the human senses displayed by the psychologists as in the apparatus developed by our astronomers and physicists. Beside the newest technique of pure research in the physical and biological sciences, you will find beautiful and diverse methods applied to the arts, to photography, to the manufacture of exquisite glass vases, as well as to the more useful clays from all parts of Europe.

Explorations.—True to the Monroe Doctrine, we are no longer allowing France, Germany or any other country to preoccupy our proper scientific territory, and you will observe proofs of especial activity along the noble western coast of the Americas from Cape Horn to Point Barrow, Alaska. From the photographs of Arequipa, Peru, the highest astronomical station in the world, the mosses of northern Bolivia, the Indians of Mexico, we have invaded British territory and are making the study of the North Pacific and the zoology of the Pacific Coast from Puget Sound to Alaska our own. We are also invading other countries by expeditions of various kinds, and our geologists and mineralogists draw their exhibitions from every part of the world, from Tasmania to Finland.

Diversity of Subjects.—The subjects treated in this exhibition are as widely separated as these geographical areas; in adjoining alcoves you will find the brains of New Guinea natives and the moth Siamese Twins. Across the aisle, in the field of electricity, signalling without wires is in process, widely in contrast with the concentrated polar cold of the liquid air in the main hall. The monster Camarasaur, at least ten millon years old, from the base of the Cretaceous, puts a Pickwickian interpretation upon the words 'old' and 'rare' as applied to the manuscripts in the department of philology.

Progress.—Scientific work day by day appears to drag. It is only when an interval of a few months passes and we have taken stock of things that we realize our immense progress. We are especially encouraged for the future by the generous gifts which are pouring into the service of science in this city. Only a week ago a gentlemen agreed to fit out an expedition to the west coast of Africa. Fortunate is the country where men of brains are drawn into the pursuit of science, and men of appreciation and wealth supply the sinews of scientific warfare. Pure research is a luxury, for it brings no immediate return, but as an investment it finally repays a city or a country a hundred or a thousand fold.

At our annual exhibition last year we signalized electricity as the especial subject of scientific progress in the person of Mr. Nikola Tesla. This year we believe that astronomy deserves the place of honor. American astronomy, reaping, as it does, the combined advantages of our mathematical genius and natural inventiveness, of our wonderfully clear sky, and the support of generous wealth, certainly occupies a commanding position. We, therefore, take pleasure in introducing Professor George E. Hale, who will tell you of the great Yerkes Observatory and the especial merits of large telescopes.

THE FUNCTION OF LARGE TELESCOPES.*

The annual exhibitions of the New York Academy of Sciences afford excellent opportunities for studying the progress of science. The photographs and specimens gathered here to-night are substantial evidence that in no department of research have investigators been idle during the last twelfthmonth. So true is this that to sketch the year's advances in even a single field would consume more time than is allotted to the annual lecture. It therefore seemed to me wise,

* An address given at the Fifth Annual Reception of the New York Academy of Sciences.

in responding to the courteous invitation with which I was honored by the Council, to select a subject involving certain details of astronomical progress, without attempting to undertake the inviting task of portraying the rapid advances which make up the recent history of the science. I accordingly invite your attention to some considerations regarding the function of great telescopes.

On the 21st of last October, in the presence of a large company of guests, the Yerkes Observatory was dedicated to scientific investigation. The exercises were held under the great dome of the Observatory, beneath the 40-inch telescope. Is there reason to suppose that some in the audience, particularly those having no great familiarity with astronomical instruments, were inclined, in the course of the reflections to which the occasion may have given rise, to attribute to the great mass of steel and optical glass rising far above their heads some extraordinary and perhaps almost supernatural power of penetrating the mysteries of the universe? It is not at all unlikely that this was the case. For there apparently exists in the public mind a tendency to regard astronomical research with a feeling of awe which is not accorded to other branches of science. In its power of searching out mysterious phenomena in the infinite regions of space a great telescope seems to stand alone among the appliances of the investigator. Partly because of this special veneration for its principal instrument, and perhaps still more on account of the boundless opportunity for speculation regarding the origin and nature of the universe, astronomy appears to command the interest of a great portion of the human race. No doubt there are also historical reasons for the special attraction which the subject seems to exercise. In the more prosperous days of the countries bordering on the Mediterranean astrology played an important rôle, and mediæval history illustrates most clearly the ascendency which the fancies of the astrologers had acquired over even cultivated minds. So strong was the tendency of the times that even so able an astronomer as Tycho Brahe was wont to cast horoscopes, in the significance of which he firmly believed. He concluded that the new star of 1572 prognosticated great changes in the world. Similarity to the ruddy planet Mars pointed to wars, pestilence, venomous snakes and general destruction, and its resemblance to Venus, Jupiter and Saturn at other times foretold temporary pleasant influences, followed by death and famine.* Thus the heavenly bodies in their courses were supposed to exercise evil or benign influences upon the human race, and the apparition of a great comet or a new star gave rise to endless speculations regarding the fate to which the inhabitants of the Earth were shortly to be exposed. Even in our own day it cannot be said that we have altogether escaped from the entangling meshes of the astrological net. With that strong desire to be humbugged which Dr. Bolton has so well illustrated in his recent paper in SCIENCE on Iatro-Chemistry, a portion of the general public seems to devote itself with enthusiasm to the encouragement of charlatans, whether they deal with alchemy, with medicine or with astrology. So it is that astrologers flourish to-day, and continue to derive profit from their philanthropic desire to reveal the future to inquiring minds.

