THE PHOTOGRAPHY OF NEBULÆ.

PHOTOGRAPHY has been a helpful handmaid in many branches of astronomical science, but in no department is the value of her assistance more clearly seen than in that which is concerned with the forms and structures of nebulæ. This is hardly to be wondered at when the fine texture, the almost imperceptible gradations of light, the intricacy of detail, and the variety of nebulous forms are considered. Many vigils must be kept by an astronomer before the trend and comparative distinctness of a particular nebulous feature is satisfactorily observed ; and even where this has been done, to represent the characteristic faithfully is beyond the power of any but the most accomplished draughtsmen. The unimaginative photographic plate, however, looks heavenwards for a few minutes and has imprinted upon it not only the delicate details which tease the eye of the observer and elude the skill of the artist, but also records a greater extent of celestial mist than the human eye is capable of grasping. On this account exceptional interest is attached to what has been accomplished in the portraiture of nebulæ, and the following survey of the subject will serve to show some of the roads along which progress has been made.

EARLY DAYS OF NEBULAR PHOTOGRAPHY.

Dr. Henry Draper was the pioneer of nebular photography ; he succeeded in obtaining a photograph of the nebula of Orion on September 30, 1880. ("Washington Observations," vol. xxv., 1878. Appendix i. p. 226.) Only the brightest parts of the nebula were comprised within the picture ; nevertheless, the result was such as to show that photography had great possibilities before it as a delineator of nebulæ. Encouraged by the tangible fruits of his labour, Dr. Draper took a number of photographs of Orion's nebula, and in March 1881 obtained a picture showing stars fainter than the fourteenth magnitude ; that is, stars only just within the limits of visibility of the telescope employed in the work. This fact was not lost upon him, for in a short note communicated to the Paris Academy of Sciences in April 1881 (*Comptes rendus*, vol. xcii. p. 964, 1881), he remarked that astronomers might reasonably expect to photograph stars which were quite beyond the visual reach of the most perspicuous observer ; in other words, that a sensitive plate at the eye-end of a telescope could see objects which were too faint to produce any impression upon the retina of an observer using the same instrument. The picture which led to this remark was taken with an exposure of 104 minutes. Towards the beginning of the following year, a fine negative was produced by exposing a gelatino-bromide plate to the nebula for 137 minutes. This photograph comprised more of the nebulous matter, and especially of the delicate outlying parts, than any of the previous ones. In commenting at the time upon the strikingly perfect representation of the nebula afforded by the picture ("Washington Observations," vol. xxv. ; Appendix i. p. 227), Prof. E. S. Holden compared it with Bond's drawing of the same object. This observer spent several years scrutinising the nebula, and, as a result of his patient observation, was able to produce a picture which represented its features with greater accuracy and artistic effect than had previously been attained. Dr. Draper's photograph of the nebula was taken in a little over two hours, yet Prof. Holden confessed that for nearly every purpose it was incomparably better than Bond's hand-drawn picture. It was evident from this that a new epoch of nebular observation had been opened. Exact and automatic representations of nebulæ were to take the place of the strange, and often crude, drawings of these objects. The new method inaugurated by Dr. Draper has developed so much that, at the present time, it may almost be said that photography entirely holds the field as a nebula-artist.

A nebula rarely has a definite form, like the sun and moon. It presents the appearance of a cloud having more or less irregular outlines, and of which the various parts differ greatly in brightness. It results from this that photographs of the same nebula may be very different in appearance, for their characters depend upon the power of the telescope employed in their production, the time during which the sensitive plate was exposed, the sensitiveness of the plate, the transparency of the atmosphere, and many other causes. While Dr. Draper was working upon the Orion nebula in America, Dr. Janssen was experimenting at Meudon with a view of determining the influence of some of the variable conditions upon the results obtained (*Comptes rendus*, vol. xcii. p. 261, 1881). By taking photographs with exposures of five, ten, and fifteen minutes respectively, the eminent French investigator found that the longer the nebulous light was beating upon the sensitive film, the greater was the extent of nebulosity portrayed. It was this fact which permitted Dr. Draper to obtain his epoch-making picture, and has led to even more remarkable results during the past few years.

