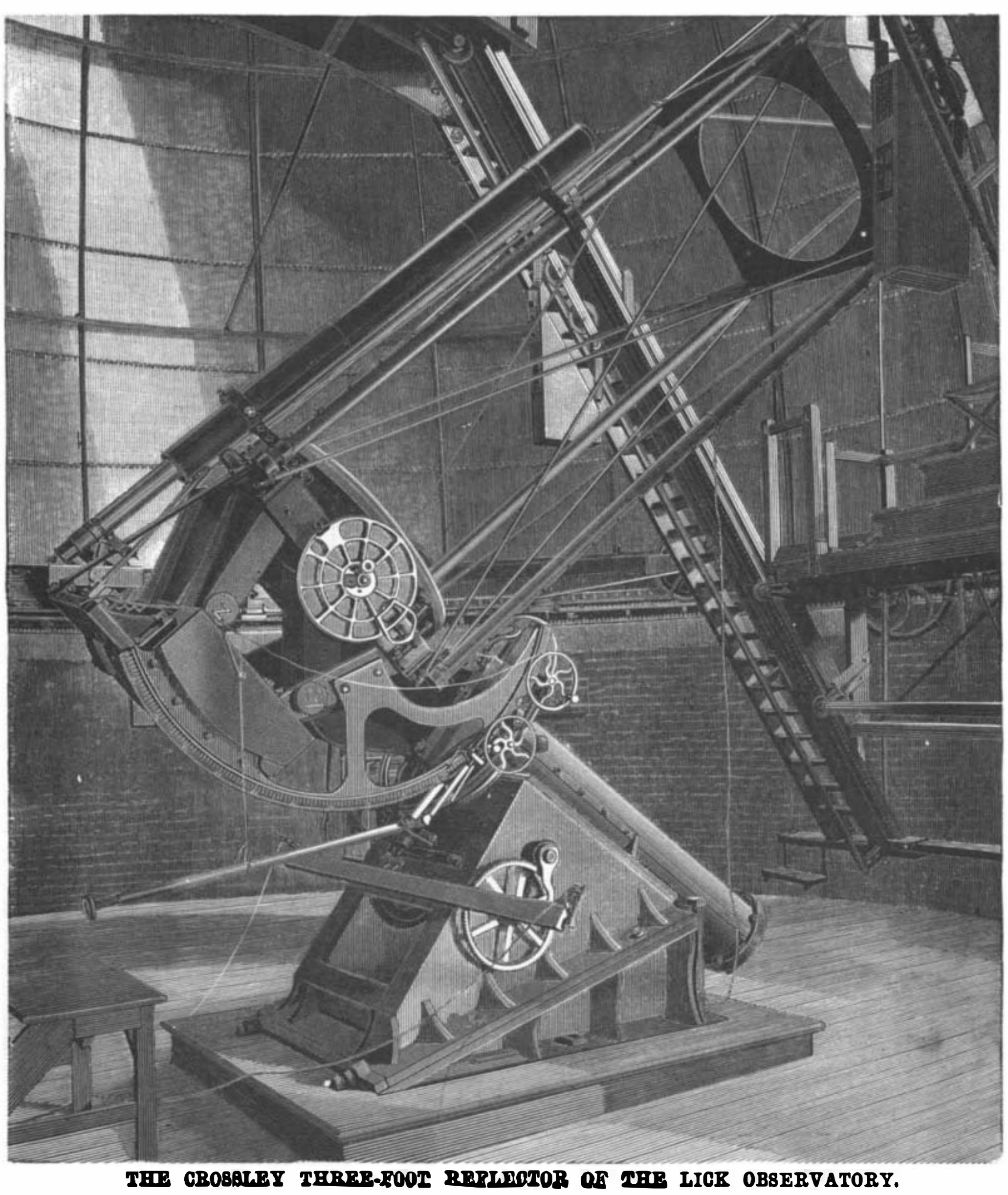
The spectrum of a nebula is regarded with great interest by astrophysicists, because, according to modern views, the stars are evolved from pre-existing nebulæ by a process of condensation. The spectrum of a nebula is, therefore, the starting point of systems of stellar classification, and is of fundamental importance. A few years ago it was independently discovered at the Lick and Allegheny Observatories that all the principal lines in the spectrum of the Orion nebula (with two notable exceptions) are represented by dark absorption lines in the spectra of the stars which are involved in the nebula, and of other stars which belong to the same great nebulous system. In other respects the spectra of the same stars are nearly blank. An intimate relation between the stars and the nebula is, therefore, proved beyond all reasonable doubt.