The interest of cultivated persons in astronomy and in the possibilities of great telescopes is by no means to be compared with the blind groping of less developed intellects after the mysteries of astrology. But if we must regard the large circulation of certain newspapers as any index to the popularity of their contents, we are forced to admit that their readers may comprise a

* See Dreyer's *Tycho Brahe*, p. 50.

class of persons whose admiration for the science is at least distantly related to the love for the sensational which dominates the followers of modern seers and sooth-sayers. Great telescopes are no sooner erected than these papers begin to demand extraordinary revelations of celestial wonders. The astronomer, quietly pursuing his investigations in the observatory, is from time to time startled by imperative demands to introduce a waiting and anxious public to the equally expectant inhabitants of Mars. Minute particulars as to the appearance, strength, stature and habits of these hypothetical beings, whose existence is freely taken for granted, are expected to be the results of a few moments' observation with the great telescope. When the astronomer mildly protests that his observations are likely to afford little or no material for discussions of such topics, he is at least supposed to so cultivate his imaginative powers that he shall be able to supplement his unsatisfactory observations by intuitive perception of things which are beyond his telescope's unaided appreciation. And it must be admitted that this demand on the part of some portion of the public press, while in one sense only a certain phase of the almost universal desire for sensation, has not lacked encouragement from men who are generally regarded as serious astronomers, intent on arriving at the truth by the methods of exact science. To such is due a widespread belief in the inhabitants of Mars, who in the popular novels of the day have not even been content with life upon their own planet, but, in accordance with the astrological significance of the god of war, have come to bring destruction upon the inhabitants of the Earth. However entertaining we may find the doings of these strange individuals, whether at home or abroad, we must not make the mistake of classing the works which describe them with the literature of science, but rather accord them their proper place among the pleasant romances which we owe to men of letters.

I cannot better illustrate one phase of this pseudo science than by a reference to the celebrated 'Moon Hoax,' which caused such a stir at the time of its appearance. When Sir John Herschel sailed for the Cape of Good Hope in 1833 he little imagined what marvelous discoveries lay before him. It is true that he was provided with a great reflecting telescope of twenty feet focal length, which was to be used upon the previously unexplored regions of the southern heavens, and it could not have been difficult for him to form some conception of the valuable additions he was certain to make to astronomical knowledge. But the imagination of others by far outran the more prosaic course of his own mind, and results were obtained for him which unfortunately his telescope never served to show. Many who are present are no doubt familiar with a pamphlet entitled 'Great Astronomical Discoveries lately made by Sir John Herschel, LL.D., F.R.S., etc., at the Cape of Good Hope,' which was 'first published in the New York *Sun*, from the supplement to the *Edinburgh Journal of Science*.' In the truly entertaining pages of this ingenious narrative we find an example which certain reporters of our own day seem to have taken to heart. Let me quote a paragraph of nonsense which is so amusingly conceived and proved so effective when published that one is almost ready to forgive the perpetrator. After a lucid historical discourse on the great telescopes which had been made by Sir William Herschel and other previous investigators, followed by an impassioned paragraph which may well be considered to approach in eloquence the most fervid astronomical literature of our own day, our author treats us to an account of a conversational discussion between Sir John Herschel and Sir David Brewster, which began with a consideration of certain

