THE AMATEUR ASTRONOMER

GIDEON RIEGLER

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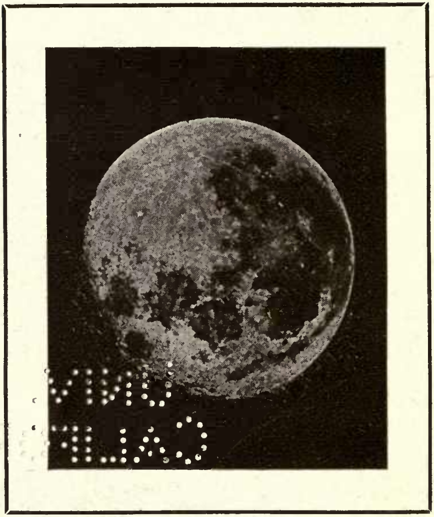

THE MOON.

Photograph taken shortly after full moon, showing the commencement of waning.

The Amateur Astronomer

BY

GIDEON RIEGLER

TRANSLATED BY

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WITH 112 ILLUSTRATIONS

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The Amateur Astronomer

CHAPTER I

INTRODUCTION

"There are two things that always fill my soul with ever-increasing inspiration, the oftener and the more assiduously my mind applies itself to them: *the starry heavens above me, and the ethical law within me.*"—KANT.

TO those people who dwell within huge cities and important commercial centres, wherein modern life pulses with feverish beats, to those who watch the striving and struggling with which mankind pursues work in its varied forms, any occupation, even though it be but a hobby, may appear quite useless if it brings them no practical profit. We willingly pursue one amusement or another, but we take good care, at the same time, that it is one from which at least some profit may be obtained, whether it be mental or material.

And even when we come to cities, we are often in two minds as to which way we shall spend our spare time, and after much picking and choosing, we often apply ourselves to that particular object which appears to us to be the most practical and opportune, though in many cases our interest in quite another sphere may be far greater.

In the country, however—it need not necessarily be in quiet, remote villages, or in world-forgotten places, still untouched by the spirit of the age—we cannot so easily find ourselves in such a dilemma, for there we are placed in direct contact with the myriad manifestations of nature, and we feel a secret longing, a silent but unceasing impulse, to set ourselves to work, even in any way, upon this infinitely wide field. It may dawn upon the minds of even those men whom "modernity" has infected with somewhat of a lukewarmness and indifference towards the phenomena of Nature, that the really true knowledge is to be found only in nature. The study of Nature and the knowledge of its immutable laws, enable us to develop our intellectual powers, and to stimulate our activity in a way that scarcely any other occupation can do. The eternal order of

Nature's household, the profound plan, hardly within reach of human comprehension, which extends throughout all the natural phenomena, the marvellously prearranged co-operation of the individual phenomena towards the attainment of one supreme purpose—all this fills us with a legitimate admiration and wonder, quite inexpressible in words, and we entertain an ardent desire to become co-workers in this wide realm, and to thereby provide ourselves with inward gratification and exaltation. Delight in Nature—delight in life.

Astronomical science, which to-day finds the most universal interest of all the exact sciences, had in former times a more general character, for it included all phenomena which occurred both within the earth's atmosphere and beyond it. The nineteenth century, which saw such an enormous increase of nature knowledge, also enlarged the field of astronomy to an extraordinary extent, and it was therefore an inevitable result that those departments previously connected with it only formally should have become separated, or should have developed into independent fields of scientific research. The three independent, specially developed fields of research, *Geodesy*, *Meteorology*, and *Astrophysics*, have each already attained such an extent that still wider separation is either taking place, or is at least imminent.

It is clear that it would be an impossibility for an investigator to carry on a survey of the whole, and to work in each of these separate fields. So much the more, then, will the student of the heavens, who only in leisure hours can occupy himself with these stirring studies, see the necessity of deciding in favour of one or other specific department. How great and general is the interest that astronomy holds for the widest circles, is shown by the large number of "Popular Astronomy" books that are constantly appearing in new editions.

This little volume, then, is intended for those who have already done observational work in astronomy, as well as for those who wish for the first time to become acquainted with the heavens, and is a small *vade-mecum* for reading in leisure time, and also for immediate use at the telescope.

Within these narrow limits it is naturally impossible to go more closely into the reasons and causes of the phenomena shown us by the starry heavens. They are, moreover, well known to the already working amateur, while the beginner will, out of sheer interest, begin the study of some popular astronomical work, in order to assimilate the fundamental principles of this most sublime of all the sciences.

CHAPTER II

OBSERVING STATION—SELECTION OF A SITE FOR OBSERVATION

THE place for observation will in general depend upon where the observer happens to live. Apart from the climatic conditions, which affect the number of clear and cloudless nights in the course of a year, it will be a question of whether the position of our observing station is, on the whole, suitable for astronomical observation. Places situated high above the sea-level will have the advantage over those lying at a low level; on the other hand, the outlook towards all parts of the heavens should be as free as possible, and not be curtailed by the proximity of any hills or elevations. Places lying in hollow valleys, which naturally have a very limited and irregular horizon, will not be specially favourable for observation, since many regions of the sky, as for example the constellations and stars of the southern skies, which rise only very slightly above the horizon, and describe very short paths in the heavens, will not come within the observer's view. Nevertheless it may at the same time be remarked, that the observation of such heavenly bodies as are quite close to the horizon, and also those just rising and setting, is extremely difficult, even in places having a free and level horizon; the reason being that the rays of light from these objects must make their way through a much greater thickness of the earth's atmosphere, and therefore the objects appear much fainter, less steady, and less distinct, either to the naked eye, or through the telescope, than do those objects which we see under otherwise similar circumstances in the neighbourhood of the zenith.

The advantage of the high elevation of a place lies chiefly in the transparency and clearness of its air, observations being the more favourably influenced the steadier the air is; that is to say, the less disturbed it is by currents in the higher and lower strata. Exactly the reverse of this are the air conditions in large cities.

The daily activity of the thousand and one factory chimneys, and not least, the heat and smoke of the various railway stations, together with many other factors, occasion such a pollution and gloom in the air, that observational work in astronomy requiring precision can scarcely any longer be expected to be done by those institutions lying within the precincts of a city.

It is also on this account within recent times that at astronomical meetings the question is so often discussed of the removal of observatories out of the cities to more elevated positions having more favourable air conditions.

As city-dwellers, we know only too well what we have to suffer from the dust and smoke nuisance, and many a one among us who, particularly in spring-time and autumn, has seen from some elevated point in the neighbourhood the heavy swathes of smoke lying over a beautiful city, may have made his way back to the sea of houses with very mixed feelings indeed. Even air currents, or a rather strong breeze, are not able to sweep away the veil of smoke and haze overhanging the city; it seems rather as if the smoke and haze were bound to the streets. It is certainly not always so desperate, and we have had during winter-time in the city a clean and clear air; but generally it must be admitted that the air conditions even a mile or so beyond the city are decidedly more favourable for observation.

One other consideration that will most prejudicially affect astronomical observation at night-time in the city, is the so-called "city glare," the reflection of light from the innumerable street lamps and other artificial sources of illumination. In the city itself we notice this annoyance actually less, since we ourselves are in the midst of the sea of light; but let us, however, transfer ourselves only a little beyond the city boundary, and then this "city glare" appears as an extensive, widespread brilliance, not unlike the zodiacal light. In the immediate vicinity of the city this reflection is so intense that even the brighter stars become invisible to the eye, while faint celestial objects cannot be observed at all. Even at great distances, up to thirty or forty miles, this glare makes itself noticeable, but its intensity and extension, however, diminish rapidly at greater distances from the city, so that it ceases to cause any trouble.

These difficulties, which stand in the way of the observer within the city, really more affect the professional observer, who is often in the position of having not only to observe, but also to measure, very faint celestial objects, such as delicate little nebulæ, extremely faint telescopic comets, or the surface details of the planets. The amateur in astronomy, who, with the modest technical and optical means at his disposal, can hardly give himself the task of making such things the objects of observation, will suffer much less from these troubles; for the field of observation stretches far and wide, and, should he devote himself to either one or other of the special departments of observational astronomy, he can find quite sufficiently satisfactory objects within the province of his meditation and study. But with observers stationed in the country, he will scarcely be able to compete, even though he may have the otherwise similar conditions of equal instrumental equipment.