The two lines which have been noted as exceptions to the statement made above are the two lines which are generally most easily seen in the spectrum of a nebula. One is the so-called "chief" line, λ5007 (that is, the line whose wave length is 0·5007 thousandths of a millimeter); the other is the "second" nebular line, λ4959. These lines can be readily identified in the diagram of the spectrum by means of a wave-length scale placed above the spectrum.* They seem never to be reversed under any circumstances.

A very important discovery was made in 1893 by Prof. W. W. Campbell, of the Lick Observatory, Mount Hamilton, California. Previously to that time it had always been supposed that the visible spectrum of the Huyghenian region was essentially the spectrum of all parts of the nebula. Prof. Campbell, employing a spectroscope attached to the great 36-inch telescope, found that the relative intensities of the three brightest lines changed greatly when he moved his spectroscope slit from one part of the nebula to another. Thus, while in the Huyghenian region the intensities of the lines λ5007, λ4959 and $H\beta$ were respectively as 4 : 1 : 1, in the neighborhood of the star Bond 734 (shown herewith, surrounded by nebulosity, below the main nebula) they were as 4 : 1 : 20. In general, the hydrogen spectrum was relatively strong in the fainter parts and outlying regions of the nebula.

The significance of these observations has recently been questioned, on the ground that they admit of a physiological explanation. By what is known as the "Purkinje effect," the position of maximum brightness in a spectrum shifts toward the violet end when the

* The last two ciphers are omitted for economy of space.


THE CROSSLEY THREE-FOOT REFLECTOR OF THE LICK OBSERVATORY.

light is weakened, even though its quality remains the same. If, therefore, we suppose that two lights, one red and one blue, appear equally bright when the intensity has a certain value, the blue one will appear the brighter when the intensities are equally diminished and the red one will appear brighter when they are increased. On lowering the brightness sufficiently the blue light will even remain visible after the red one has disappeared.

It will be observed that the Purkinje effect acts in the right direction to explain the observations of Campbell, since it was the blue line $H\beta$ which appeared rélatively brighter in the faint parts of the nebula, but it seemed very doubtful whether it was competent to explain the amount of the observed differences. The lines observed by Campbell were not at opposite ends of the spectrum, but were close together, all being in the bluish green. The physiological effect must have been small, yet the observed variations of the $H\beta$ line were as much as 20:1. Careful observations made at the Lick Observatory during the past winter have shown that these variations are in fact real, and cannot be explained on physiological grounds.

The non-homogeneity of the Orion nebula must, therefore, be regarded as proved. The substances (or substance) yielding the chief and second nebular lines are more particularly concentrated in the Huyghenian region; in the faint and remote regions hydrogen predominates.

It may be admitted that this non-homogeneity of the nebula may be only apparent, that the substances of which the nebula is composed may be distributed in the same proportions throughout its whole extent, and on account of differences of temperature, density, etc., the spectrum is not everywhere the same; but the fact remains that the quality of the light emitted by the Huyghenian region differs from that emitted by the outlying parts, as if the materials themselves were distributed in the manner already stated.

When this non-homogeneity of the nebula was discovered, it was pointed out by Prof. Keeler, then director of the Allegheny Observatory, that it would necessarily cause a difference between drawings and photographs; for the light from the diffuse hydrogen streamers, though strongly actinic, would scarcely affect the eye. The nebula is seen by one set of rays and photographed by a different set, so that the two impressions cannot be expected to agree unless these sets of rays are emitted in like proportions by all parts of the nebula. This is not the case; and only the amount of the differences thus produced can be called in question.