suggested improvements in reflecting telescopes, and soon directed itself "to that all-invincible enemy, the paucity of light in powerful magnifiers. After a few moments silent thought, Sir John diffidently inquired whether it would not be possible to effect *a transfusion of artificial light through the focal object of vision!* Sir David, somewhat startled at the originality of the idea, paused awhile, and then hesitatingly referred to the refrangibility of rays and the angle of incidence. Sir John, grown more confident, adduced the example of the Newtonian reflector, in which the refrangibility was corrected by the second speculum, and the angle of incidence restored by the third. 'And,' continued he, 'why cannot the illuminated microscope, say the hydro-oxygen, be applied to render distinct, and, if necessary, even to magnify the focal object?' Sir David sprung from his chair in an ecstacy of conviction, and, leaping half-way to the ceiling, exclaimed, 'Thou art the man!' Each philosopher anticipated the other in presenting the prompt illustration that if the rays of the hydro-oxygen microscope, passed through a drop of water containing the larvæ of a gnat and other objects invisible to the naked eye, rendered them not only keenly distinct, but firmly magnified to dimensions of many feet; so could the same artificial light, passed through the faintest focal object of a telescope, both distinctify (to coin a new word for an extraordinary occasion) and magnify its feeblest component members."

Here, indeed, was a discovery fit to startle the world; and one cannot be surprised that, after so extraordinary an advance, Sir John Herschel should have immediately arranged for the construction of an object-glass 24 feet in diameter. Contributions towards this important work were received from many royal personages, culminating in a gift by his Majesty the King of some seventy thousand pounds, which was considered ample to meet all expenses. Many difficulties were encountered in casting the great object-glass, which was composed of "an amalgamation of two parts of the best crown with one of flint glass, the use of which in separate lenses constituted the great achromatick discovery of Dolland." Notwithstanding the prodigous size of this enormous lens, which weighed 14,826 pounds after being polished, and whose estimated magnifying power was 42,000 times, Sir John was not satisfied. Not content with the mere illuminating power of the hydro-oxygen microscope, "he calculated largely upon the almost illimitable applicability of this instrument as a second magnifier which would supersede the use and infinitely transcend the powers of the highest magnifiers and reflecting telescopes." Indeed, so certain was he of the successful application of this idea that he counted upon "his ultimate ability to study even the entomology of the Moon in case she contained insects upon her surface."

It would be interesting, if time permitted, to consider with our inspired author the various further details in the construction of a telescope which was the first to render visible the inhabitants of the Moon. It may well be imagined with what breathless interest the report of Sir John's extraordinary discoveries, which constitutes the body of our pamphlet, was received by a willing public. "It was about half past nine o'clock on the night of the tenth, the Moon having then advanced within four days of her mean libration, that the astronomer adjusted his instruments for the inspection of her eastern limb. The whole immense power of his telescope was applied, and to its focal image about one-half of the power of his microscope. On removing the screen of the latter, the field of view was covered throughout its entire area with a beautiful distinct and even vivid representation of *basaltic*

rock." For further details regarding the rock and the lunar flora which covered it, reference must be made to the original pamphlet. There, too, can be found descriptions of deep blue oceans, breaking in large billows upon beaches of brilliant white sand, girt with wild castellated rocks. Passing inland wide tracts of country of apparently volcanic character were rapidly passed over, soon bringing to the observer's eye lofty chains of slender pyramids of faint lilac hue, which, when examined with the highest power of the instrument, were seen to be monstrous amethysts reaching to the height of sixty to ninety feet, and glowing in the intense light of the Sun. It must not be supposed that such delightful regions were devoid of life. Birds and beasts of strange and uncouth form were soon brought to view, and, last and greatest marvel of all, the observer was permitted to behold beings of manlike form. Although not seen engaged in any work of industry or art, they were evidently of a high order of intelligence, and to them was doubtless due a magnificent temple, built of polished sapphire, with roof of yellow gold. The observer did not at the moment pause to search out the mystery symbolized in the unique architectural details, for he was then "more desirous of collecting the greatest possible number of new facts than of indulging in speculative theories, however seductive to the imagination."

But we have already dwelt too long upon this product of enterprising journalism, which poor Sir John was too far away to be able to contradict. It is enough to remark that the author accomplished his immediate purpose, and moreover bequeathed to future generations a classic in this special field of literature.

The astronomer of to-day is unfortunately exposed to similar misrepresentation. On account of the fact that it is a little larger than any other refractor, the Yerkes telescope is particularly open to attack. Take, for example, these sentences from a newspaper which would not ordinarily be considered as one of the sensational class: "After Professor Barnard had swept the sky in the region of the nebulæ he pointed the instrument toward a region located to the astronomer in Pos. 312 degrees; Dist. 53 minutes. He swung the giant tube toward the region and the first discovery at the Yerkes Observatory was registered on the dial near the dome." This is merely the newspaper's own peculiar way of paraphrasing a simple statement in the *Astrophysical Journal* regarding the detection of a faint star near Vega. A persistent search by all the members of the staff has not yet brought to light the mysterious 'dial near the dome,' with its precious record of discovery. It seems probable that the same dial must have treasured up the remarkable observations of the Moon, which the Associated Press thought worthy of transmission to Europe, though they originated in a reporter's fertile brain, and still remain unknown to the telescope to which they were ascribed. An influential newspaper selected these latter observations as the text of an editorial setting forth the marvelous benefits the Yerkes telescope is destined to confer upon mankind.

