THE DEVELOPMENT OF PHOTOGRAPHY IN ASTRONOMY (II.).*

THE great nebula of Andromeda has been known to astronomers for upwards of a thousand years, as it is a rather noticeable object with the naked eye. It has received its full share of attention ever since the invention of the telescope. It also appears to be a vast body of gaseous matter shining far away in the depths of space, but it seems to be in a different condition from that of the great nebula of Orion, for its spectrum is continuous and does not show the bright lines, indicating an incandescent gas, which are present in the spectrum of the Orion nebula. Though the mystery of its physical condition has not yet been solved, photography has at least shown us its true form. It has ceased to be the long spindle-shaped body of the elder Herschel, or the broad irregular object, with two dark parallel channels in one side, as drawn by the Bonds and Trouvelot. The photographic plate reveals to us in their place a beautiful symmetrical mass of nebulous matter, surrounded with several more or less concentric rings, claimed by some astronomers to be a representation of the nebular hypothesis of La Place in full operation. The first picture to show the true form of this wonderful object was taken in 1885, with a 20-inch reflector, by Roberts. It does not, however, require a powerful photographic telescope to show its peculiar features, for a 6-inch portrait lens will show the rings well with anything above one hour's exposure.

Important photographs of some of the spiral nebulæ, and especially of the 'whirlpool nebula' of Lord Rosse, were made as early as 1888, by von Gothard, with a 10-inch reflector. Excellent photographs of these objects have also been obtained by Dr. Roberts.

While it is absolutely necessary to use a considerable photographic telescope for the accurate registration of star positions, etc., where measures of precision are required, there are a great number of objects in the sky which are not necessarily subject to measurement, and which for their greatest value require a simple pictorial representation. The Milky Way, one of the most beautiful and certainly the most stupendous of the celestial features, is not susceptible of accurate measurement. The individualizing and measurement of all its stars would be the most hopeless task imaginable. Nor would such a task be of any very great importance could it be accomplished as a whole, for we could not form any special idea of its structural peculiarities from such a work. Though a conspicuous object to the unaided eye, the view we thus get of it is not sufficiently tangible, from the lack of details, to enable one to form any more than a crude idea of its coarser features. But even the naked-eye view of it is far more comprehensive than a catalogue would be containing accurate determinations of all its individual stars. What is required, therefore, in the study of this wonderful object—this mighty universe of stars—is something that will increase the penetration of our vision, and at the same time give us a certain amount of accuracy of position with a large field of view, so that we may study its peculiarities of structure in detail, and at the same time closely locate these details with reference to the whole, and thus, by finally putting structure and detail together, form a comprehensive idea, not only of the details themselves, but also of the relation of these features to each other. The long-focus telescope with a very limited field is not capable of dealing with the Milky Way in the manner stated. Its structural details are very large, far larger

*Address of the Vice-President before Section A—Mathematics and Astronomy—of the American Association for the Advancement of Science, August 22, 1898.

in general than the field of view of the ordinary photographic telescope, and vastly greater than that of a powerful visual telescope. We want, therefore, a short focus instrument, one capable not only of taking in a wide part of the sky, but also of giving a brilliant image, or, in other words, the reduction of the large details to a smaller scale, with a correspondingly great increase of effective light-power. These conditions exist in the large portrait lenses which were needed in the early days of photography to reduce the exposure time by collecting a great quantity of light from the object, and which in these days of rapid dry plates are no longer required for portrait work. Taking in some ten or twelve degrees of the sky, these lenses are specially suitable for photographing large surfaces, such as are presented by the Milky Way.