Concerning the selection of the observing station, local conditions will also influence the student of the heavens. Here also it is important that the observer should have as free an outlook as possible towards all parts of the sky. The observer situated in the country has herein also the advantage, for at any time he can select for his observations a highly favourable place in the open neighbourhood, and at the same time can take into consideration his own comfort. The amateur who has the opportunity of working only in the city, will have greater difficulty, but doubtless will eventually find some little place where, undisturbed, he can devote himself to the pleasant study of the stars.

Many modern houses are provided with attics or other outbuildings, which have a small, flat roof, generally railed round for safety, and in such cases the amateur may conduct his observations therefrom. It is then often impossible to avoid, for instance, the gable end of the adjoining house, some neighbouring chimney, or other object, masking the view in some direction; but such a small disadvantage will have to be put up with.

As soon as the most suitable spot for the erection of our small instrument is found, a small but firm table-stand, with sitting accommodation, will complete the elementary fittings of our observing station. If we have at our disposal a large instrument, say a four-inch or larger telescope, the removing of which every now and then for practical reasons presents difficulties, it is recommended that it should be permanently mounted on a pedestal. Care should then be taken that the instrument is not interfered with by unauthorised persons, nor affected by the influence of climatic changes. A wooden framework covered with tarred pasteboard, which can be easily placed over the instrument, and firmly secured, should furnish a sufficient protection. For larger instruments, it would be well worth while building a small dome.

It is not recommended that observations should be made at the window of a room. Apart from the fact that the observer has at his disposal only a third, or at the most only one half, of the visible heavens, very considerable difficulties will present themselves in setting up an instrument securely and comfortably within the narrow limits and small space so common, unfortunately, in modern buildings. Another circumstance which will readily induce us to give up the comfort of our living-room is, that the dimming of the telescope lenses by moisture cannot be avoided, on account of the constantly existing difference of temperature between the room and the open air, which makes itself most noticeable in winter-time, and also during the early morning hours. The necessity of every few moments removing the dimness from the object-glass and eyepiece will finally become such a nuisance to the observer, that he will gladly change his post of observation.

Once having decided upon a place for observation, however, we shall remain faithful to it, for herein also habit will play a part. We shall next try to ascertain the geographical position of our place. Of course this can be accurately done only by exact time comparisons and determinations of latitude, for which purpose the amateur will in most cases lack the ways and means. But a determination of the geographical position, of sufficient accuracy for all ordinary astronomical observations, can be easily done with the help of a survey map, or a plan of the city. Our next problem, then, is an accurate orientation towards the parts of the heavens. This is easily accomplished by the aid of a good compass, which should be in the possession of every amateur astronomer. But as the north and south line, as shown us by the compass needle, differs from the true (astronomical) north and south line, according to time and place, it is better to ascertain the so-called "meridian line," the true north and south line.

Upon a perfectly horizontal plane surface—a sheet of smooth white cardboard would be best—five or six concentric circles should be drawn, from any point as centre, and in the central point an iron nail, about four inches long, should be fixed straight up. The head of the nail should be hammered out into a disc shape, and should have a very minute "pin-hole" bored through it. When the sun shines this nail will throw its shadow on the plane surface, and in the centre of the shadow of the head the tiny point of light passing through the hole will give a sharper indication than the end of the shadow of a simple pointed peg, because in the case of the latter the surrounding half shadow will have a disturbing influence. With the movement of the sun the white point of light moves towards the circles,

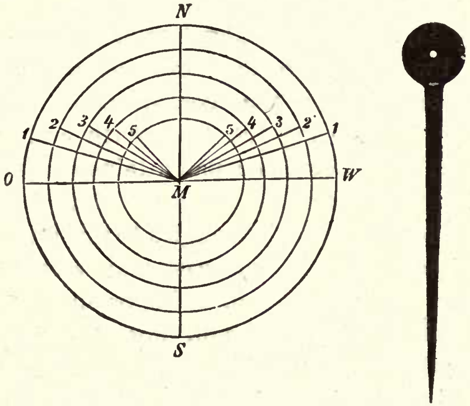

Fig. 1.—Determination of the meridian line.

touches the first circle at 1, the second at 2, and so on at 3, 4, and 5.

Then, after true noon, the shadow of the nail will cross to the other side, and will increase in length in the same way as it decreased before midday. First it will touch circle 5, and gradually cross 4, 3, 2, and 1. All these places where the white point falls upon a circle are to be accurately marked with a pencil. Finally, the points 1 to 5 and 5 to 1 are joined to the common centre of the circles and the included angles are bisected.

If the bisecting lines fall upon one another, then the work has been correctly done; if not, then the process must be repeated on the next sunny day. The bisecting line, when produced from the centre to the circumference of the outermost circle, is the required meridian line, and on it, as being the true north and south line, the shadow of the nail attains its shortest possible length for that particular day.

The line drawn at right angles to this line gives the direction of the true east and west points. It is, as a matter of course, important that the sheet of cardboard should not be displaced during the whole operation, and must, therefore, to begin with, be fastened securely to ensure this. The meridian line thus found must be then transferred to the pedestal mounting of the telescope, or to wherever it is desired to have it marked. Since the varying altitude of the sun at any particular time during the course of a year would affect the experiment, it should be added that the determination of the meridian line may be carried out with great accuracy at the times of the solstices, that is, on June 21st and 22nd, and on December 21st and 22nd.

CHAPTER III

INSTRUMENTAL EQUIPMENT

THE instrumental equipment of the amateur astronomer will first of all depend upon the means he may have at his disposal for procuring the instruments. Even though sooner or later he may turn himself towards one particular department of observational astronomy, a good telescope will always constitute the most important implement of all his instruments.

Before, however, entering into the description and recommendation of those telescopes which more especially come within the consideration of the amateur astronomer, it will be of considerable advantage for the beginner to become acquainted with the principles upon which such an instrument is constructed.

If we wish to view an object clearly, we place it at the correct distance from the eye, *i.e.*, at a place where we obtain a sharp image of the object upon our retina. If the object under observation is very small, we can enlarge its image upon the retina by bringing the object nearer to the eye. The angle of view will certainly be enlarged thereby, but the image, which is no longer formed upon the retina, will gradually become indistinct, since a sharp image is formed only when the object is at the necessary distance from the lenses in our eyes. We are, however, in a position to help ourselves in the matter.

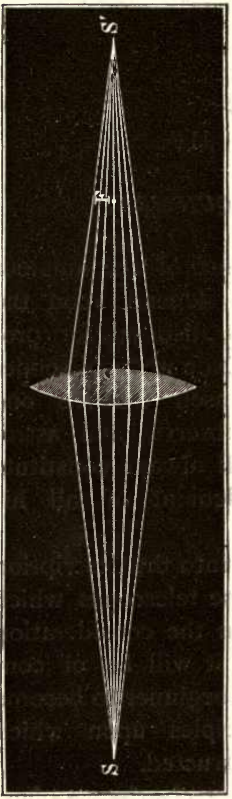

Fig. 2.—Image with a convex lens.

Let us bring to our assistance an ordinary magnifying glass, then this will permit us to bring the object nearer to our eyes, and at the same time will allow a sharp image to be formed.

We see the object magnified. If we allow rays of light to fall in a parallel direction upon a convex glass lens, then these rays will unite on the other side of a lens in a point (Fig. 2) which is termed the "focus," for here the rays of heat which accompany the light rays all unite, and produce a high temperature. At the same time there appears at the focus a reduced and inverted image of the bright object.

If we now bring the latter closer to the lens we obtain no image, but if we transfer the object to the focus of the lens, then we see the object through the glass magnified. The lens now serves us as a microscope, and the greater the curvature of its surfaces, the more powerful is its magnification.

The two properties of the lens—to yield a reduced and inverted image at the focus, and to make an object placed at the focus appear magnified—are the principles upon which rests the production of an astronomical telescope. It consists of a tube, at one end of which is a lens of great focal length, called the "objective," or "object-glass," because it is turned towards the object under observation. At the other end is a lens of much shorter focal length; it is called the "ocular," or "eyepiece," since, when observing, we apply our eye to it, and it is so placed that its focus and that of the object-glass coincide. The rays of light from the object under observation pass through the object-glass, and form at its focus a reduced and inverted image of the object. This image is magnified by the eyepiece as through a magnifying glass. (Fig. 3.)