It may be added that the great telescope of the 'Moon Hoax' is hardly more extravagant in conception than certain schemes which have been proposed in all seriousness within the past year. One of these inventors, whose familiarity with the difficulties of telescopic observation is certainly surpassed by his optimism, remarks: "I think the limit (of magnification) will be due to the shaking of the instrument caused by the trembling of the earth and of the clockwork mechanism which moves the telescope. Under these high magnifications extremely minute vibrations are so much magnified that a small object like that of a house

upon the surface of Mars would dart in and out of the field of vision so as to prevent its being photographed." And this he believes to be the only obstacle (though fortunately it is to be overcome) which can interfere with his studies of Martian architecture.

So far we have considered only what great telescopes *cannot* accomplish, and were I not to pass rapidly on to some positive statements of another character, I might be supposed to believe that they have no reason for existence, or at best are no better than small ones. But I shall endeavor to show that exactly the contrary is true; that while large telescopes do not possess the extraordinary powers conferred upon them by fertile imaginations, they nevertheless play a most important part in scientific research, and render possible many investigations which are altogether beyond the reach of smaller instruments. It seems the more necessary to dwell upon this point, for only a few years ago there appeared in print an article entitled 'Do Large Telescopes Pay?' which was evidently not written by one of those to whom reference has just been made, but by one of another class, whose known acquaintance with astronomical work would tend to give his opinion considerable weight with many intelligent readers. In discussing the subject it was seriously asked whether the great investments of money which had been made in the giant instruments of the latter half of the nineteenth century had been attended by commensurate advances in astronomical knowledge. The question is certainly one that deserves serious consideration, for it would surely be poor policy to erect great telescopes if they are no better than smaller and much cheaper ones. It is desirable, therefore, to point out, if I can, some of the elements of superiority of large instruments which seem to me to make them worth all that they cost and more.

Leaving aside reflecting telescopes, as most of the very costly instruments in use are refractors, it will be seen that our problem is, for the most part, a comparison of the properties of a large achromatic lens with those of a small one. To render the discussion more definite let us compare a 40-inch lens of 62 feet focus with a 10-inch lens of $15\frac{1}{2}$ feet focus. The large lens, then, has a diameter four times that of the small one, which means that its area is sixteen times as great. It will thus receive upon its surface from a given star sixteen times as much light, and all of this will be concentrated in the point-like image of the star, except that portion which is lost in transmission through the lens. On account of its greater thickness, the large lens transmits only about 65 per cent. of the visual rays that fall on it, while the small lens transmits about 77 per cent. But after allowance has been made for the loss due to both absorption and reflection it is found that the image of a given star produced by the large telescope will be nearly fourteen times as bright as that given by the small one. In this instance all of the light is concentrated in a point, but in the case of a planet or other extended object, on account of the fact that the focal length of the telescope increases as its aperture increases, the brightness of the image is no greater with the large glass than with the small one. The image is, however, four times as large, and this has a most important bearing upon certain classes of observations, particularly in photographic and spectroscopic work.

There remains still another peculiarity of the large lens as distinguished from the small one. On account of the nature of light, the power that a lens possesses of separating two luminous points which are so close together as to be seen as a single object by the unaided eye depends directly upon its aperture. Thus, if we consider a

double star, the two components of which are separated by a distance of 0″.5 of arc, it will be barely possible with a 10-inch telescope to resolve the star into two points of light just touching one another. If the members of the pair are closer than this they cannot be separated with a 10-inch glass, no matter what magnifying power is used. With a 40-inch telescope, on the other hand, it is not only a simple matter to separate stars 0″.5 apart, but it is even possible to distinguish as two points of light the components of a double star of only 0″.12 separation.

To sum up, then, we see that the principal advantages of a 40-inch object-glass as compared with one of 10 inches aperture are: first, its power of giving much brighter star images, and thus of rendering visible faint stars which cannot be seen with the smaller telescope; second, the fact that it gives at its focus an image of any object, other than a star, four times as large as the image given by a lens of one-fourth its aperture and focal length; and third, its capacity of rendering visible as separate objects the components of very close double stars or minute markings upon the surface of a planet or satellite. Mention should be made here of the fact that the large glass assuredly has some disadvantages as compared with the smaller one, particularly in that it requires better atmospheric conditions to bring out its full qualities. But I think it will be seen from what follows that these disadvantages are by no means sufficient to offset the great advantages possessed by the larger instrument. Let us now consider what practical benefit the astronomer enjoys from the special properties of large lenses which have just been enumerated.