This subject was taken up by the writer in the first part of 1889 at the Lick Observatory, with a large 6-inch portrait lens of 31 inches focus, and with it was inaugurated the photography of the Milky Way. The first picture to show the real structure of the Milky Way was made in 1889, with this instrument. In the few following years a large series of photographs of those portions of the Milky Way seen from the northern hemisphere was made. The work with similar instruments was next taken up by Dr. Max Wolf, in Germany, who has also succeeded in making excellent pictures of the Milky Way. Mr. Russell, of Sydney, New South Wales, has also photographed portions of the southern part of the Milky Way, with a large portrait lens. Those who have seen some of the Milky Way photographs taken with the regular Astro-Photographic telescope, or who have tried to make out its complex structure with a visual telescope, must be struck with the great beauty of a photograph made with one of these short focus portrait lenses. The extraordinary complexity of structure of the Milky Way is brought out with marvellous beauty of detail, and the peculiarities of its different portions can be traced and connected in the different photographs, which thus afford the most direct means for studying every feature of structure and detail. These pictures show many peculiarities which must materially alter our ideas of the constitution and structure of the Milky Way. Some of them show strong evidence that the general body of the Milky Way may be made up of small stars which are not at all comparable with our sun in dimensions. This is especially shown in the region of the star Rho Ophiuchi. Many parts of the Milky Way appear to be comparatively thin sheetings of stars with relatively no very great depth, for it is not possible otherwise to explain the black holes and rifts shown in them. One of the most important revelations made by the portrait lens in connection with the Milky Way is the presence in it of very diffused nebulous matter apparently freely mixed with the groundwork of stars, and seemingly showing no definite tendency to condensation about the individual stars. These photographic nebulosities of the Milky Way are apparently of a different nature from the ordinary nebulæ of the sky, since they are extraordinarily large, diffused and but feebly luminous. These nebulous regions seem to be peculiar to the Milky Way and its vicinity, and are certainly in some way physically connected with it. It will be in the study by photography of such regions that we shall finally clear away some of the mysteries of the Milky Way. These masses of diffused nebulosity mainly affect regions of the sky in Scorpio, Cygnus, Cepheus, Perseus and Monoceros. I believe it to be true that no other form of telescope but the old time portrait lens or similar combination is capable of dealing with these extraordinary objects.

It was not until the study of the peculiarities of comet tails with portrait lenses that we knew anything of the strange phenomena shown by them. It may be said that our knowledge of the extremely rapid transformations in the tails of comets dates from the photographs of Swift's comet of 1892, taken at the Lick Observatory with the lens previously mentioned and similar ones taken of the same object by Professor Pickering at Arequipa, Peru. Although the great comet of 1882 was successfully photographed, it showed no phenomena not known and already seen with the telescope. While only an insignificant affair visually, and but fairly visible to the naked eye, Swift's comet showed upon the photographic plates the most extraordinary and rapid transformations yet seen in any comet. One day its tail would be separated into at least a dozen individual streams and the next present only two broad streamers, which a day later had again separated into numerous strands, with a great mass, apparently a secondary comet, appearing some distance back of the head in the main tail, with a system of tails of its own. This remarkable appearance was the first known of its kind, though it was repeated in the photographs of Rordame's comet of 1893 taken by Professor Hussey. These peculiar phenomena seem to be a production of the comet itself—a result of the forces at work in the head of the comet.

The photographs of Brooks' comet of 1893, also secured with the Willard lens, showed such an extraordinary condition of change and distortion in the tail as to suggest some outside influence, such as the probable collision of the tail with some resisting medium, possibly a stream of meteors, such as we know exist in space. The long series of photographs obtained of this comet frequently showed great masses of cometary matter drifting away into space, probably to become meteor swarms. One of the pictures showed the tail of the comet streaming irregularly as if beating against a resisting medium and sharply bent at right angles near the end, as if at that point it encountered a stronger current of resistance. All of these wonderful phenomena would have been unknown to astronomers had it not been for these photographs, and the comet, instead of proving to be one of the most remarkable on record, would have passed without special notice. Though these phenomena were so conspicuously shown, scarcely any trace of the disturbance was visible with the telescope. On account of the apparent insignificance of the comet visually, no photographs were made of it elsewhere during its active period.