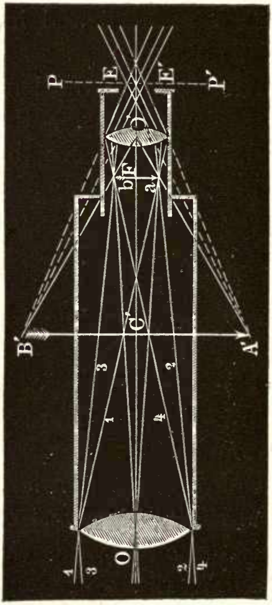

Fig. 3.—The Astronomical Telescope.

The telescope thus gives us the advantage of bringing the image of a very distant object quite close to us, and of being able to magnify it to our liking. In addition the eyepiece is movable, in order that it may be correctly focused to suit the peculiarity of the eye.

The instrument we have just described is the chief of all optical instruments ; it is the astronomical telescope, which, through the great development of modern optics and mechanics, has become the most important implement of astronomical observation. The fact that this system of lenses inverts the images is of no consequence whatever in astronomical work. Even the uninitiated soon get used to it, so that a terrestrial telescope, which shows the images in an upright position, often becomes troublesome to work with, after one has become familiar with the use of the astronomical telescope.

The degree of magnification in these instruments increases as the focal length of the object-glass exceeds that of the eyepiece, and just so much in degree as the focal length of the former is greater than that of the latter. We can thus very easily calculate the magnifying power of such an instrument, by dividing the focal length of the object-glass by that of the eyepiece. The quotient obtained is the required magnification. This is supposing that the eyepiece consists of a single lens. In the case of compound eyepieces the calculation becomes somewhat more complicated. The magnifying power can also be found experimentally without calculation, if a measuring scale is observed through the telescope and at the same time looked at directly with the naked eye. Both images are then made to coincide, and the number of unmagnified scale divisions that are covered by one magnified division can then be read off, and the ratio of these numbers gives the magnification.

The magnitude of the field of view is not dependent upon the aperture of the object-glass, but is inversely proportional to the magnifying power. It can be ascertained practically by marking the two points which limit the field of view, and then measuring the angular distance between them.

The light-grasping power, and accordingly the brilliance of the image, depends chiefly upon the aperture of the object-glass. It is a most important factor in every telescope. The greater the area of the object-glass, the greater the amount of light that is admitted into the instrument. The light-grasping power is proportional to the square of the diameter of the object-glass, but is inversely proportional to the square of the magnification, since by increasing the magnification two, three, or four times, the light received is distributed over an area four, nine, or sixteen times as great, and therefore the brilliance is diminished to one-fourth, one-ninth, or one-sixteenth of its original intensity.

With regard to the *sharpness of the image*, this depends chiefly upon the good quality of the lenses, of their material, and of their perfection of form and polish. If the latter does not meet the required conditions, the appearance shows that the rays, after their passage through the lenses, have not a common focus, since the marginal rays are refracted more than the central rays. There is then formed at the focus not a sharp little point of light, as the image of some far-distant shining object, but instead a small bright circle. This appearance is termed *spherical aberration*.

If it happens that the focus of a lens for the rays of different colours is not the same, it leads likewise to a similar appearance, in which the images are surrounded by a coloured fringe or border, and thus, as violet is refracted most, it will appear nearest the lens, while red, in consequence of having the least refraction, appears farthest from the lens.

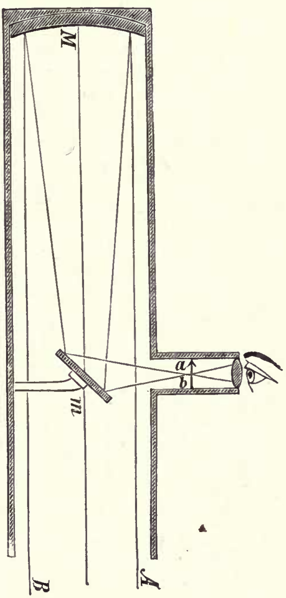

Fig. 4.—Path of Light Rays in a Newtonian Reflector.

This appearance is termed *chromatic aberration*.

Spherical aberration can be prevented by grinding the lens to a form other than perfectly spherical. Such lenses are then called *aplanatic*, or shortly "*Aplanats*."

Chromatic aberration can be done away with by employing, instead of a single lens, two, one of which is bi-convex, and the other concave. The two lenses are composed of two different kinds of glass, which are known by the names of *crown glass* and *flint glass*, whereof flint glass refracts light more strongly than does crown glass.

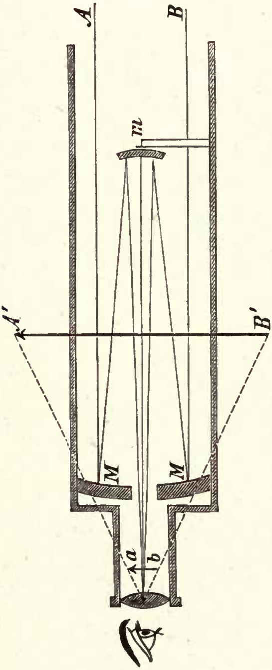

Fig. 5.—Path of Light Rays in a Gregorian Reflector.

All such correctly adjusted telescopes as are constructed upon the principles which have just been described, are termed *refractors*. The place of the object-glass can, however, be taken by a concave mirror, and the eye-piece must then be placed opposite to the mirror. But, as in such a position, the observer's head would cut off a large portion of the light falling on the mirror, the plan has been adopted of placing in front of the concave mirror a small plane mirror inclined at an angle of 45°, which reflects the small image formed by the concave mirror to the side of the telescope tube, where it can be viewed through the eyepiece; or an alternative plan is used, whereby the concave mirror is slightly inclined to one side, so that its focus lies close to the edge of the aperture, where the observer's head does not greatly obstruct the light rays. Telescopes in which a concave mirror replaces the object-glass are known as *reflectors*.

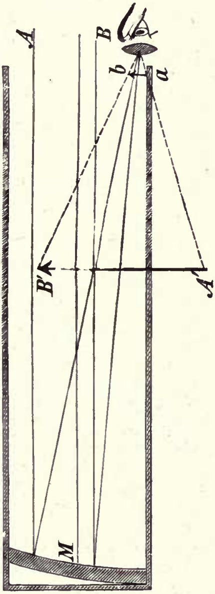

Fig. 6.—Path of Light Rays in Herschelian Reflector.

The arrangement of mirror and eyepiece can also be otherwise than that already mentioned, which is named, after its inventor, the *Newtonian Reflector*. James Gregory had the large concave mirror pierced in the centre and placed behind this opening the eyepiece, in the axis of the telescope. The image formed by the large mirror is reflected by a smaller concave mirror through the orifice into the eyepiece. Reflectors upon this system are named *Gregorian Reflectors*. In the *Herschelian Reflector* the large concave

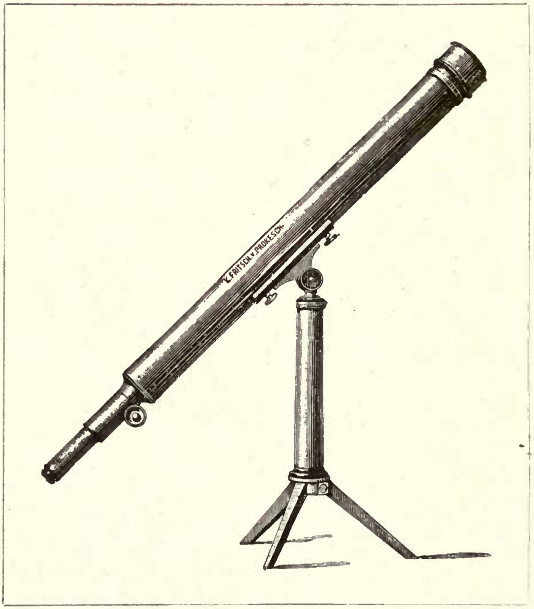

Fig. 7.—Azimuthally mounted 2-inch Telescope without slow motion.

mirror is inclined to the optical axis of the tube, and thus saves the use of the second smaller mirror.