So long ago as 1874, Dr. A. A. Common was engaged in celestial photography, but it was not until May 1882 that he exhibited a photograph of the nebula in Orion (*Monthly Notices, R.A.S.*, vol. xliv. p. 222, 1883-84). The instrument used by him was a reflecting telescope three feet in diameter, specially constructed for photographic work. Such a large instrument is necessarily difficult to adjust and drive, and a laborious series of experiments had to be made before it could be said to be in working order. But the time spent in devising improvements was well repaid by the photograph of the Orion nebula taken by Dr. Common in January 1883. The photograph showed details of the nebula never before properly represented by the hand, and which can hardly be discerned by the eye. With the confidence that comes from experience, it was then predicted that "we are approaching a time when photography will give us the means of recording in its own inimitable way the shape of the nebula and the relative brightness of the different parts, in a better manner than the most careful hand-drawings."

This prophecy was strikingly fulfilled in less than three years after it was made.

THE PLEIADES NEBULA.

In the early part of the year 1885 a fine photographic telescope was added to the equipment of the Paris Observatory, and placed under the control of two brothers, MM. Paul and Prosper Henry. The instrument had only been mounted a few months when it was used to photograph a cluster of stars—the Pleiades—which has attracted attention from time immemorial. The picture obtained showed truthfully the relative positions and grandeurs of the stars in and near the beautiful bunch of lucid points to which the telescope had been directed. But it was not so much the imprints of hundreds of stars that made the picture interesting to astronomers, as the fact that a new nebula appeared upon it. Round "stately Maia"—a star just visible to the naked eye—several wisps of nebulosity were clearly portrayed. Three further photographs of the same celestial region confirmed the existence of this nebulous matter, though no trace of haziness had previously been detected by ordinary telescopic observation (*Monthly Notices, R.A.S.*, vol. xlvi. p. 98, 1885-86).

It is a remarkable fact, however, that when an object has been discovered an observer is frequently able to see it, though he may have passed it over many times in previous surveys. So it was with the nebula round Maia. Very shortly after the announcement of the discovery had been made, M. Struve turned the 30-inch refractor at Pulkova towards the star to which attention had been directed, and found that he could distinctly see the nebulous surroundings (*Comptes rendus*, vol. cii. p. 281, 1886).

But faint objects are not only overlooked by the observer while viewing celestial scenery through his "optic tube"; they often go undetected on photographs themselves. The announcement of the discovery of the nebula recalled to Prof. E. C. Pickering's mind that certain irregularities had been noticed in a photograph of the Pleiades taken at Harvard College Observatory on November 3, 1885 (*Astronomische Nachrichten*, vol. cxiii. p. 399, 1886), that is, thirteen days before the MM. Henry obtained their first photograph showing Maia's nebulous surroundings. A re-examination of the Harvard College picture confirmed his surmise that the markings, which had previously been passed over as blemishes, were really the wisps of nebulosity photographed at Paris. Extending the scrutiny to the remainder of the Pleiades, indications of nebulous light were found about Merope, and a strange narrow streak was seen projecting from Electra. The Paris photographs showed similar appendages to these stars. This was not, however, a new discovery ; the nebula near Merope was seen by W. Tempel while observing at Venice as far back as 1859 (*ibid.*, vol. liv. p. 286, 1861), and though several astronomers unsuccessfully searched for the object, many illustrious observers had attested to its existence (*Monthly Notices, R.A.S.*, xl. p. 622, 1879-80). Photography established the reality of Tempel's observations ; and what is more, it was soon able to show that the faint patch, which had been the subject of so much discussion, was but a bright part of a vast nebulosity, in which the clustering stars were immersed.

Dr. Isaac Roberts was the astronomer who brought to light

the wonderful extensions round the Pleiades. His work in celestial photography has been so fruitful in results, that a brief record of its growth will not be out of place. In 1883, Dr. Roberts made a series of experiments to test the suitability of ordinary photographic lenses for the delineation of celestial objects ("Photographs of Stars, Star-Clusters, and Nebula," I. Roberts, 1894). The results were so promising that he determined to develop the photographic method of observation, and, with this end in view, he ordered to be constructed a reflecting telescope of twenty inches diameter, and one hundred inches focal length. The instrument was ready for use in April 1885, and work was then commenced with it. But it was not until more than a year later that its performances began to reach Dr. Roberts's expectations. Only those who have had to coax astronomical instruments into a tractable condition, can understand and appreciate the difficulties with which he had to contend. It was found that satisfactory photographs could not be obtained until the driving-clock of the telescope had been greatly improved in regard to its ability to keep the instrument accurately following the apparent movements of the stars. When a sensitive plate has to be exposed to starlight for three or four hours, the beams from individual stars must continually beat upon the same spot, otherwise the stellar images do not appear as circular discs upon the resulting picture. To attain this desideratum—that is to say, to make a clock capable of driving a telescope so

FIG. 1.—The Pleiades Nebula. (From a photograph by Dr. Roberts, with an exposure of ten hours.)