Like other scientific men, astronomers who expect to accomplish much of importance at the present day find it necessary to specialize, and to devote their attention to certain classes of work in which long study and experience have given them particular skill. Thus it is that to some astronomers certain of the advantages of a large telescope appeal much more strongly than do others. In fact, in order to derive the best results from the use of the instrument it is necessary to have observations made with it by men who are capable of bringing out its best qualities in various kinds of investigation. Thus the first mentioned property of rendering visible faint objects should be utilized by an astronomer who has gained much experience in searching for and measuring objects at the very limit of vision. One who has not given special attention to this class of work would be surprised to see in a large telescope certain of the faint stars or satellites of whose discovery he may have read. When the fifth satellite of Jupiter was discovered at the Lick Observatory by Professor Barnard, in 1892, claims were put forward by certain amateur astronomers who possessed small telescopes that they themselves were entitled to the honor of the discovery, for they had seen the satellite long before. Such claims might be taken in earnest by one unfamiliar with the instruments employed by the respective observers. But it is only necessary to examine this minute object with a 36-inch or a 40-inch telescope in order to appreciate the great merit of the discovery and the absurdity of such claims as have been mentioned. The tiny satellite is so faint that hitherto it has been seen with very few telescopes, all of them having large apertures. In its rapid motion close to the surface of the great planet it is completely invisible to an eye unprotected from the brilliant light of Jupiter. Even the close approach of one of the other satellites is sufficient to cause it to disappear. In measuring the satellite Professor Barnard finds it necessary to reduce the light of Jupiter with a piece of

smoked mica, through which the planet is still clearly visible and easily measurable, though not annoying to the eye. Without an instrument like the Lick telescope the fifth satellite of Jupiter would never have been known. It may be interesting to mention here that Professor Barnard's recent measures of this satellite with the Yerkes telescope have shown that his original determination of the time of its revolution in its orbit, made five years ago at Mt. Hamilton, was not in error more than 0.03 seconds. It was found that the time of elongation differed less than half a minute from the time predicted in the *Nautical Almanac*. The period is now known within a few thousandths of a second. In this connection also it is well to add that Professor Asaph Hall's discovery in 1877 of the two small satellites of Mars was directly due to the advantage given him by the large aperture of the 26-inch telescope at the United States Naval Observatory.

Such small members of the solar system are by no means the only feebly luminous objects which great telescopes have brought to light. Faint stars in the close proximity of bright ones are usually beyond the reach of small telescopes. Thus the companion of Sirius was not seen until 1862, when the late Alvan G. Clark encountered it in his tests of the 18-inch objective now at the Dearborn Observatory, which was the largest glass that had been constructed up to that time. The small companion to Procyon, discovered not long ago by Professor Schaeberle with the Lick telescope, is another object of the same type. These are conspicuous examples of that great class of objects known as double stars, which consist of two stars revolving about their common center of gravity. From the third advantage of large instruments to which reference has already been made, it will be seen that they are peculiarly adapted for the investigation of these binary systems, not only because of their power to show faint objects in the neighborhood of brighter ones, but also on account of their capacity to separate two closely adjacent stars which in a smaller instrument would be seen as one. Thanks to this property, many interesting binary systems whose components are exceedingly close together have been found by Professor Burnham with the Lick telescope, and, although he has devoted no special attention to a search for such objects, Professor Barnard has already encountered several of them in his work with the Yerkes refractor. From what the spectroscope has taught us of binary systems, we have every reason to believe that telescopes may go on increasing in aperture almost indefinitely without ever arriving at the possibility of separating into their component parts all existing double stars. As has been stated, the Yerkes telescope can show as distinct objects stars which are no further apart than 0.″12 of arc, and on account of the elongation of the image a double star whose components are only 0.″1 apart can be distinguished from a single star. But there undoubtedly exist stars far closer together than this, some of which can be separated by an aperture of not less than forty feet.