In conclusion, a few remarks may be made upon the mounting of telescopes. The smaller instruments are mostly mounted "azimuthally,"

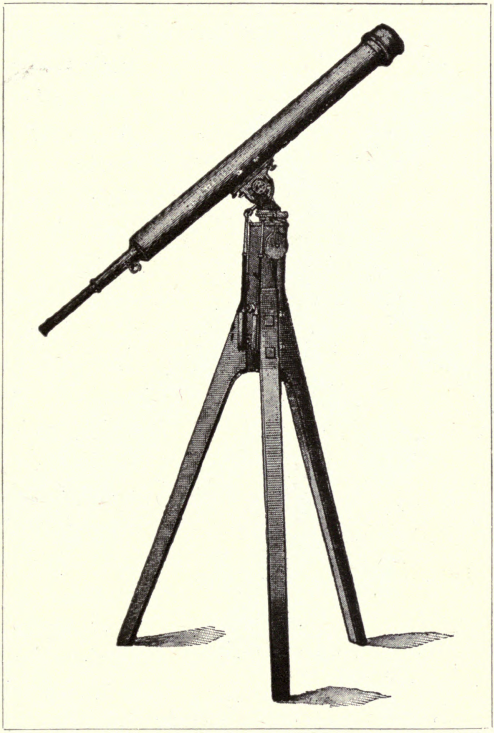

Fig. 8.—Azimuthally mounted 3-inch Telescope with slow motions.

i.e., they can be moved round a horizontal axis, and also round a vertical one. In the larger instruments the equatorial style of mounting is generally employed, by which the tube of the telescope can be moved round two axes, one of which lies parallel to the earth's axis, and is termed the *polar* or *hour* axis; while the second axis is fixed to the first at right angles, and is called the *declination* axis. With this style of mounting, the telescope can easily follow the apparent course of a star, since the declination remains unchanged, and therefore motion need be given only round the hour axis. In all strictness this applies with truth only to the observation of the fixed stars. The movement of the hour axis can always be accomplished by means of driving

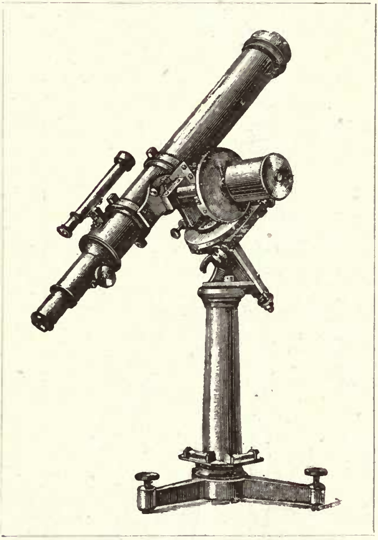

Fig. 9.—Equatorially mounted 3-inch Telescope.

mechanism, so that the heavenly body being examined at the time may be kept in the

Fig. 10.—Equatorially mounted 4½ inch Telescope.

field of view without the observer's aid, even though the circumstances require many hours, and it will also remain in the optical axis of the telescope. In order to obtain this motion the polar axis is connected with the driving mechanism in such a manner that the telescope, if used to observe a star for twenty-four consecutive sidereal hours, would make a complete revolution.

All the medium and larger sized instruments generally have mounted on the telescope tube, a smaller telescope, a so-called "finder," the axis of which is parallel to that of the larger telescope.

When a high magnification is used, and the field of view is therefore very small, it becomes a very difficult matter to bring the observed object into view. By the aid of the finder, which has got fixed inside it a simple cross-thread or cross-wire, this is easily accomplished, by making the object in question occupy the centre point of the cross-wires. It is then brought into the optical axis of the main telescope, and consequently into the centre of the field of view.

In the selection and purchase of a telescope it is advisable to proceed cautiously, and, if possible, under the guidance of an expert in the matter. If a good deal of money can be laid out, it is advisable for the amateur to deal with first-class firms only. But even with moderate means, really good second-hand instruments can be obtained, and the offices of the popular astronomical periodicals can often negotiate such sales and purchases. With an azimuthally mounted 2-inch or 3-inch refractor—the latter size is generally provided with slow motions—really fine and interesting observations can be made. As an uncommonly suitable instrument for the amateur, we would strongly recommend the "*Brachyt*," a reflecting telescope of very considerable focal length, with a comparatively speaking short length of instrument. It is a form of Herschelian reflector, but modified, however. The

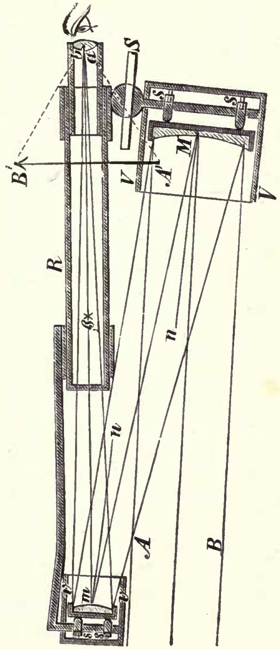

Fig. 11.—Path of Light Rays in the "Brachyt" Telescope.

rays of light from the object are reflected convergingly from the large concave mirror on to a smaller convex mirror at the end of the eyepiece tube, and from this mirror they are again reflected towards the eyepiece in such a way that they unite in the focus to form an

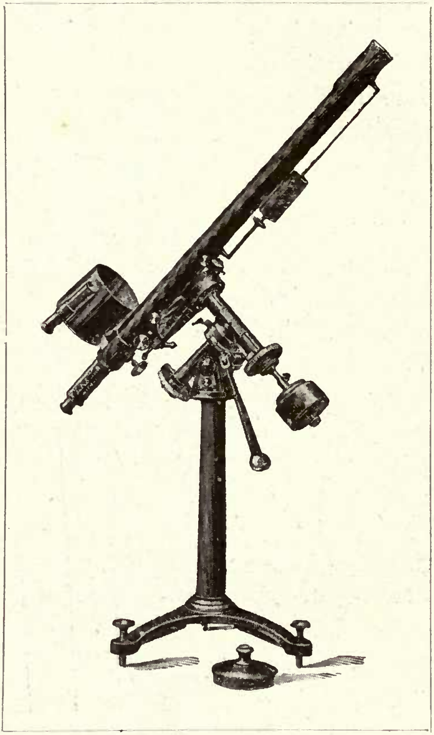

Fig. 12.—Brachyt Telescope with 3-inch mirror. One eighth actual size.

image which is magnified by the eyepiece in the same way as in every other telescope.

The path of the light rays can be understood by reference to Fig. 11.

The Brachyt is made by Karl Fritsch, optician and mechanic, of Vienna, and its ad-

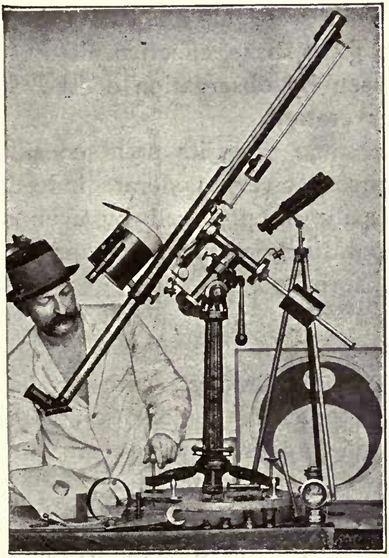

Fig. 13.—Brachyt Telescope with 4-inch mirror.
(Fritsch, Vienna.)

vantages lie chiefly in its compact build, due to the shortening of its tube, and also in its cheapness. The smaller Brachyts are mounted azimuthally, the larger ones also equatorially, and they are very portable, as they are mounted on short stands, provided with levelling screws.

A Brachyt with a mirror of 10 cm., or about 4 inches diameter, will easily show Castor, Polaris, Rigel, &c., to be double stars, and also gives sharp, effective pictures of what can be seen by observation of the details of the lunar craters.

At the same time, its price, considering its performances, is very moderate indeed, so that it can easily be procured by even amateurs of comparatively slender means, while its compact form greatly facilitates its employment, not only on heavenly, but also on terrestrial objects.

In a 4-inch Brachyt, with a magnifying power of about 250, the definition of the Moon, Saturn, and Jupiter is very clear, and with a power of 150 even sharper.

It must, however, be emphasised that these instruments must be treated extremely carefully, and must especially be protected from moisture and dust, since the former easily affects the thin film of silver on the mirror, Once this surface is damaged, it should be removed with nitric acid, and the concave glass should be then re-silvered.