In the matter of discovery the photographic plate has accomplished a very great amount in certain directions. In spectroscopic work it has a field singularly suited to display its possibilities. In this direction it deals not alone with what can be seen, but it enters into the unseeable regions where the eye takes no cognizance of things. For though it is partly blind to the light which affects the eye, it can readily penetrate regions where we in turn are blind. And it is in this direction mainly where the photographic discoveries in spectrum analysis are immediately concerned, since it extends our vision into the invisible regions of the spectrum. The result must necessarily be one of discovery. It not only faithfully records spectral lines that cannot otherwise be seen, but by special treatment of the plate it also registers those visible to the eye and permits their accurate measurement.

From Doppler's principle it is known that the spectral lines have a normal position only while the object whose light is under examination is motionless in the line of sight. When it is in motion to or from us these lines are displaced from their normal position, in the first case towards the violet region of the spectrum, and in the other towards the red. By comparing any of the lines in the spectrum of a heavenly body with the same lines in the spectrum of a stationary object it is possible to tell not only the direction of motion of the moving object, but to determine accurately the amount of this motion, for there is a known relation between the amount of displacement and the actual velocity, and this is independent of the distance.

This peculiarity, besides showing the motions of the individual stars, has revealed to us, through the aid of photography, an entirely new class of bodies, the so-called spectroscopic binaries.

The visual spectroscopic work, long ago, in the hands of Dr. Huggins, had shown the displacement of the spectral lines as the stars moved towards or from us. It remained, however, for photography further to extend this remarkable work by showing that not only were the lines displaced, but that in the case of certain of the stars the lines were periodically doubled at short intervals, thus indicating the presence of two bodies which must be rapidly revolving about each other. The doubling of the lines is due to the alternate approach of one and recession of the other body, which thus causes a displacement of the two sets of spectra, for when the motion is at right angles to the line of sight (and this must occur at two points in the orbit) the two spectra will be exactly superposed. It can readily be shown from the known periods of these stars and their enormous distances that no telescope is likely to be made so powerful as to show visually their independent components. The visual double star having the shortest period is one discovered by Burnham, and known as Kappa Pegasi, which he found to have a period of about eleven years. The spectroscopic binaries seem to revolve in extremely short periods—a few days—and in at least one case in a few hours, showing that they must be extremely close to each other. The explanation, to account for the observed peculiarities of their spectra, that these are actual double stars in rapid orbital motion must be accepted until some better explanation of the phenomenon be forthcoming, which does not at present seem likely to occur.

Among the first of these spectroscopic binaries discovered was Beta Aurigæ, which was detected at the Harvard College Observatory by Miss Maury, through the doubling of its spectral lines as shown on the various photographs obtained of it at that Observatory. This star has a period of four days, the relative motion of the components about each other being about 150 miles a second, and the distance between them about six millions of miles. In a similar manner, Dr. Vogel has found that the star Algol, so famous for its light variations, alternately approaches us and recedes, in a manner that can only be explained at present by the revolution of that star about some other body or about the center of gravity of the two. The spectrum of this star does not show any doubling of the lines, but a simple displacement from one side to the other of their normal position occurs consistent with the changes of the star's light. As there is no doubling of the lines, the conclusion is that there is but one spectrum. One of the stars is, therefore, a non-luminous body, and hence produces no spectrum. The old explanation of two hundred years ago, that the variation in the light of Algol is due to a dark body revolving about it and partially eclipsing it at intervals of a little less than three days, is hence proved by the spectroscope and photography to be the correct one. The frequent discovery of these spectroscopic binaries shows that they are by no means uncommon, and that possibly a considerable percentage of the stars consist of two or more bodies rapidly whirling about each other.