There has been much discussion in recent years regarding the relative advantage of large and small telescopes for observations of the markings on planets. I do not propose to enter into the details of this discussion, partly because my own investigations are primarily concerned with observations of another nature, and thus have not especially qualified me to form an opinion on this point, and partly on account of the fact that additional arguments in favor of large instruments would serve little purpose. It seems to me only necessary for an unprejudiced person to examine a planet first with a small telescope of from five to fifteen inches aperture, and then to

look at the same object with an instrument of 36 or 40 inches aperture, under identical atmospheric conditions. When the seeing is distinctly bad, that is, when the atmosphere is in so disturbed a state that the images are blurred and unsteady, the smaller instrument will assuredly show all that can be seen with the larger one. But with better atmospheric conditions, to my eye at least, the advantage lies wholly on the side of the larger instrument, whether the object be the Moon, Jupiter, Mars or Saturn. In the case of the Moon particularly much fine detail which I have never been able to see with the 12-inch telescope is clearly and beautifully visible with the 40-inch. I am certainly inclined to think that large telescopes are greatly to be preferred to small ones for work of this character. But I give much less weight to my own opinion on this subject than to that of Professor Barnard, who for many years has observed the planets with instruments varying in size from a 5-inch telescope to the 36-inch on Mt. Hamilton and the 40-inch of the Yerkes Observatory. He believes a large aperture to be immeasurably superior to a small one for these observations. This seems to me quite sufficient to settle the question, for it would be difficult to name a better authority.

One incidental advantage of such an instrument as the 40-inch telescope, which depends to a great degree upon the stability of its mounting, is the ease and certainty with which micrometrical measures can be effected. Since the telescope was first ready for regular use last September, Professor Barnard has made with it a long series of micrometrical measures, which have included such objects as the satellite of Neptune, the companion to Procyon and the fifth satellite of Jupiter. The precision of these measures is most satisfactory, and lends special interest to an attempt which he has made to determine the parallax of the nebula N. G. C. 404, which is in the field with the bright star β Andromedæ. This object has a definite condensation, which permits its position to be accurately determined with reference to a number of stars in the neighborhood. A long series of measures, covering a period of five months, have led to the conclusion that the nebula cannot possess a parallax as great as half a second of arc, and, therefore, cannot be nearer the Earth than about four hundred thousand times the distance from the Earth to the Sun.

Mention should be made of one more interesting observation by Professor Barnard, which would have been much more difficult with a small telescope. It will be remembered that in the valuable work which Professor Bailey has been doing at the station of the Harvard College Observatory in Arequipa, Peru, excellent photographs were obtained of southern star clusters, which show that these clusters contain an extraordinary number of variable stars. Not only do scores of stars in a single cluster vary in their light, but the change is exceedingly rapid, occupying in some instances only a few hours. So far as I know, none of these remarkable variations had been seen visually until Professor Barnard undertook the systematic observation of one of the clusters with the 40-inch telescope. On account of the large scale of the images, he is able to distinctly see stars in the cluster without confusing them with others in their neighborhood, and has thus been enabled to follow their changes in brightness. In this way he has confirmed the variability of many of the stars on Mr. Bailey's photographs. There are few more remarkable objects in the heavens than these magnificent star clusters, so many members of which are subject to fluctuation in their light. Professor Bailey's discovery is the more note-

worthy considering the fact that such an object as the great cluster in Hercules contains not more than two or three variable stars, while the Harvard plates show that the cluster Messier 3 contains 132 variables. This is only one instance out of many of the striking efficiency of the photographic work which is being carried on under Professor Pickering's able direction.

It may be well to introduce here a few words regarding the magnifying powers employed in actual observations. The optimistic writer, who is planning to photograph houses on Mars, believes that his recent invention will render possible the use of powers as high as a million diameters, and even greater, so that if men exist upon the planets they can easily be seen. Astronomers know nothing of such powers in practice. For double-star observations, with the largest telescope and under the most perfect conditions, powers as high as 3,700 diameters have occasionally been used. But in regular work it is not a common thing to exceed 2,700 diameters. Under very exceptional circumstances the Moon might perhaps be well seen when magnified 2,000 diameters, but this would be an extreme case, and in general a much better view could be had with powers ranging from 500 to 1,000. Jupiter can rarely be well seen with a power greater than four or five hundred, though Saturn will stand considerably higher magnification. Mars is best seen with a power of five or six hundred. With small telescopes lower powers are generally used. The difficulty is not in finding optical means to increase the magnification, as some of these newspaper writers seem to imagine. It is rather a question of being able to see anything but a confused luminous object after the high eyepieces have been applied. The more or less disturbed condition of the Earth's atmosphere is mainly responsible for this, but it is doubtful whether, with even perfect conditions, such an object as Jupiter could be advantageously submitted to great magnification.