Before we leave the telescopes, and pass on to the other indispensable implements of the amateur astronomer, the opinion of an expert relative thereto should be mentioned. Herr von Konkoly, Director of the Royal Hungarian Astronomical and Meteorological Observatory in O'Gyalla, says in his "Practical Instructions for Arranging Observations":—

"Amateurs very often come to professional astronomers for their advice upon where they can obtain a good (naturally cheap and large) telescope, and what sort of a one they should select. The astronomer is often in a difficulty over such questions, since an amateur with a telescope costing barely £15 to £20 would like to see everything that is to be seen with the giant refractors. If they cannot make out the markings on Mars as sharply as they are—unfortunately—far too often drawn, then the telescope is immediately declared to be 'bad,' and the astronomer who had ordered it gets all the blame. For that reason it is explicitly recommended in such cases only to go to the nearest optician, for then at least the astronomer will be safeguarded from such blame. Respecting the size of telescope, various additional circumstances come into consideration. If the amateur in question intends to build a revolving dome, then he can go as far in the size of his telescope as his means will allow. If, however, the building of a dome is not intended, then no larger achromatic refractor should be bought than one of 4 inches aperture and about 4 feet focal length, or a Brachyt of 16 cm. ($6\frac{1}{2}$ inches), or a Newtonian reflector of similar aperture. In the great majority of cases, amateurs get the idea into their heads of having something large and striking to the eye. Therefore they do not buy a Brachyt telescope, but prefer a cumbersome Newtonian reflector."

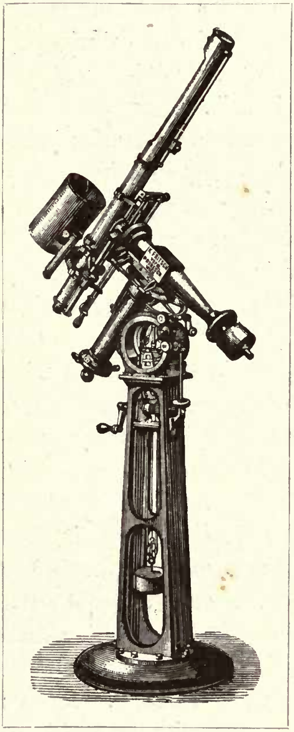

Fig. 14.—6-inch Telescope with clockwork driving mechanism.

Besides having a smaller or larger telescope, either refractor or reflector as the case may be, a good pair of opera-glasses or field-glasses will render good service to the amateur. The beginner especially, who has to become acquainted with the starry heavens, can scarcely afford to dispense with them. In procuring such an instrument, it is likewise recommended to do anything rather than waste money in obtaining productions of doubtful value from obscure makers at a cheap price. Binocular glasses of the highest quality, giving perfect definition and clearness and having large fields of view, are made by such firms as Watson, Ross, Goerz, and Zeiss; and no amateur, who is at all interested in the observation of the variable stars, can afford to neglect purchasing such an instrument.

Chief among the instruments that are absolutely necessary, alike to professional and amateur astronomers, are those pieces of mechanism which serve for the division and measurement of time, namely, clocks. For use in astronomy there are two kinds to be considered—those constructed to show mean time, and those constructed to register sidereal time. The former show the hours as do ordinary clocks, only they are provided with an arrangement which causes a perfectly uniform rate of going. The motive power of such a clock—which is a stationary clock, and not adapted for portable use—is a weight, this being the simplest and most constant motor at our disposal.

The pendulum serves as the regulator. But since changes of temperature alter the length of the pendulum rod and pendulum bob, and thereby seriously influence the rate of the clock, such adjustment must therefore be made, for the sake of astronomical precision, as will entirely nullify such a baneful influence. In pendulums this is achieved by the employment of a gridiron form of pendulum, made of rods of different metals, between which a definite relation of expansion must exist (steel and brass, or zinc). This is called the *Gridiron Pendulum.* Another method is to compensate by fitting the ordinary pendulum bob with a receptacle containing mercury. The mercury expands upwards through the action of heat to such an extent, that the centre of gravity of the pendulum is thereby raised by the same amount as it is lowered by the downward expansion of the pendulum rod, and thus compensation is effected. This is known as the *Mercury Pendulum.*

Portable timekeepers are driven by springs, and their regulation is effected by means of a compensated balance wheel. Timekeepers of this type, which reach the highest possible perfection, are named *chronometers.* The smaller sizes are called *pocket chronometers.*

The amateur astronomer should at least be in possession of a timekeeper upon which he can rely for a considerable time, with a certain degree of exactitude. For the purchase of first-class pendulum-driven timepieces, it is not necessary to expend too much money. Chronometers and pocket chronometers are most rigorously tested at certain Observatories in each country and if found efficient are sent back to the makers, accompanied by a certificate.

There remains still to be mentioned how the amateur observer may obtain the correct time wherewith to compare his timekeepers. In certain of the larger cities, institutions devoted to this purpose give a signal daily at noon, or some arranged hour, by some means or other, such as time-balls or signal guns, and with these signals comparison may be made. In the country districts, however, the observer is recommended to obtain the time from the nearest railway station, which time in this country is Greenwich mean time.

With longer practice in the domain of astronomy, it will not be difficult for the amateur to control his timekeepers most accurately by taking an exact observation of one or other of the many celestial phenomena announced in the astronomical almanacs, and of which the exact time for any particular place is given, provided of course they are visible from his station. The controlling of all the timepieces in his possession, as well as the keeping of exact notes of their rates, will in itself be for the amateur quite a pleasant task.

Of those instruments used to measure the heavens no mention has as yet been made.

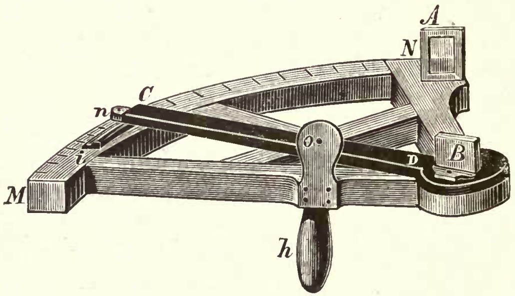

Fig. 15.—Sextant.

The amateur will, however, scarcely be in a position to work with them. Apart from the fact that such telescopes of precision as the great equatorials, meridian transit instruments, photometers, and heliometers used in the large Observatories are quite inaccessible to him on account of their great cost, it may also be stated that in the case of instruments such as these, the accuracy of which has become a bye-word, quite a thorough course of theoretical and practical instruction is needed before they can be properly used.

A small instrument, which is much less

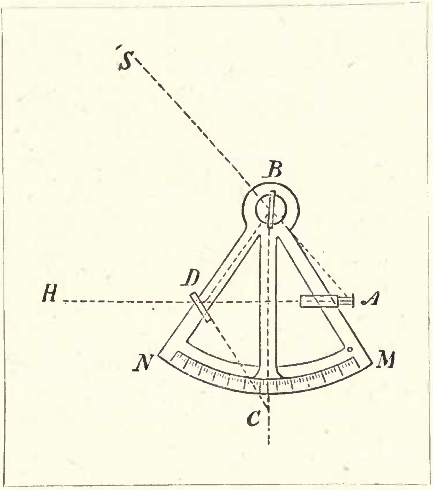

Fig. 16.—Sextant.

frequently used to-day than formerly by professional astronomers, but which has played an important part among sailors, can still be well recommended to amateurs, and that is the *sextant*, invented by Newton, for it enables the angular distance between two objects to be measured.

With some little practice, it can be used to obtain sufficiently accurate measures of altitudes, particularly that of the sun, for the determination of the latitude and the local time of the observing station. For the description of this familiar instrument and its use, reference should be made to treatises on popular astronomy or physics. How important it is to be able to work correctly with such an instrument we shall learn in a later chapter, namely, in determining the apparent place of any large meteor that might suddenly flash into view during the daytime.

Besides the articles already mentioned, the amateur astronomer will require a number of other likewise important auxiliaries, of which the most necessary will be mentioned. In order to gradually extend his knowledge of astronomy, to make good any existing deficiencies in his study, to be able at any time to obtain information upon the various questions and problems of astronomy and time reckoning, the purchase of some good work on popular astronomy is advised. In this matter, notice should be taken that the work is quite up-to-date, because the purchase of old works, which can generally be picked up for a mere song, is often almost useless to the beginner.

The unsuspected rise which astronomy has taken during the last decade, and in recent times especially, through the epoch-making conquests of spectrum analysis and celestial photography, can be learned and understood only in the latest works; and still the inventions and discoveries in these fields of science continue to increase in a way never dreamed of.