as to keep absolutely the same time as the stars—taxes the instrument-maker to his utmost; and, when Dr. Roberts commenced his work, there was no controlling clock that completely supplied the want. His early photographs, therefore, did not exhibit the stars as perfectly circular spots, nevertheless they greatly extended the state of knowledge of the Pleiades nebulosities. In October 1886, the first of his remarkable long-exposure photographs was obtained, the sensitive plate being kept directed to the Pleiades for three hours. With regard to the amount of nebulosity shown, the resulting picture was far in advance of all previous ones. It demonstrated that the MM. Henry had merely picked up the fringe of the nebulous matter round the Pleiades, for not only were all the stars of the cluster shown to be shrouded in nebulæ, but, to quote Dr. Roberts's words (*Monthly Notices*, *R.A.S.*, vol. xlvii. p. 24, 1886-7), "the nebulosity extends in streamers and fleecy masses, till it seems almost to fill the spaces between the stars, and to extend far beyond them. It suggests the probability that these stars in the Pleiades, together with many of the stars around them, are involved either directly or else in slight alignment with one vast nebula." This surmise was more than justified by future results. A year after it was made, the Henrys succeeded in obtaining a photograph which confirmed it. They, like Dr. Roberts, had been working towards perfecting their new engine of research. By the use of more sensitive plates, and by increasing the duration of exposure, they were able to bear witness that the feeble traces of nebulosity shown around the stars Maia, Merope, and Electra, on the views taken two years previously, appeared on the new photographs as bright nebulous masses, all more or less merging into one another, while an extensive lucid patch surrounded Alcyone (Observatoire de Paris, *Rapport Annuel*, 1887). Threads of nebulosity were also revealed, projecting from the central mass and having stars strung upon them like beads on a rosary.

Until recently, the best result of Pleiades photography was reached by Dr. Roberts at the end of 1888 (*Monthly Notices*, *R.A.S.*, vol. xlix. p. 120, 1888-89). The view of the wonderful group then obtained was produced by exposing the sensitive plate for four hours. It showed more clearly and more beautifully the filmy sea in which the stars are immersed, but did not extend the limits defined by the earlier pictures. The *ne plus ultra* of Pleiades photography was lately obtained by Dr. Roberts with an exposure of ten hours, and a reproduction of the picture is here given (Fig. 1). No process of reproduction can, however, do justice to the brilliant picture which Dr. Roberts has permitted us to reproduce.

The epoch-making views of the Pleiades obtained ten years ago gave a great impetus to nebular photography. The thought that for a time to be reckoned in æons, the gauze-like veil on which the Pleiades were studded had been unable to affect man's visual perceptions, but could register its existence automatically upon a prepared surface, was sufficient to open up a vista of marvellous possibilities.

Dr. Roberts's photograph of the Pleiades nebula has become a classic. Of his numerous other photographs of nebulæ, three have attained a like eminence; they represent the Great Nebula in Orion (to which reference has previously been made), the Great Nebula in Andromeda, and the Spiral Nebula in the constellation of Canes Venatici, and to these attention must here be confined. It is perhaps invidious to select these pictures from the collection of five hundred photographs of nebulæ and clusters with which Dr. Roberts has enriched astronomy, for every one of his photographs adds to what was previously known about the objects portrayed. The nebulæ above designated, however, were all made to record their own forms at about the same time, and each of the monochromes produced exhibited striking novelties.

THE ORION NEBULA.

A photograph of the Orion nebula taken by Dr. Roberts in November 1887, though only representing a tentative result, showed nebulous matter covering an area quite seven times greater than that covered by Dr. Common's photograph (*Monthly Notices*, *R.A.S.*, vol. xlvii. p. 89).

What Dr. Roberts had gained in extent, however, he had lost in detail. The delicate structure of the central part of the nebula appeared but a splash of white upon the print presented to the Royal Astronomical Society, though it is fair to add that they could be distinguished upon the negative. The lesson learned was, that it was extremely difficult to obtain upon one and the same print a representation of the nebula showing it to the fullest extent, and also exhibiting the fine markings and imperceptible gradations that characterise such objects. An increase of the time of exposure certainly increases the area of nebulosity depicted upon a photographic plate; but while the picture is having its limits extended, the filmy rays in the brighter regions of nebulosity are being "burnt out" by the cumulative action. This difficulty has now been overcome; for since Dr. Roberts revealed to astronomers the vast extent of the Orion nebula, he has taken, upon a single plate, photographs which show the fine detail of the nebulous structure as well as the great sky-area covered by the nebulous mass. One of these pictures, taken with a dual exposure of seven hours thirty-five minutes, on two evenings in February 1894, is here reproduced (Fig. 2), and it represents, according to Dr. Roberts, "the maximum of extent and detail that can be shown by aid of photographic methods." The illustration is, however, but a feeble representation of the original picture. Longer exposure with a reflecting telescope, such as that used by Dr. Roberts, would result in the photographic plate being fogged by the general luminosity of the sky sufficiently to obscure dim nebulous streamers and faint stars. With a refracting telescope Dr. Gill has given an ex-