The beautiful phenomenon of the displacement of the spectral lines through motion in the line of sight has given rise to many important and interesting results, but certainly none more striking than that offered by Professor Keeler's spectroscopic proof of the meteoric constitution of the rings of Saturn. It was suggested soon after the discovery of the rings that they must be made up of discrete particles revolving in zones about the planet, which, from their smallness and great distance from us, gave the appearance of a system of solid rings encircling Saturn. This had been shown by Clerk Maxwell to be a mathematical necessity, and as the rings lay within Roche's limit, within which a large solid body would be broken up in revolving about a planet by the unequal attraction of the planet itself, it was certain that the rings must consist of small individual bodies. It remained for the spectroscope, through the aid of photography, to add its testimony to that of mathematical analysis. The problem offered to the spectroscope was simply to show whether the inner or the outer portion of the rings moved the faster. Should they revolve as a solid body the outer edge must necessarily have the greater velocity. But if they are made up of individual particles, then the attraction of the planet would cause those nearest to it to move the fastest, or, in other words, the inner part of the rings must have the greater velocity. This beautiful problem was successfully solved by the photographs of the spectrum of the rings obtained by Professor Keeler, where the displacement of the spectral lines by motion in the line of sight showed that the inner portion of the rings moved faster than the outer, and hence that the rings must consist of small bodies responding individually to the attraction of the planet.

The discovery of variable stars by photography can be compared with the wholesale business in commercial circles, because of the great number that are found on the various plates. These stars are not only found by the actual variation of their light, as shown by the size of their images on different plates, but many of them also show peculiarities in their spectra which at once stamp them as being members of a certain class of variable stars. So expert has Mrs. Fleming, of the Harvard College Observatory, become in detecting these bodies by their spectra that she instantly recognizes them at a glance among hundreds of other spectra on the same plate.

The most interesting and important of these Harvard College variable-star discoveries are found in the photographs of the globular clusters taken by Professor Bailey with the 13-inch telescope at Arequipa, Peru. It was found that a great many of the small stars that make up these clusters varied regularly and rapidly in their light, and in some cases a large percentage of the entire mass of stars was variable. So abundant are these variables, indeed, that as many as a hundred of them have been found in a space in the sky that would be covered by a pin's head held at the distance of distinct vision.

The clusters most prolific in variables are M 3, Omega Centauri, M 5, and a few others of this class. Perhaps the most remarkable circumstance, outside of the actual grouping of variables in such great numbers, is the fact that not a single variable star has been found in the great cluster of Hercules, the best known of these objects, and apparently like them in all other respects. Professor Pickering finds every star in this cluster constant in its light from the photographic evidence extending through ten years.* This would seem to mark this great cluster as being physically very different from the others referred to.

* Professor Bailey has since found that two of the stars of this cluster are slightly variable.

The writer has examined the cluster M 5 with the great telescope of the Yerkes Observatory and has visually verified a number of these variables. The brighter of them appear to vary slowly in their light, while many of the smaller ones are extremely rapid, passing through their entire light changes in a few hours. In the discovery of such objects, photography offers special advantages, since on the different photographs a thousand or more stars can be rapidly and accurately compared with each other and any variation in their light at once detected, while such comparisons in the actual sky, visually, would be limited to a very few stars. By the aid of the Harvard photographic plates over five hundred variable stars have been discovered in these clusters. It must be said, however, in speaking of the variables in the cluster M 5, that the two most prominent ones were really discovered visually nearly ten years ago by Mr. D. Packer with a very small telescope. These two seem to have been the first of the variable stars found in this cluster.

The shortest period variable so far discovered in the globular clusters—indeed, the shortest known variable—is a small star in the great southern cluster Omega Centauri, whose period is seven hours. These cluster variables seem to form a distinct class from the ordinary variable stars. It is very interesting to watch one of these small stars in a powerful telescope and to see with what quickness it passes through its light variation. One of the small stars in M 5, whose period is 12 h. 31 m., seems to be dormant for a large part of the time, as a very faint star, invisible in ordinary telescopes. It begins to brighten, and in two or three hours has risen nearly two magnitudes and faded again to its normal condition, while another and larger star quite near it seems to require a month or more to go through its light fluctuation.

Frequent reference has been made to the photographic work of the Harvard College Observatory. It is to be regretted that time does not permit a more detailed account of this work. No other observatory is so active in the application of photography to the various departments of astronomy. Not content with the available sky as seen from the northern hemisphere, Professor Pickering wisely established a branch observatory at Arequipa, in Peru, where a thorough photographic survey of the southern skies has been made, and a vast amount of work of high value has been accomplished, which has resulted in many important discoveries among the southern stars.