Prof. Keeler proposed a method for testing this point, and for producing photographs directly comparable with drawings, which he successfully put in practice last winter at the Lick Observatory. The method consisted in photographing the nebula, through a ray filter or color screen, on an orthochromatic plate. The color screen, which had to be chosen with special reference to the nature of the spectrum of the nebula, was of a light green color. It completely suppressed the entire spectrum of the nebula, down almost to the $H\beta$ line, transmitting, therefore, only the lines which are recognized by the eye. By means of orthochromatic plates sensitive to green light the nebular lines λ5007, λ4959, and $H\beta$ were rendered with nearly their proper visual relative intensities. The image of the nebula photographed through the color screen, in this way, was therefore practically identical with the image which is seen in the telescope in ordinary observation.

The instrument which was used was the three-foot reflecting telescope already referred to as having been made by Dr. Common. This telescope had come into the possession of Mr. Edward Crossley, of Halifax, England, who presented it to the Lick Observatory; and through the offices of Dr. Holden, the former director, it was transferred to California and set up on Mount Hamilton.

The Crossley reflector is a very effective photographic telescope. The Huyghenian region of the Orion nebula can be photographed on an ordinary plate in thirty seconds, and an exposure of five minutes shows a large amount of the surrounding nebulosity. Nevertheless, so feeble is the actinic power of the rays transmitted by the color screen, that the exposures had to be increased from thirty to fifty times to obtain corresponding results when the screen was used. The correct ratio of exposures having been ascertained by experiment, two photographs were taken on the same night, one on an ordinary plate and the other through the color screen on an orthochromatic plate. In order to secure comparable negatives, the two plates were developed together. A considerable number of such photographs was made.

The result of the investigation was that the earlier spectroscopic observations are confirmed and extended, and that the most obvious discrepancies between photographs and drawings are explained. The photographs taken with the color screen are in much better general agreement with drawings than are ordinary photographs. Thus the Huyghenian region is relatively very strong, while the features which have been referred to as abnormally strong on an ordinary photograph, as, for instance, the nebulosity surrounding the star Bond 734 and the nebulous curves west of the Huyghenian region, are much reduced.

Another example of particular interest is the following: The long, scimiter-like streamer, extending upward (south) from the Huyghenian region, is easily visible in small telescopes. It was discovered by Messier in 1771, and is known as the Messerian branch (see Fig. 1). It is, of course, represented in all the drawings. Just to the left of the Messerian branch, and running parallel to it, is a shorter streamer, which is not easily seen, even with large telescopes, and is not shown on any drawing except Lassell's drawing of 1862. Yet on an ordinary photograph these two streamers have nearly equal strength (Fig. 1). The explanation as given by the orthochromatic photographs is, that the lowest nebular lines are strong in the spectrum of the Messerian branch and very weak in that of the companion streamer.

The question has been raised whether the spectrum of hydrogen given by the nebula of Orion is identical with the spectrum obtained from hydrogen in our laboratories, and, incidentally, why it is that the red hydrogen line, $H\alpha$, cannot be seen in the spectrum of the nebula. Prof. Scheiner, of Potsdam, has shown that a hydrogen tube cooled down to −200° C., and excited by feeble electric waves, gives the same spectrum as it does at ordinary temperatures. We cannot suppose, therefore, that the spectrum of the nebula is influenced by the cold of space.

Prof. Scheiner very plausibly explains the invisibility of the $H\alpha$ line as a consequence of the Purkinje effect. A simple observation due to Mr. W. H. Wright, Assistant Astronomer at the Lick Observatory, seems to show, however, that some other than physiological causes are also concerned in this peculiarity of the nebular spectrum.

The great telescope, carrying a spectroscope, was directed to the nebula of Orion, and the light from a hydrogen tube was thrown into the spectroscope, so that the two spectra appeared side by side. The hydrogen tube was mounted on a long slide in such manner that, by simply changing its distance from the slit, the brightness of its spectrum could be altered, while the quality of the light, of course, remained the same. It was thus easy to adjust the tube until any line of the artificial hydrogen spectrum exactly matched the corresponding line in the spectrum of the nebula.