posure of nearly twenty-five hours to the nebulous region around Eta Argus, without the film of the photographic plate being much darkened, but the conditions with a refractor are not precisely similar to those which obtain in the case of a reflector having a short ratio of focal length to aperture.

It appears, however, from some photographs recently taken by Mr. W. E. Wilson, F.R.S., and exhibited at the Royal Astronomical Society, that the time of exposure needed by the photographic plate to depict the greater part of the Orion nebula may be considerably reduced. Mr. Wilson uses a reflecting telescope of twenty-four inches aperture, and ten feet six inches focal length, constructed by Sir Howard Grubb, and provided with his usual type of driving-clock and electrical control. With this instrument, and an exposure of only forty minutes, he has been able to produce a portrait of Orion's great nebula which, as regards structural detail, will bear comparison with any previously obtained. Good photographs of the Orion nebula and other nebulæ have also lately been taken at the Paris Observatory with exposures of an hour or less (see p. 374). A comparison of Mr. Wilson's photograph of the Orion nebula with one recently taken by Dr. Roberts with the same exposure shows that they both contain about the same amount of detail and extent of nebulosity, so the decrease of the time of exposure is

FIG. 2.—Great Nebula in Orion. (From a photograph obtained by Dr. Roberts, with an exposure of 7½ hours.)

probably to be accounted for by the use of more sensitive plates than were formerly available. The central part of the Orion nebula, as photographed in forty minutes, is here reproduced by the side of a well-known drawing of the nebula lithographed by Mr. L. Trouvelot in 1864, from drawings made by Prof. G. P. Bond, of the Harvard College Observatory (Fig. 3). We have thus what is undoubtedly the best drawing of the nebula compared with a good photograph on the same scale (Fig. 4), and though much of the fine detail in the latter picture has been lost in reproduction, the difference between the work of the hand and that of the photographic plate is very striking.

Prof. Bond had to use every available hour for about five years in order to determine accurately the structure and distribution of the parts of the nebula. Such devoted perseverance cannot but command admiration, yet, except for the satisfaction which the celestial draughtsman derives from his work, a like expenditure of time and energy would now be almost useless. It is not, however, for the celestial photographer to depreciate the labours of the plodding observer. As Dr. Roberts himself has said, "we ought, with all gratitude, to admire the patient, long-suffering endurance of those martyrs to science, who, during the freezing nights of many successive winters plotted, with pencil in benumbed fingers, the crude outlines which have been handed down to us as correct drawings of this wonderful nebula, which we can now depict during four hours of clear sky with far greater accuracy than is possible by the best hand-work in a life-time" (*Monthly Notices, R.A.S.*, vol. xlix. p. 297, 1888–89).

THE SPIRAL NEBULA IN CANES VENATICI.

The years 1888–89 will be marked with a white stone in the annals of celestial photography, for it was then that so many remarkable proofs of its great capabilities were presented to the astronomical world. A photograph of the wonderful spiral nebula in the constellation Canes Venatici was obtained

FIG. 3.—Bond's drawing of the Great Nebula in Orion (1859–63).

by Herr von Gothard in 1888 (*Astronomische Nachrichten*, No. 2854, 1888), and by Dr. Roberts in April, 1889 (*Monthly Notices, R.A.S.*, vol. xlix. p. 389, 1888–89). Dr. Common appears to have taken a good photograph of the nebula in 1883, but he did not publish any description of it at the time (*Observatory*, vol. xi. p. 393, 1888). An accurate picture of the object was certainly much needed. The nebula had been drawn by Herschel, Rosse, Lassell, and numerous other astronomers, and its convolutions had been more or less symmetrically traced. But so long as only drawings, differing widely from one another, existed of the spiral nebula in Canes Venatici, little was learned about the physical nature of the object. The photographs

FIG. 4.—Photograph of the Great Nebula in Orion, obtained with an exposure of forty minutes.