In addition to a book on popular astronomy, there is, however, one book which can be recommended with the utmost confidence that the amateur will find it a most extremely useful book. This is Sir Robert Ball's "Popular Guide to the Heavens."[1] Its utility will readily be understood when we say that it consists of a large number of plates (83 in all), comprising a set of lunar maps showing the moon's disc gradually increasing from new to full, accompanied by key maps indicating each lunar feature as it comes into view, and also a map of the moon in four quadrant sections, with a complete reference index of all the maria, craters, mountains, rills, and other lunar formations. Then there is a series of star maps, twelve giving the midnight sky month by month, and twenty sectional maps of the

[1] Published by Geo. Philip & Son, Ltd., 32, Fleet Street, London, E.C.

heavens, showing all stars visible to the naked eye. Plates and diagrams of the planets, their orbits, phases, and satellites, are given, and the great advances made by celestial photography within recent years are shown by the unusually fine plates of characteristic lunar scenery, solar spots, typical nebulæ, and comets. Explanatory text accompanies all the plates, and there are some useful tables, one set of which gives the positions, phases, and conditions of visibility of all the planets at any time up to 1950, as well as the means of identifying any planet that may be seen within that time.

To the star maps mentioned in the work we shall again refer in the section dealing with the shooting stars and meteorites.

The small star charts, or planispheres, which are made so as to revolve, are specially helpful to the beginner when learning the constellations, and will be discussed in that chapter.

One article that should never be wanting in the amateur astronomer's collection is an astronomical almanac or year-book. These almanacs generally give the places of the sun, moon, and planets from day to day (called an Ephemeris), the sidereal time of mean noon, and lists of celestial phenomena which take place during the year, with details thereof. The Greenwich Nautical Almanac is of course the standard work of its kind, and the most important and complete, but there are quite a number of others, some giving lists of double and variable stars as well as nebulæ and clusters. The elements of the orbits of the planets and periodic comets, and lists of the meteoric radiant points are also in some cases given. Generally speaking the amateur will find the astronomical almanac or year-book so true a friend, that of all his books it will be by far the most often referred to.

In order to obtain news of all the latest results of astronomical research, and thus to be thoroughly up-to-date with all the events that may happen in the various branches of astronomy, it is a good plan to become a subscriber to one or other of the astronomical periodicals, the cost of which is generally comparatively small. Since these papers gladly publish the observations and work of amateur societies, it will be possible for the amateur to compare his work with theirs, and he may thereby find a friend and colleague with whom he may unite in a mutual task. He also obtains the fellowship, if not in person, at least in mind, of those distinguished professional people of the whole world, to whom, because they have chosen this sphere of knowledge as their calling, it is not begrudged that they should profitably serve this grandest of all the sciences, by virtue of their professional accomplishments, and with the help of the best and most exact instrumental means that the human mind ever devised.

For the benefit of those who are for the first time just entering the circle of amateur astronomers, it may be stated that for many generations there has existed a companionship among friends of astronomy and cosmical physics, the members of which are numerous and loyal, and are scattered over the whole face of the earth. Many of them have laboured nobly and profitably in this field of science, even though only as amateurs, and not a few of these labours have earned for them the unreserved acknowledgment and recognition of the professional astronomers.

* * * * *

Journal of Observations.

In all work connected with astronomy it is essential to keep an exact record of observations. Even from the very beginning the amateur must keep precise accounts of his observations, and also of the new facts which little by little obtrude themselves upon him. The points of view from which such an observation journal must be kept are indicated by the questions What? Where? and When? some object was observed. It is also of considerable importance if the observer happens to have a talent for drawing; this being especially advantageous in observations of the sun, moon, and planets. But even the amateur who is only very slightly skilled in drawing should not neglect to make use of it in such observations as would be scientifically enhanced in value by a drawing or by a slight sketch, even though it be made in a few rough strokes. The ability to grasp detail certainly plays an important part, and it is proved that even good draughtsmen, who are at the same time experienced astronomical observers, may frequently considerably differ in their rendering by drawing of difficult subjects, such as, for example, planetary surface details.

The beginner in observational astronomy, after he has become sufficiently acquainted with the whole field of the science, and has attained the necessary knowledge as a basis for the pursuit of the subject, will sooner or later choose one particular department for working at. A good draughtsman, who possesses a sharp eye, and who at the same time is in a position to provide himself with one of the larger instruments, will know how to devote himself to the study of the surface details of the planets. Another department is that which takes for its task the regular observation of the sun, that is, the appearance of the solar surface. Many amateurs will show an especial interest in our moon, and will find here a wide field for their observational activity. A large number of amateur astronomers belong to that group which has made the variable stars the object of their study, and who, out of pure love of and delight in the subject, actively aid those professional astronomers working in this department. By extensive and systematic observation of meteors on the part of amateurs, many a cosmical problem, which is doubtful to-day, might be solved. To whichever chapter we may eventually turn ourselves, our first and most important task will be to obtain an exact acquaintance with the starry heavens.

CHAPTER IV

THE FIXED STARS

In the observation of the fixed stars, we betake ourselves into those depths of heavenly space, which we may tread only with a thrill of reverence; into those regions from which our unaided eye would no longer perceive our sun, or if it did so, it would at the most be as a tiny, insignificant star; into regions where we stand immediately in the presence of infinity of space and eternity of time.

Even at the first glance towards the heavens, we notice a property common to all the fixed stars—the ceaseless changes of light shown us by those stars glittering first brighter, then fainter, in rapid alternation, and even also with a varying colour, an appearance to which we have given the name of *scintillation*, and which is caused by the pencil of light rays from the star entering our atmosphere and having to traverse unequally dense and unequally humid strata of air.

Another property of the fixed stars, as well as an important characteristic of difference between them and those heavenly bodies that belong to our solar system, is that we are quite unable to measure their diameter. A fixed star appears to the naked eye as a luminous point, and also remains such, when we view it through our field-glass or telescope; it even appears more minute the greater the magnifying power employed, because the irradiation which makes it appear larger to our eye, vanishes in the telescope. Precisely the same thing can be seen if we view any artificial source of light —for example, a candle flame—from some distance. To the naked eye it appears a point of light, which sends out rays in all directions, but with the telescope it appears as a sharply defined flame. If we then examine a fixed star with a telescope magnifying ever so strongly—in other words, however near to our eye we may bring it—the star remains a point of light.

If, however, all fixed stars appear in the telescope as luminous points, yet when viewed with the naked eye they exhibit a great difference. Some of them are so bright, and appear so large, that we can see them immediately after sunset; while others, which are fainter, become visible by degrees later on, and as the night advances, still smaller ones can be seen.

We speak, then, of stars of different *magnitudes*, notwithstanding that the word "magnitude," after what has been already said, is not the correct word to use, and that really the light intensity or brightness of the star is meant. Thus we call the brightest fixed stars *first magnitude*, those rather less bright *second magnitude*, and so on down to the sixth magnitude, which magnitude can just be seen by an unaided normal eye, under favourable conditions, *i.e.*, in clear and quiet air, and without being affected by light from any other source. All the remaining magnitudes belong to the telescopic stars, and the faintest stars, namely, those of the sixteenth and seventeenth magnitudes, mark the utmost limit of what our present optical means can show to the eye.

Notwithstanding all this, it must not be forgotten that the observation of telescopic fixed stars is by no means entirely dependent on the quality and power of the telescope used, but that the ability and experience of the observer play a considerable part therein. The yet somewhat unskilled observer will only gradually come to be able to see objects which are about the limit of the optical power of his instrument. Naturally, then, the more powerful the telescope is, the farther will the trained observer be able to penetrate into the lower magnitudes of the fixed stars. The aperture of the object-glass of the telescope used, upon which depends the amount of light rays conveyed to the eye, determines, therefore, the light-receiving power, and allows of deeper penetration into the starry realms.

In order to acquaint the reader who possesses a telescope, or who aspires to obtain one, with the performance that may be expected of such an instrument, it may be stated that an object-glass having an aperture of about $1\frac{1}{4}$ inches will show stars down to the ninth magnitude, one of 2 inches to the tenth magnitude, one of 3 inches to the eleventh magnitude, and one of 6 inches to magnitude twelve. The extremely faint stars of the fourteenth magnitude require an objective aperture of about 15 inches, while those of magnitude fifteen require a 25-inch object-glass.