During the present century there has grown up side by side with astronomy, to which it in fact owes its existence, the new science of astrophysics. In a broad sense this science may properly be classed as a department of astronomy, but at the present time its interests are so manifold, its methods so distinct, and its relationship to pure physics so pronounced, that it may fairly claim to be considered by itself as a coordinate branch of science. While astronomy deals more especially with the positions and motions of the heavenly bodies, it is the province of astrophysics to inquire into their nature and to search out the causes for the peculiar celestial phenomena which the special instruments at the disposal of the astrophysicist bring to light. It should be added that no hard and fast line can be drawn between astronomy and astrophysics, as one of the principal problems of the latter subject involves just such determinations of motion as are particularly to be desired for the purposes of the astronomy of position. The subjects are thus intimately related and closely bound together, and the bond between astrophysics and physics is hardly less strong. They should thus be cultivated together, so that they may mutually assist one another in bringing about the solution of the varied problems with which they are concerned.

It is particularly in astrophysical research that a great telescope is advantageous. For the principal instrument of the astrophysicist, the spectroscope, it is necessary to have as much light as can be gathered into a single point. With sufficient light the chemical analysis of the most distant star resolves itself into a comparatively simple problem. But with small telescopes and consequently faint star images such analysis, except of a roughly approximate

character, is impossible with the less brilliant stars.

One of the principal problems of the astrophysicist is to determine the course of celestial evolution. It has been found that the spectra of stars are susceptible of classification in a few well defined types, which seem to correspond with different periods in stellar development. Starting from the great cloud-like masses of the nebulæ, it is supposed that stars begin to form in regions of condensation, and that the great masses of gas and vapor continue to contract under the action of gravitation, meanwhile radiating heat into space. It is known from theoretical investigations that such cooling gaseous masses not only continue to grow smaller; they also rise in temperature with the advance of time. Finally a certain point in their career is reached when the rise in temperature ceases, though the contraction of the mass is not arrested. The balls of condensing vapors continue to cool, losing more and more heat, and becoming smaller and smaller in diameter. It is perhaps at about this period in their history that they pass through such a stage as is now exemplified by the Sun, which has presumably cooled from the condition of a white star like Sirius to that of a star of the second or yellow class. The spectra of such hot stars as Sirius contain little more than dark and exceedingly broad lines, grouped in rythmical order and due to the gas hydrogen. As these bodies continue to cool the strong lines of hydrogen become less prominent, and lines due to metallic substances begin to appear. These become more and more striking, until finally we reach such a type of spectrum as that of Procyon, which is intermediate in character between the Sirian and the solar stars. From this point on we find a continual approach to the solar type, until at last stars are reached whose spectra agree line for line with that of the Sun. After passing through the condition of the central body of the solar system the yellow and orange color of the stars becomes more pronounced, and subsequently a reddish tinge appears, until finally stars of a deep red color are found, which seem to mark the last stage of development before complete extinction of light. Through a part of this line of evolution it is easy to trace the changes in stellar spectra, the solar lines still continuing to be present, and superposed upon them a remarkable series of flutings which are characteristic of these reddish stars of the third class. But between such stars and those of the class which Vogel has designated as IIIb there seems to be a break in the evolutionary chain.

Stars of Class IIIb are of an orange or red color, and with the telescope alone some of them cannot be distinguished in appearance from the more fully developed stars of Class IIIa. But in the spectroscope they are entirely different. All of these objects are extremely faint, the two brightest of them being hardly visible to the naked eye. For this reason but little has been learned of their spectra, although the spectra of stars like Vega and Arcturus, which are some scores of times more brilliant, have been carefully investigated by both visual and photographic means. According to Dunér and others, the spectrum of the star known as 152 Schjellerup consists of certain heavy, dark bands, which coincide closely in position with bands given by compounds of carbon, and, in addition to these, a luminous zone in the orange portion of the spectrum. Three or four of the most intense solar lines have also been detected in these objects. But beyond this it is impossible to go with the appliances used in the earlier investigations, although it may well be that photographic methods would have greatly changed the character of the results obtained.

During the past winter a photograph-

ic study of the red stars has been rendered possible by the 40-inch Yerkes telescope. Photographs of the spectra of many objects of this class have now been obtained, and many lines which were not previously recognized on account of the faintness of the spectrum in small telescopes have been recorded. In the case of two stars of Class IIIb, 132 and 152 Schjellerup, the spectra have been photographed with a powerful spectrograph containing three prisms, giving high dispersion and considerable precision to the measures. It has been found that among the most characteristic features of these spectra are numerous bright lines, some of which seem to have been glimpsed by Secchi in his pioneer work at the Collegio Romano, though his drawings do not correctly represent their appearance or position. In fact, he recorded bright lines where none exist, and failed to record others, among which are the brightest in the spectra. Both Dunér and Vogel, who are certainly to be regarded as the best authorities on the subject, altogether deny the presence of bright lines. And had my own observations been confined to an examination of the spectra with the instruments used by these observers I would unhesitatingly subscribe to their opinion. But the great light-collecting power of the 40-inch telescope renders the detection of the bright lines a comparatively easy matter. Even with this instrument, visual observations with the low dispersion spectroscopes used by Dunér and Vogel would hardly show them, but they are easily seen with a three-prism spectroscope, and they have been repeatedly photographed with one and with three prisms. Some of these photographs have been measured and the wave-lengths of the bright and dark lines determined. A comparison of the results with those obtained for other types of stellar spectra suggests certain interesting relationships, which, if confirmed by subsequent work, will be of service in tracing the course of stellar evolution.