When this was done, it was found that the other hydrogen lines did not match, the upper lines being brighter and the lower lines fainter in the spectrum of the nebula; and this in spite of the fact that the upper nebular lines must have been considerably weakened by the absorption of the great object glass. When the $H\gamma$ lines were matched, the $H\alpha$ line was visible in the spectrum of the tube, though not in that of the nebula.

There is consequently a real difference between the spectrum of hydrogen in the nebula and hydrogen in a tube. The spectrum of the nebula, interpreted by our laboratory experience, indicates a high temperature, which, in the case of such enormously rarefied gases, is not easy to understand. We may suppose that the light of the nebula is excited by electrical disturbances, in which case the temperature of the gases may be low; but of these electrical disturbances we have no independent knowledge. The problem is one of many which still await solution.

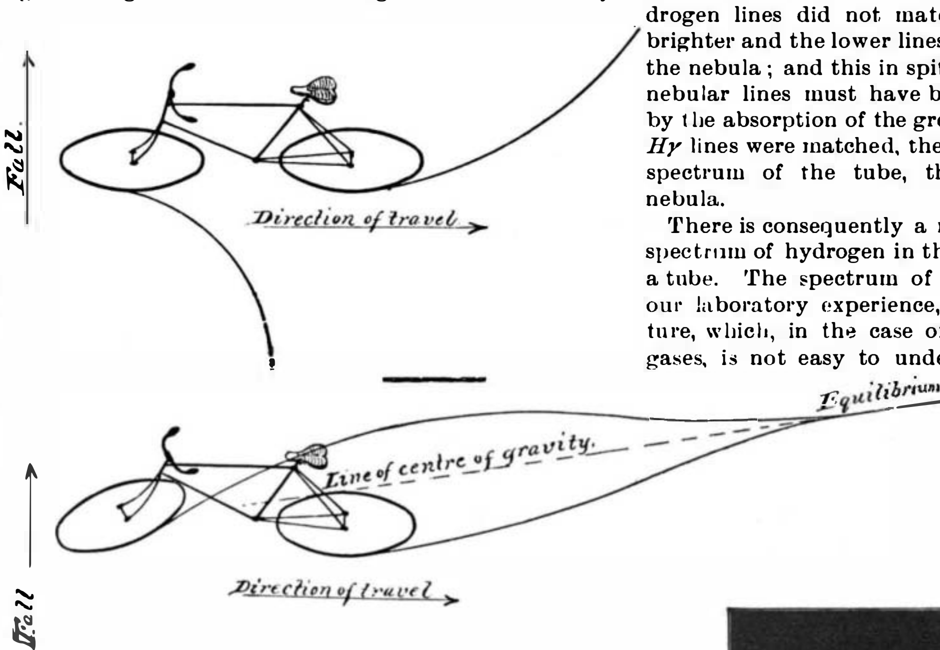
RIDING A BICYCLE BACKWARD.

BY E. J. PRINDLE.

A study of the mechanics of the bicycle is very interesting; for the safety bicycle is a wonderfully perfect machine when considered in relation to the purpose for which it was intended; in fact, it is one of the most perfect solutions of a mechanical problem that has ever been devised. So perfect is the safety bicycle, in fact, that, if the rider has sufficient skill not to interfere with its action, it will travel straight ahead and keep its own balance. The perfection of its design is, perhaps, most easily seen by an analysis of the various ways of riding the bicycle.

To explain the manner of balancing and steering by controlling the front wheel, it is not necessary to go very deeply into the structure of the bicycle. A rider loses his balance when his weight is not over a line connecting the points of contact between the wheels and the ground. To regain his balance, he turns his front or steering wheel in the direction in which he is falling, thus causing the line of contact of the wheels and ground to pass sideways in the direction of the fall until it is again under his center of gravity.

To steer to one side, the rider should throw his



Method of Regaining Equilibrium.

Regaining the Balance.

Retaining the True Balance.

The Two White Cords show the Axis of the Head and the Point of Contact of the Wheel.

THE PRINCIPLE OF RIDING THE BICYCLE BACKWARD.