showed that the whorls of nebulosity were knotted with bright spots—stars in the course of formation—and these followed so closely the trend of the streams of nebulous matter, that their connection with it was placed beyond the possibility of doubt. The picture is a striking view of a stage of progress in the evolution of stellar systems; it exhibits in a most unmistakable manner a "fluid haze of light" eddying into worlds, and enables us almost to see cosmic processes at work. In the accompanying illustration the nebula, as observed with Lord Rosse's six-foot telescope and drawn by hand, is represented (Fig. 5) side by side, and on the same scale, as a photograph of the object obtained by Mr. Wilson with an exposure of forty

minutes (Fig. 6) Considered as pictures, the drawing is perhaps more attractive than the photograph, but this is because the photograph has been enlarged to such an extent that the grain of the film is shown. The comparison should be made between the original negative and the drawing, in order to be able to appreciate fully the assistance given by photography to the delineation of the structure of the nebula.

FIG. 5.—From a drawing.

FIG. 6.—From an enlarged photograph by Mr. W. E. Wilson.
The Spiral Nebula in Canes Venatici.

THE ANDROMEDA NEBULA.

Until Dr. Roberts took the photograph of the nebula of Andromeda in 1888 (*Monthly Notices R.A.S.*, vol. xlix. p. 65, 1888-89), astronomers did not understand that this object was a remarkable example of the ring-stage in celestial evolution. Bond's drawing (Fig. 7) was acknowledged to be the finest representation of the nebula, but how much it is inferior to the photograph (Fig. 8) is shown in the accompanying comparison of the two. It will be seen that the major axis of the small nebula near the top on the right has a different relative position in the two pictures, when considered with reference to the great nebula. The difference may indicate a change in the direction of the axis between 1847, when the drawing was made, and now, but it would be unwise to conclude that this difference is real, seeing that the distinct statement is made that "the lithograph represents somewhat inaccurately the relative positions of the chief nebulous centres of condensation" (*Annals of Harvard College Observatory*, 1876). But though this possible change is important in itself, it is not so instructive as the rings of nebulosity seen surrounding the bright central portion of the great nebula on the photograph. The dark lanes drawn by Bond are seen upon the photograph to be divisions between the zones of nebulous matter; and what visually appears to be accidental and enigmatical vacuities, are shown photographically to be the consequences of cosmogonical action. The hypothesis of the formation of worlds from nebulæ was thus confirmed, if not demonstrated, by the discovery of this new link to connect celestial species.

FIG. 7.—The Andromeda Nebula. (From a drawing by Bond and Trouvelot.)

FIG. 8.—The Andromeda Nebula. (From a photograph obtained by Dr. Roberts, with an exposure of ninety minutes.)

THE PORTRAIT LENS IN NEBULAR PHOTOGRAPHY.

It was at one time supposed that large telescopes were necessary to obtain valuable pictures of celestial objects; but as the work went on, it was found that ungainly instruments were not at all essential, and that excellent results were given by instruments of very moderate dimensions. For photographing faint stars, where the images on the photographic plates are practically points, the aperture of the object-glass or mirror is almost the only factor to be taken into account in estimating efficiency; but for nebulæ, comets and similar celestial objects, the images of which cover sensible areas on the plates, the ratio of focal length to aperture is all-important, and the actual aperture is a secondary consideration.

Experience has shown that a lens constructed in the same way as a portrait lens for use in an ordinary camera, is really the best instrument for several branches of celestial photography. The lens must of course be mounted, so that it can be made to follow the motions of the celestial sphere, but in other respects the camera need not differ essentially from that used in the ordinary portrait studio. The advantage of the portrait lens over the photographic telescope is that the field of view is much greater—it is therefore able to take a broader view of things.

The telescopes used for the international star catalogue and chart may be taken as the standard instruments for *star* work. The aperture of the object glass is 13 inches, and the focal length, roughly, 130 inches (ratio 1 to 10), the effective field being a little over 2 degrees square (4 square degrees on the celestial sphere). A portrait lens of 6 inches aperture and 30 inches focus (the favourite size with those who use portrait lenses for celestial photography) has a ratio of aperture to focal length of 1 to 5, and an effective field of 15 degrees square (225 square degrees). In photographing a nebula, this portrait lens only requires about one-half the exposure necessary when the standard telescope is used, while the area covered is nearly forty times as great. It follows, therefore, that for an extended nebula covering over 100 square degrees on the celestial sphere—and such nebulæ exist, and have been photographed—the portrait lens can give in two hours a complete picture comparable, in area of sky covered, with a picture that would require twenty-five exposures of four hours each with the standard star telescope; and that, whereas the picture with the portrait lens would all be on one plate and taken with one exposure, that with the standard telescope would be a mosaic built up from at at least twenty-five plates taken at different times, and consequently under very various atmospheric and astronomical conditions.