In dealing with the ordinary stars of the sky it has been shown that measures of the relative positions of the photographic images are strictly comparable with the best meridian circle work, while the number of stars that can be measured is vastly greater. The Pleiades, the cluster of Perseus, Præsepe in Cancer, etc., have all been measured with the micrometer, the heliometer and by photography. The comparisons have shown that photography has many advantages over the older methods, and the results are possibly even more accurate. These objects, however, are loose clusters, and the stars are not thickly crowded, and, moreover, the small scale of the photographic plate in such cases does not seriously interfere with the work. The great globular clusters of the sky, however, from the extraordinarily crowded condition of their stars, would almost forbid any attempt to deal with the individual positions by photography, except in outlying regions, where the stars are thinly scattered. No comparison between photographic and visual measures of such objects has yet been made, because no visual measures exist. The great cluster of Hercules is, perhaps, the easiest of these objects, both visually and photographically. It requires, however, a powerful telescope to measure the individual stars. Dr. Scheiner has given a catalogue of 833 of the stars of this cluster measured on photographs taken with the 13-inch refractor of the Potsdam Observatory. The stars that were measured all lie between the magnitudes 11.7 and 14. As a matter of comparison with visual measures, the writer has taken up the measurement of a few of the stars contained in Scheiner's catalogue. A rough inspection of the results so far obtained shows a close agreement between the visual and the photographic work. These observations also show that no appreciable change has taken place in the positions of any of the stars in the past six years, which, perhaps, is surprising, since one would expect a possible rapid change in some of the positions of the individual stars when they are massed so close together. They, however, seem to be as stable in their relative positions as are the stars elsewhere in the sky. A more remarkable object with a great telescope is the cluster Messier 5, in which the stars are more closely compressed and irresolvable than in the cluster of Hercules. This object has already been mentioned in speaking of the variable stars discovered at the Harvard College Observatory. The measurement of nearly 100 of these small stars has been undertaken with the great telescope of the Yerkes Observatory. Many of them are apparently in the very heart of the cluster, where the compression is the greatest. It is doubtful if at this time photographs can be made of this cluster upon which the crowded individual stars can be accurately measured.

It has been frequently photographed, but no measures have been made of the great mass of stars in the center of the cluster. It has been already stated that the accuracy of the photographic positions of individual stars is as great as the best meridian observations. The facility and ease with which the photographic positions are obtained is well shown in a report by Professor H. H. Turner, who is making the Oxford portion of the great Astrographic catalogue. An average of 3,951 measures per week is obtained. Over 150 stars per hour each can be measured by those most skilled in this work.

In the discovery of nebulæ, variable stars and asteroids, the photographic plate has done a great work which is still being carried on. The number of known asteroids has been doubled in the past few years (as many as nine have been found in a single night), and now it has become a matter of impossibility to keep track of them all, and they are found and turned adrift again unless they show some striking peculiarity of orbit.

Up to the present time but two comets have been discovered by photography. The first of these was discovered on a photographic plate taken by the writer on October 12, 1892, with the 6-inch Willard lens of the Lick Observatory, and was subsequently verified visually and observed at the different observatories. The second was photographed at the same Observatory by Mr. Coddington, with the same instrument, in July, 1898.