However, before we point our telescope at individual objects of interest in the sidereal system, we shall first get acquainted with the starry heavens as a whole—we shall begin to find our way about in this wide domain. By attentive contemplation we soon see that the starry host is not countless, as it at first sight appeared, but is still far too great to allow of our reckoning and designating them individually without some aid. Therefore in ancient times certain fixed stars were grouped together, and a suitable name was given to the group thus composed. Either the people of olden times saw in them definite figures, and gave them a corresponding name, or else they

Fig. 17—Philip's Planisphere.

immortalised and honoured by the nomination mythical heroes, memorable events and occurrences, and also commemorated thereby such everyday proceedings as agriculture and hunting. The boundaries of these individual groups are certainly very arbitrarily chosen, and their extent is irregular and unequal. In many constellations the chief stars belonging to it so far give the suggestion of a figure; but generally speaking, the imagination of the observer must be extremely active in order to make out for himself from the constellation the picture signified by its name.

To facilitate finding out the constellations, in default of verbal instruction, we cannot do without a simple aid, such as a star chart or map. To begin with, the most suitable will be one of those adjustable maps, called a planisphere, having a movable horizon, which can be adjusted for every hour in the year. They are to be highly recommended on account of their neatness, handiness, and low price. One of the best of these is illustrated in Fig. 17. It is published by Messrs. George Philip & Son, Ltd., of London. These charts, which facilitate the solution of many practical problems, are accompanied by complete directions for use.

On the next clear evening let us betake ourselves to our observation point, with our planisphere correctly adjusted to the proper hour. Then after having correctly orientated ourselves and our chart towards the heavens, let us hold the chart in the prescribed manner, and try to find one of those demarcated (and perhaps already known to us) constellations.

Almost universally known, for example, is the constellation of the Great Bear, which is quite easy to find at any time in the northern skies, because it never sinks below the horizon, belonging consequently to the group of circumpolar stars. Using this constellation as a starting point, we can gradually work outwards towards the other surrounding constellations, always referring to our star map. One good method of thus becoming acquainted with the constellations is to join the brightest fixed stars by imaginary straight lines, or properly speaking, by arcs of great circles, and thus proceed from the already known stars to those still unknown.

For example, if we join the two stars at the end of the quadrilateral in the Great Bear by a straight line, and then produce this line to a length about five times as great, we arrive at the brightest star in the Little Bear, known as *Polaris*, or the *Pole Star*. It is situated in the immediate proximity of the Pole, round which the whole heavenly vault appears to revolve, and it describes so small a circle round this Pole that it appears to stand quite still the whole night through.

For the beginner it will be a good plan when thus acquainting himself with the heavens, to proceed slowly, and not to attempt to learn more than four or five new constellations each night, which, however, he should thoroughly impress upon his mind. It will be of great advantage if, to begin with, he makes sketches of the separate constellations from nature as well as from the star map, the same as is done in the study of the earth's surface in geography. It really is of no great consequence whether a tiny star of fourth or fifth magnitude belongs to this particular group, or has to be included in another ; the chief point is that the form of the constellation as a whole should remain fixed in the memory.

In this manner, by continued observation, we shall gradually become acquainted with the whole of the starry firmament, even if we should have but little time and leisure to devote to it.

It should also be mentioned here that, while studying the constellations of the Zodiac, we may often come upon large and bright stars, of which we can find no trace in our star maps. In such a case it is not a fixed star, but one ot those heavenly bodies which belong to our solar system, and which we shall very soon learn to recognise as a planet, on account of the fact that in the course of time it either lags behind or hastens on in front of those other stars surrounding it.

Once having firmly fixed the greater number of the constellations in our memory, we can then proceed to learn those proper names attached to the individual brighter stars, which names are generally indicated on the star chart in small print. All the more brilliant stars have received special names, but in order to be able to indicate the smaller and less brilliant stars, all the stars in each constellation have been designated by the small letters of the Greek alphabet, and wherever practicable this has been done in the order of their brightness, so that the star designated by Alpha (α) is as a rule also the brightest of its group, and the one designated by Beta (β) the next brightest, and so on. But as there are many more stars in a constellation than there are Greek letters, after these are exhausted, the stars are known by letters of the ordinary alphabet, or by numbers. For example, we have α *Tauri*, R *Leonis*, 61 *Cygni*.

In order to make it easier for the beginner to find the different constellations, and to readily pick them out on the map, the characteristics of the northern constellations and of those of the Zodiac will be reviewed shortly. At the same time the names of the brightest stars will be mentioned.

Group of the Great Bear.

The Great Bear (*Ursa Major*), popularly known as the Plough, is formed by six stars of the second magnitude and one star of the third magnitude. Four of these stars form a quadrilateral, while three others run outwards in a curve from it and form the "handle of the plough" or the "tail of the bear." The remaining stars are much fainter. It is by far the best known constellation of the northern skies. The two last stars in the quadrilateral are known as the "Pointers," owing to the fact that a line drawn through them and produced will indicate the Pole Star.

The Little Bear (*Ursa Minor*) shows seven stars between the second and fifth magnitudes, in an arrangement somewhat similar to that of the Great Bear. The last star in the tail is the already mentioned Pole Star, which lies in a straight line with the "Pointers" of the Great Bear.

The Dragon (*Draco*) winds itself between the Great and Little Bear. Nine stars of the third magnitude and one in its head of the second magnitude form a long, sinuous line. Close to this constellation, between the Great Bear and Auriga, is to be found the constellation of the *Giraffe* (*Cameleopardalis*).

Boötes. A straight line drawn through the two upper stars in the quadrilateral of the Great Bear, and prolonged in the direction of the tail, passes near to a beautiful shining ruddy star, which bears the name of *Arcturus*, and which is the chief star in the constellation of *Boötes* (*the Herdsman*). Between it and the Great Bear comes the constellation of the *Hunting Dogs* (*Canes Venatici*), and below this a group of smaller stars forms the constellation of *Coma Berenices*.

Group of Auriga.

If the line from the two upper stars in the quadrilateral of the Great Bear be prolonged in the direction opposite to that of Boötes, it will reach the constellation of *Auriga* (*The Charioteer*, or *Waggoner*), the brightest star in which is *Capella*, of the first magnitude, forming, together with five other stars of the second and third magnitudes a six-sided figure.

This constellation forms with *Taurus* (*the Bull*) and *Gemini* (*the Twins*) in the Zodiac, an easily recognisable group. One part of this constellation Auriga reaches the Milky Way, and, forming part of that structure, we find adjoining Auriga the constellation of *Perseus*, with the two bright second-magnitude stars

Mirfak and *Algol.* About the latter of these two stars we shall have more to say upon another occasion.

Group of Cassiopeia.

Cassiopeia is a readily recognisable constellation, of which the five chief stars of the second and third magnitudes take the form of a **W**. It occupies a position on the other side of the Pole opposite to the Great Bear, so that when the latter is in the highest part of its daily path, Cassiopeia lies close to the northern horizon in a reversed position.

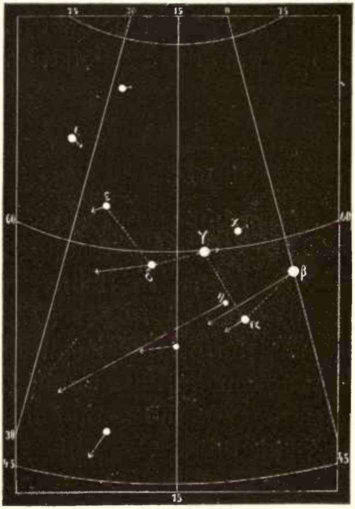

Fig. 18.—Cassiopeia.

(The arrows show the direction of the proper motion of the stars to which they are attached.)

Cepheus, between Cassiopeia and the Little Bear, contains three stars of the third magnitude, the most northerly one of which lies in line with the

"Pointers" of the Great Bear and the Pole Star.

Adjoining Perseus and Cassiopeia is the constellation of *Andromeda*, which is considerably extended, and of which the brightest stars are of second magnitude. Close to it stands the constellation of *Pegasus*, of still greater extent. Three stars of Pegasus and one of Andromeda from the so-called "Square of Pegasus."

Group of Lyra.

Just as the Great Bear is directly opposite to Cassiopeia, so Auriga stands opposite to the constellation of *the Lyre* (*Lyra*) on the other side of the Pole. The brightest star in this constellation bears the name of *Vega*, and the brillant white light with which it shines makes it one of the brightest stars in the northern skies. Close beside Vega stand three stars of the fourth magnitude; rather more to the south are two other stars of the third magnitude. This constellation just borders on the Milky Way.

Situated in the midst of the Milky Way, which is here divided into three portions, stands the constellation of *the Swan* (*Cygnus*), the five brightest stars of which, shining with a warmer light, form a large, regular cross, the uppermost star, *Deneb*, being of the first magnitude, the others of third magnitude.