During the past eight years or so, a large number of photographs of nebulæ and nebulosity have been obtained by means of portrait lenses; and year by year the work done, both in this and other branches of astronomical photography, has been admirably summarised by Mr. Albert Taylor in the *Photography Annual*. Every one interested in the progress of celestial portraiture should refer to these annual records of results, as we have had frequently to do in preparing the subjoined account of the use of the portrait lens in astronomical photography.

The great advantage of the portrait lens or doublet over the telescope was admirably brought out by Prof. W H. Pickering, who, using a small camera at Wilson's Peak, California, in 1889, obtained a photograph including on one plate the whole constellation of Orion. The great nebula in Orion was clearly shown, but the chief value of the photograph lies in the large number of detached nebulous patches shown, which appear to be part of an enormous zone of nebulosity encircling the great nebula, and practically covering the entire constellation. The existence of this great mass of nebulous matter, and its obvious connection with the well-known nebula in the sword-handle of Orion, would probably never even have been discovered with long-focus instruments with small photographic fields; yet with the portrait lens it is a comparatively easy object.

In 1890, Mr. H. C Russell, F R.S., obtained a large number of striking photographs of nebulæ and the Milky Way with a 6-inch Dallmeyer portrait lens attached to the mounting of his telescope. The pictures thus obtained show many details of structure which are quite invisible in the telescope. Exposures of between four and five hours brought to light many peculiarities of arrangement of stars in Nebecula Major and Minor—the Magellanic clouds—and showed that the whole of the former apparently detached portion of the Milky Way had the structure of a complex spiral nebula with two nuclei two degrees apart. The Nebecula Minor as portrayed by Mr. Russell's camera bears a resemblance to the well-known Dumb-bell nebula.

Following closely on Prof. W. H. Pickering's work in 1889, the greatest advances in the photography of nebulæ in 1891 were due to Prof. Barnard at the Lick Observatory, Dr. Max Wolf at Heidelberg, Mr. Russell at Sydney, and Dr. Archenhold at Helensec, each of these observers using ordinary portrait lenses.

Dr. Max Wolf, with a 2½-inch aplanatic lens of 7¾ inches focus, photographed in one hour all the nebulæ in the Pleiades obtained by the Brothers Henry at Paris with four hours' exposure with the 13-inch charting telescope; and afterwards using a 4-inch Vöigtlander Euryscopic lens and a 5-inch Kranz Euroscopic lens, Wolf obtained more extension of the great nebula in Orion in 4 hours than Dr. Roberts had obtained with 4½ hours' exposure with his 20-inch mirror. These same plates of Wolf amply confirmed Prof. W. H. Pickering's results, and revealed an enormous amount of new detail in the nebula around ζ Orionis.

Turning his attention to the constellation Cygnus on June 1, 1891, Dr. Wolf, by 3 hours' exposure with the 5-inch Kranz lens, discovered an enormous nebula full of the most complex structure, and connecting a number of bright stars with many fainter ones in the Milky Way (*Astr. Nach.*, 3048). Starting apparently from a central point, the nebula spreads out branches which curve and meet "fold on fold of nebulous matter surging over the sky" and "becoming notably compact and luminous in the immediate neighbourhood of γ Cygni." Some of these branches are 8° long, so that at least four plates would be required for one of them with a photographic telescope of standard size; but the portrait lens secures all on one plate, and their true relations to each other and to the involved stars become at once apparent.

The great feature of this photograph, and of many subsequent pictures, is the obvious connection between bright stars and fainter ones. It was formerly believed that the brightness of a star was to some extent a measure of its distance from us, but the photographs with portrait lenses effectively disposed of this idea. Stars of nearly first magnitude were found to be joined to stars of the eighteenth magnitude by wisps of nebula, and to obviously form part of the same system in the heavens. These stars, the brightest of which are about 4,000,000 times more luminous than the faintest, must be at practically the same distance from us, and their differences in brightness must be due to differences of size or physical condition, or both, and not to any differences in distance.

Another interesting result from the photographs was the proof of the connection of nebulæ with stars of the Wolf-Rayet type of spectrum—stars with bright lines in their spectra—which Sir Norman Lockyer classifies as stars only just condensed from nebulæ, and next in order of evolution. Dr. Roberts, with 3¼ hours' exposure with the 20-inch mirror, could detect no nebulosity round these stars in Cygnus, but the portrait lenses with exposures extending up to 13½ hours, indicated that all these stars are nebulous.