In photographing the sky it is found that the short focus portrait lens, from its small scale and large field, will show faint nebulosities beyond the reach of the larger photographic telescopes. This results from various causes. The action of these lenses upon the Milky Way, comet's tails and the great nebulosities of the sky does not seem to be strictly subject in practice to the law of the ratio of aperture to focus; or, if it is, this law must be somewhat modified in effect. The action seems to be quicker with the short focus lens than it should be. Probably, however, much of this is due to the small scale and the consequent compression of the image into a smaller space, which would produce an intensification of its action. It is possible, also, that the photographic plate may be relatively more active with a bright image than with a faint one, which would give an advantage to the small relatively bright image of the portrait lens. This idea seems to be partly borne out by some experiments with a small lantern lens. This lens, $1\frac{1}{2}$ inches in diameter and about $5\frac{1}{2}$ inches focus, is much quicker than its light ratio would warrant, for it will photograph in a few minutes what the ordinary quick-acting portrait lens would require several hours to show. This was strikingly shown in photographs taken with it of the Milky Way. The scale of this lens is very small, and the cloud forms are so compressed that they act as a surface, and not as an aggregation of individual stars, as they must do in a larger telescope. If the focus is increased, the stars are scattered and the cloud no longer acts as a surface. With this small lens the earth-lit portion of the new moon was readily photographed in a single second, while with a 6-inch portrait lens of ratio $\frac{1}{5}$ from 20 to 30 seconds were required to show it well. The brighter cloud forms of the Milky Way were shown in from 10 to 15 minutes' time, while with the larger lens upward of three hours were required. Some of the diffused nebulosities of the Milky Way, notably in the region of Antares, are shown more quickly and more satisfactorily with this small lens, and a great wing-like nebula involving the star Nu Scorpio was discovered with it.

A list of discoveries made with these small lenses would be tedious; one of the most interesting, however, cannot be passed over because of its importance. There is no object in the entire heavens better known than the great nebula of Orion. With the lantern lens, a great curved stream of nebulosity was shown on the plates of this region covering a large portion of the constellation and some 17° long. It was found later that this had already been discovered by Professor Wm. H. Pickering with a $2\frac{1}{2}$-inch lens in 1889. This object seems to be an outlying appendage of the great nebula. The discovery very much extends our knowledge of the complicated and far-reaching influence of this mysterious object. In several other cases the photographic plate has shown us that the nebulæ are far vaster than we had ever conceived them to be, for their fainter extensions are not seen by the eye. What this knowledge may ultimately lead to in the reconstruction of our ideas of space and its contents can hardly be anticipated just now, though it must, necessarily, very greatly influence those ideas.

We have spoken of the Pleiades and the entangling nebulosities shown by photography to involve the stars of the cluster. The portrait lens has shown us that not only are the individual stars of this group involved in a nebulous system, but that streams and masses of this filmy matter stretch out for great distances all about the cluster.

The photographic plate has shown itself especially adapted, when used with the rapid portrait lens, for the accurate registering of the paths of meteors, and it promises to be of special value during the expected return of the November meteors this year, when a more exact determination of the radiant will be obtained from the photographs, and hence the orbit of the meteor stream will be better known.

In the reduction of the measures of the photographic plates for the great Cape Photographic Durchmusterung, Kapteyn discovered another 'runaway' star with a proper motion of 8.71 seconds a year, which is much greater than that of the celebrated 1830 Groombridge, and is at present the largest proper motion of any known star.

There are very few departments of astronomy where photography has not taken a prominent, if not a commanding position. It is probable, however, that it will never take the place of the micrometer in the observation of close double stars, and in this direction the micrometer of Burnham will perhaps never be displaced. The photography of the surface features of the planets is in an almost hopeless condition at present, yet much can be expected in this direction when an increased sensitiveness of the plates has been secured.

Photography has shown its value in the determination of stellar parallax, and probably hereafter it will essentially take the place of the micrometer in this direction.

This is not the place to go into a discussion of the relative values of the refractor and reflector for photographic work. Where accurate measurement is to be considered, the refractor is doubtless better than the reflector. If, however, the main object is a great quantity of light, such as is required for the photography of the nebulæ, the large aperture of the reflecting telescope of short focus makes it, perhaps, the best form of instrument (though it is very much hampered by its small field). This has been shown to be true by Common and Roberts. Since in the reflector the light does not pass through the glass, it is possible to use very large apertures without any additional loss of light through absorption, as would necessarily occur if it passed through a large object glass.

Mr. Ritchey, of the Yerkes Observatory, is making a large glass speculum, five feet in diameter and twenty-five feet focus, which, when finished, will be one of the most powerful instruments for photographic and spectroscopic work yet made, and which deserves a more extended notice than my limited time will permit me to give it here. With this instrument, and Mr. Ritchey's skill in photographic work, results of high importance will be obtained.