This is only a single instance of the advantages for stellar spectroscopic work of the great light-collecting power of large telescopes, but it would be easy to multiply examples. Our knowledge of the peculiar spectra of the stars of the Wolf-Rayet class, all of which are found in the Milky Way or its branches, is due in large part to the visual and photographic study of these faint objects made by Professor Campbell with the Lick telescope. In the able hands of Professor Keeler, whose recent election to the directorship of the Lick Observatory is so truly a cause for congratulation, the same powerful instrument rendered possible the determination of the motion in the line of sight of the planetary nebulæ. We may well be confident that the future record of the great telescope on Mt. Hamilton will be marked by many similar advances.

I might profitably go on to speak of the advantages of large telescopes for the study of the Sun, for in no field of research can they be better employed. In photographing the solar faculæ with the spectroheliograph the large image given by a great telescope is particularly useful for purposes of measurement, as well as for the study of the form and distribution of these phenomena. Prominences, too, whether of the quiescent or eruptive class, are best photographed on a large scale. With a large image it may also become possible, under good atmospheric conditions, to photograph some of the delicate details in the chromosphere, which, with a small solar image, would be wholly beyond the reach of the photographic method. It is probably in the study of the spectrum of the chromosphere, however, that one best perceives the advantage of a large instrument as compared with a small one. Recent experience has made this very clearly evident, for with the 40-inch Yerkes telescope

it has been possible to see in the chromospheric spectrum a great number of faint bright lines which were wholly beyond the reach of the 12-inch telescope used in my previous investigations. In this way it has been found that carbon vapor exists in the vaporous sea which covers the brilliant surface of the photosphere.

It will be admitted, I think, from what has been said, that great telescopes really have a mission to perform. While, on the one hand, they are not endowed with the almost miraculous gifts which imaginative persons would place to their credit, they do possess properties which render them much superior to smaller instruments and well worth all the expenditure their construction has involved. In answering the question: 'Do large telescopes pay?' it is simply a matter of determining whether the work which cannot be done without the aid of such telescopes is really worth doing. No one who is familiar with this work is likely to deny that it is worth all the money and time and labor that can be devoted to it. I therefore confidently believe that the generous benefactions which during the last quarter century have permitted the erection of large telescopes in various parts of the world have been wisely directed, and that further sums might well be expended, particularly in the southern hemisphere, in the establishment of still more powerful instruments.

GEORGE E. HALE.

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*JULIUS SACHS.**

AFTER great suffering, Julius Sachs sank peacefully to rest at six o'clock on the morning of the 29th May, 1897, at Würzburg, the scene for many years of his labors. Wherever scientific botany has a home, and by many outside the narrow circle of specialists, this loss has been regarded as irreparable. By no one has it been felt more keenly than by the writer of these lines, who will always thankfully recall the happiness it has been to him to have been closely connected throughout a long series of years as pupil and friend with him who has passed from our midst.

When I attempt to briefly sketch the life of the man to whose brilliant intellect botany is so greatly indebted, there rises involuntarily to my mind the saying of Petrarch's:

Si quis tota die currens
Pervenit ad vesperam satis est.

Yes, his life was a struggle, a ceaseless, single-minded pressing forward without rest to the goal of knowledge. To him study, research, teaching, were not merely the external activities of his calling that might be laid aside for hours, days or even weeks, and then be again resumed. They absorbed his whole being more than was good for his personal welfare. But the evening came after this long day in which he had so faithfully labored. No one realized this more fully than he himself. A prey to physical suffering, his sharpest pang was that he could no longer work for science with his former energy, and if anything made it hard for him to face death it was the knowledge that he must leave behind as an unfinished sketch much that he wanted to say to the world.

He had been chiefly occupied during these last years with a work which, under the title of *Principien Vegetabilischer Gestaltung* (*Principles of Vegetable Form*), was to set forth his views upon causal morphology. "I should feel it an immense grief if I were prevented from writing this book," he says. "It would embody the thought of forty years, and it is always important that one's ideas should be long and thoroughly brooded over. To finish it would render the last

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