This work of Wolf was supplemented by some splendid results obtained by Mr. Russell at Sydney Observatory about the same time. The lens used, a 6-inch Dallmeyer of 30 inches focus, gave, with three hours, as much extension of the great nebula round the star η Argus as the 13-inch charting telescope showed with twice that exposure, while the relations of the nebula to the surrounding stars were much better shown. Two long exposures with the same lens on those curious detached portions of the Milky Way in the southern heavens, known as the Nebeculæ Major and Minor, revealed a great amount of previously unknown nebulous matter, much of which would be very difficult to obtain with larger instruments.

Dr. Archenhold, at Helensec, recognising the true principles of photography of celestial objects of large size, had two lenses constructed by Busch, the ratio of aperture to focal length being 1 to 4·5 and 1 to 2·5 respectively. With these lenses he photographed a very striking and extensive nebula near ξ Persei on October 27, 1891, with 32½ minutes' exposure. This new nebula resembles in many respects the great nebula in Andromeda, but probably covers a much greater area of the sky. The great effectiveness of this special lens is shown by eye observations with a 12-inch telescope; for even with the photograph to indicate where to look for details, scarcely any trace of the nebula can be made out (*Astr. Nach.*, 3082). Dr. Scheiner, at Potsdam (*Astr. Nach.*, 3157), has photographed this great nebula with a 4-inch portrait lens, giving exposures up to six

hours. The spiral form is clearly shown, while the extent of the nebula is greatly increased.

Prof. E. E. Barnard, with the 6-inch Willard lens of 30 inches focus at the Lick Observatory, has enormously extended our knowledge of these great diffuse nebulosities. It is quite impossible in the limits of this article to deal with these in detail, but the extraordinary form of the nebula round 15 Monocerotis, the enormous diffuse nebulosities in the constellation Cepheus and round the Pleiades, the tremendous extensions of the Orion nebulæ shown in his numerous articles in *Astronomy and Astrophysics* and the *Astrophysical Journal* since 1893, are all magnificent examples of the use of the portrait lens in photographing nebulæ; and one can have no hesitation in saying that without the portrait lens we should still be in ignorance of many of these wonderful objects. But Barnard has gone beyond the portrait lens, and has used the lens of a cheap oil lantern, the effective aperture of which is about 1½ inches, the focal length being 3½ inches, ratio 1 to 2·3. This gives a field of 30 degrees practically flat, the scale of the photographs being 10·3 degrees to 1 inch on the plate. Twenty photographs in October 1894 (*Astronomy and Astrophysics*, vol. xiii. p. 811) fully brought out the value of this instrument. One hour's exposure gave all the Andromeda nebula; thirty minutes gave all the diffuse nebulosity round the Pleiades photographed by Archenhold in four hours, and by Barnard with the Willard lens in three hours. The most valuable of all results, however, were those with Orion, obtained on October 3 and 28, 1894, with exposures of 2h. and 1h. 15m. The extensive spiral detected by Pickering in 1889 is fully shown in correct proportion, and "no description can give any idea of the form and magnitude of this nebula." Extending over 17 degrees in length and nearly the same in breadth it includes almost all the stars of the constellation, and forms in fact a robe for the body of the giant. The well-known "great nebula of Orion" is but a pigmy compared with the greater nebula revealed by Prof. Barnard's plates, and it is not too much to believe that longer exposure will probably fill the whole constellation with nebulosity, and show that the great nebula is simply the inner termination and the brightest part of the enormous spiral.

An English amateur, Dr. E. M. Sheldon (*Journal of the British Astronomical Association*, vol. v. p. 397), using a lantern lens similar to that used by Prof. Barnard, photographed this enormous spiral in Orion with 1¼ hours' exposure, in February 1895. Four hours on the constellation Cygnus with this lens gave all the nebulæ on Wolf's photograph taken with 13 hours' exposure.

The nebulosities in the Pleiades have attracted great attention since they were first photographed by the Brothers Henry at Paris in 1885. These nebulæ have always been remarkable from their intimate relations with individual stars in the cluster —"Maia is a diamond clasp on a curving plume, Electra extends a tentacle towards Alcyone, while Merope has a sweeping gauze trail and probably a nebulous satellite." In striking contrast to this we usually have in other regions of the sky stars and nebulæ intimately mixed, although frequently on recent photographs wisps of nebulæ are found joining stars, so that the structures appear to resemble festoons of pearls on a gauzy string. The most recent photographs of the Pleiades by Barnard at the Lick Observatory, taken 10h. 15m. exposure with the Willard (6-inch) lens; by Mr. H. C. Wilson, with a similar lens and 11 hours' exposure; and by Dr. Max Wolf, have revealed an enormous extension of the Pleiades nebulosity. The whole area is now 158 square degrees, and there are indications that even this is not the real limit, and that more prolonged exposures will give still greater extension, probably joining up the whole of the nebulosity into an enormous spiral similar to that covering the constellation Orion.