Through the intelligent generosity of Miss Catherine W. Bruce, of New York City, astronomical photography has been placed on a firmer basis than it ever was before. Her gifts have been made to all departments of astronomy, and it would take considerable space to properly enumerate them all. Perhaps the most important of these are the ones that bear directly upon astronomical photography.

The first of these gifts was the great 24-inch photographic doublet by the late Alvan Clark, presented to the Harvard College Observatory, and which is now doing such excellent work in Peru; the two 15-inch portrait lenses for Dr. Max Wolf, of Germany, and a 10-inch photographic doublet for the Yerkes Observatory. These instruments are the most powerful of their kind, and for certain classes of work are superior to any other form of telescope. The results of the splendid gifts of this lady must hereafter have the greatest influence upon the higher development of astronomical photography.

It is impossible within the limits of this address to give more than a general, and at best incomplete, sketch of the rise and progress of photography in the various lines of astronomical research. To those who have kept pace with these rapid strides in the last twenty years this brief history will seem imperfect, and perhaps of little interest. Many applications of the photographic art and many valuable results have necessarily been omitted. But few of the names of those prominently identified with this subject have been mentioned, and but little of their work even alluded to. A volume of no small dimensions would be necessary to give a complete history of the development of photography in the many directions in which it has been applied to astronomy. The time to do this has not yet come. Progress has been so rapid and far-reaching that its history, however complete and exhaustive, a year later requires to be re-written; and there is no reason for supposing that the end, or even the beginning of the end, has been reached. With new materials and new methods, and new workers who will profit by the experience and results gained by those who have in our time accomplished so much, we may expect for the new century far greater results than those briefly recorded here.

It would be difficult just here to predict the future of astronomical photography, though one can foresee something of the great results it must accomplish. It will displace some of the visual work, but it is more likely to move along new lines, opening up new fields of research. The older astronomy, so nobly represented by Simon Newcomb and a few others, will be strengthened at every point, and will stand all the more sublime for the help it shall receive from photography.

E. E. BARNARD.

YERKES OBSERVATORY.

THE ZOOLOGICAL SECTION (F) OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

THIS section had a successful meeting. Papers of both a general and special nature were presented. The address of Vice-President Alpheus S. Packard, entitled 'A Half-Century of Evolution, with Special Reference to the Effects of Geological Changes on Animal Life,' has appeared in this JOURNAL. A brief outline of the papers read is presented in the following:

Evolution and Migration of Hawaiian Land Shells. By PROFESSOR ALPHEUS HYATT.

THE author studied about 22,000 shells, of which 18,000 at least were from Oahu. In that island there are about 280 species, as compared with about 140 in all the other islands of the group. There are three leading genera, Bulimella, Achatinella and Apex. The distribution of the species of these genera was represented on a large relief map of Oahu, by means of colored pins, connected by similarly colored threads. Each pin or series of pins represented a species, as indicated by attached labels.

All the shells probably sprang from a common ancestor, *Achatinella phœozona* G., which has become extinct in late years. Starting in the valley Kiliouou, as the shells migrated northward, there was an evolution of species and genera as plotted on the map. The principal occurrence of these mollusks is on the western flanks of the eastern range. The Bulimellæ inhabit the highest sides of the mountains, crossing to the eastern side, and there evolving a considerable number of species. This genus does not succeed in forming colonies in the range on the western crest of the island. The Achatinellæ occupy a lower zone below both the Bulimellæ and Apex. They cross to the eastern side of the mountains in several places; but are unable to contend successfully with the climate on that side. They were also unable to cross the valley lowlands in the center of the island, except in sporadic cases. The species of Apex occupy a middle zone, between the Bulimellæ and Achatinellæ, on the western flanks of the eastern range. They seem more delicate, and less able to contend with the surroundings on the ocean side of the hills. Not a species has been recorded from that side; but, on the other hand, it crossed the broad plain of the interior, and was successful on the short western range, where only a few sporadic species of the Achatinellæ are found. The evidence is that the species are distributed over the island in definite lines, which correspond to definite geographical areas. In the oldest part of the island are the oldest forms as evidenced by development.