Other photographs exhibiting the same class of structure have been obtained of the region round Antares with 7½ hours' exposure by Prof. Barnard at the Lick Observatory. At first sight this new nebulous mass would easily be mistaken for the Pleiades Nebula, and it is a remarkable and very significant fact that both these masses and all other great nebulosities in the Milky Way either occupy vacancies amongst the stars, or are on the edges of such vacancies; and that in their immediate neighbourhood the stars exhibit long vacant lanes and other remarkable features, indicating that the nebula, stars, and vacant lanes are but different features of some vast and at present imperfectly comprehended system of celestial grouping.

The first results obtained by Prof. Bailey, at Arequipa, with the Bruce photographic telescope of the Harvard College Observatory have lately been recorded. This portrait lens, the largest in the world at present, has an aperture of 24 inches and a focal length of 135 inches, so that while the scale of the photographs is equal to that of the international star charts (1 minute of arc to 1 millimetre), the light-gathering power of the telescope is three times as great, and exposures with this instrument need be only about one-third of those required with the standard international telescopes to achieve the same results. But the Bruce telescope has a further advantage over the standard instruments. Its effective field is 25 square degrees (14-inch by 7-inch plates are used), whereas the effective field of the international instruments is only 4 square degrees in area. The daring experiment of Prof. Pickering in devising, and Mr. Alvan Clark in constructing, this enormous portrait lens has been completely successful (although several eminent astronomers on this side of the Atlantic doubted whether such an instrument could be constructed), and as a result we have an instrument which can do all the international work on less than 4000 plates and with very much reduced exposure. Prof. Pickering does not at present intend to duplicate the work of constructing the photographic chart of the stars, but will confine the instrument to nebulæ and special regions of the sky, and, with the aid of a 24-inch object prism, to spectrum photography. The published preliminary results are of very great value.

This article ought not to be concluded without mention of the fact that more than one astronomical photographer is of the opinion that some of the nebulosity shown upon pictures obtained with small portrait lenses is not real, but due to diffused starlight. A warm controversy has taken place with reference to this point, but this is not the place to present the views of the two parties. It has been shown in this article that large instruments, such as those used for the International Chart, with long focal length but restricted fields, can give us pictures full of delicate details of bright nebulæ, and these photographs are of extreme value; but we must look to the portrait lens for the larger details and for the fainter nebulosities which are absolutely beyond the reach of any photographic object-glass or mirror. There can be no rivalry between the two classes of instruments; each is perfect in its way, each will mislead if solely relied upon. Photographs of the same nebulæ, both with long focus object-glasses or mirrors and with portrait lenses, are necessary, and must be used to supplement each other, if we are to get correct ideas of the phenomena of stellar distribution and the connections between nebulæ and stars. The "best instrument to use" is not a matter of personal experience nor of individual opinion: the optical and photographic laws bearing on the subject are well known, and the practical limits of atmospheric definition and instrumental construction are within sight. The ideal instrument for photographing nebulæ will probably combine large aperture, short focal length, and the large flat field of the portrait lens; will be, in fact, a glorified portrait lens: there are optical reasons why neither the object-glass nor the mirror can be wholly satisfactory. While waiting for this instrument, every possessor of an ordinary rectilinear lens with an ordinary camera can, by strapping his camera on to an equatorially mounted telescope and using infinite patience, materially advance our knowledge of nebulæ by means of photography.

R. A. GREGORY.

PHOTO-MICROGRAPHY WITH HIGH POWERS.

PHOTO-MICROGRAPHY has for some years past advanced but slowly, although its present status as a means of delineating minute structure is undoubtedly much higher than it has ever been. In optical appliances the improvements have been many, the most notable being the introduction of apochromatic objectives. Their greater aperture and freedom from effects of the secondary spectrum have combined to render it possible to obtain good results with much greater ease than formerly. Some of the photomicrographs obtained, however, in the early days of microscopy are even now hardly excelled, although they were produced at the cost of enormous labour, and required extraordinary skill on the part of the operator, with the apparatus then available. The production of satisfactory photographs, when the magnification exceeds one thousand diameters, has always been a matter of some difficulty. One of the greatest of these has been the want of a source of illumina-