If we follow the Milky Way southwards, we can easily find below Vega and Deneb, the constellation of *the Eagle* (*Aquila*), with the first magnitude star *Altair*, which, with the two already mentioned bright stars, Deneb and Vega, forms a large right-angled triangle. Five other stars of this constellation belong to the third magnitude and one to the fourth. In the neighbourhood of the Eagle, but, however, beyond the confines of the Milky Way, towards Pegasus, stands *the Dolphin* (*Delphinus*), which may easily be recognised by the cross-like arrangement of its four chief stars of the second and third magnitudes.

Adjoining the constellation of the Lyre, and southward from the Dragon, lies the widely extended constellation of *Hercules*, with its brightest star of second magnitude. South of Hercules lies *Ophiuchus* (*the Serpent-bearer*), which together with *Serpens* (*the Serpent*), plainly traceable by a sinuous line of brighter stars, stretches from near Altair almost as far as Arcturus.

The Northern Crown (*Corona Borealis*) is a very characteristic constellation, situated between Hercules and Boötes. At the centre of the lower curve of bright stars is *Gemma*, of the second magnitude, lying in a line with Vega and Arcturus. Northward of the Lyre, Hercules, and the Crown, we again come upon the Dragon.

CONSTELLATIONS OF THE ZODIAC.

These are the twelve constellations through which the sun gradually passes during the twelve months, as it pursues its apparent course through the heavens, and they form, as it were, the huge universal clock, indicating the divisions of the year. To the Zodiac belong the following constellations :—

1. *The Ram* (*Aries*), formed by the three stars α of the second, β and γ of the third to fourth magnitudes, lying south of Andromeda and not difficult to find. Between these two constellations lies the little constellation of the *Triangle* (*Triangula*), of which one star only is of the third magnitude, the others being still fainter.

2. *The Bull* (*Taurus*), readily visible on account of the two very beautiful star groups, the *Hyades* and the *Pleiades* (sometimes called the "*Seven Sisters*"). The Hyades consist of the bright ruddy star *Aldebaran* of the first magnitude, along with four other stars, and the group takes the form of a V. The Pleiades, in which a sharp eye under the best conditions can distinguish about a dozen stars, lie in a beautiful

easily known star group, the brightest star bearing the name of *Alcyone.*

3. *The Twins* (*Gemini*), worthy of note because in this constellation the sun reaches its highest altitude, contains the two bright stars *Castor* and *Pollux*, the most northerly of all the zodiacal stars.

4. *The Crab* (*Cancer*), a rather insignificant group of small stars. The two brightest, γ and δ, reach the fourth magnitude.

5. *The Lion* (*Leo*), with the first magnitude star *Regulus*, three others of the second magnitude, and four of the third.

6. *The Virgin* (*Virgo*). Five stars of the third magnitude, the most northerly of which is called *Vindemiatrix*, form an L. South-east of these stars is one brilliant white star of the first magnitude, called *Spica.*

7. *The Scales* (*Libra*). South of Arcturus and the Crown, known by three stars, two of the second magnitude and one of the fourth, forming a right-angled triangle.

8. *The Scorpion* (*Scorpio*), adorned by the first magnitude red star *Antares;* to the right of it towards Libra stand three other stars of second to third magnitude, closely one above another.

9. *The Archer* (*Sagittarius*) is the most southerly constellation of the Zodiac, and very little seen by us. Four stars lying on a line

between Antares and Altair show it easily. The brightest of them forms with the three smaller a quadrilateral.

10. *The Sea Goat* (*Capricornus*), a constellation with very little appearance, and also very low in the southern sky, known by three stars of the third magnitude.

11. *The Water Bearer* (*Aquarius*), to be found south of Pegasus and between the "Square of Pegasus" and the Dolphin. Consists of five stars of the third magnitude, while the rest are still fainter.

12. *The Fishes* (*Pisces*), a rather extensive constellation south of Andromeda and Pegasus. It contains one third-magnitude star, all the others being still lower in magnitude.

Constellations of the Southern Skies.

The Whale (*Cetus*), south of Aries and Pisces. Two stars of the second magnitude, six of the third, and seven of the fourth are included in the composition of this constellation. Of the first mentioned two, *Mira* is especially noteworthy. We shall again refer to this star in another chapter. *Eridanus* begins south of the Hyades, and stretches far away to the south. The brightest star, *Achernar*, of the first magnitude, is not visible from our latitudes, but can be observed in the north of Africa.

Orion is the most magnificent constellation in all the heavens, and offers the lover of astronomy an extremely fine field for observation. Four stars of from first to third magnitude form a quadrilateral, and in this stand three stars of the second magnitude in one straight line, forming the well-known "*Orion's Belt.*" The two very fine stars of the first magnitude α, with the name of *Betelgeuse*, and β, called *Rigel*, are the brightest in the constellation. The light of Betelgeuse is reddish, and that of Rigel white. The second magnitude star γ is called *Bellatrix*. By the inclusion of the star κ of the third magnitude, a figure resembling an X is formed, round which all the remaining stars are grouped.

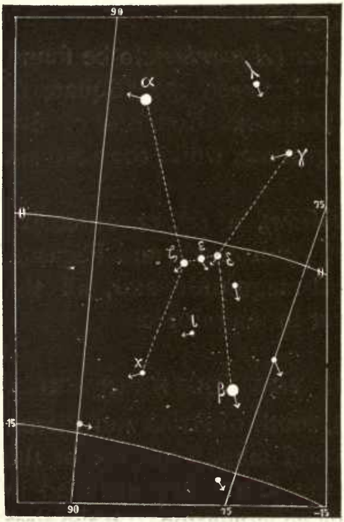

Fig. 19.—Orion.
(The arrows show the direction of the proper motion of the stars they are attached to.)

The Lesser Dog (*Canis Minor*) will be found on the other side of the Milky Way from Orion, and just south of Gemini. Not far off from its brightest star α, called *Procyon*, in an oblique line towards Gemini, stands the third-magnitude star β.

The Greater Dog (*Canis Major*) lies opposite the Lesser Dog on the other side of the Milky Way. The star α, well known of old, named *Sirius*, is the brightest star in the whole firmament. To the right of it stands *Mirzam*, a star of the third magnitude. Sirius, Procyon, and Betelgeuse form an almost equilateral triangle. A line drawn through the stars in the "Belt" of Orion, and produced, will reach Sirius.

The Crow (*Corvus*), with three second-magnitude and one fourth-magnitude stars forming an irregular quadrilateral, belongs to the less important of the southern constellations.

The Southern Fish (*Piscis Australis*), with the first magnitude star *Fomalhaut*, is, on account of its low position, difficult of observation in our latitudes. In the southern lands it is a striking constellation, and was much mentioned of old.

Until the student of the heavens, who for the first time essays to penetrate the mysteries of the stars, has become perfectly familiar with these just mentioned constellations, a considerable length of time may pass. We can never at any time, even though we remained at our observation post the whole night through, succeed in observing all these constellations. It is true certainly that those in the western sky slowly sink beneath the horizon, and new ones, still unknown to us, creep slowly up the eastern sky, while only those constellations lying close to the Pole remain continually above the horizon. But with the coming of the early morning hours, the twilight and the dawn, first the fainter stars, then the brighter ones, gradually disappear from the eastern sky, and we can no longer observe the advance of the rising constellations and make ourselves familiar with them. We are not able to observe those stars lying in close proximity to the sun, and therefore standing in the heavens during the daytime, for the all-animating ruler of our solar system quenches their feeble rays with the glare of his brilliant light.

But as the sun advances along its apparent course through the zodiacal constellations, we can by degrees observe the other constellations and commit them to memory. If, for example, we utilise the early hours of the evening and night for our observation, as far as we have the time and leisure to do so, and if the light of the moon does not hinder us, then as a reward for our perseverance we shall, in a little more than six months' time, be fully acquainted with the whole of the constellations in our skies.

There will be ample time for us to be very particular in thus familiarising ourselves, and we shall be quite as able to find our way among the stars in the heavens, as we can in the streets of a city well known to us.

Before we proceed to apply optical aid to our eye, and begin to examine any interesting details in the realm of the stars, it will be of great advantage to give ourselves a kind of training which will be of great importance in a department soon to be treated of.

When learning the constellations, we can hardly fail to notice that those brilliant stars, which we counted as being of the first magnitude, are in reality very different in their degrees of brightness. Let us, for example, compare *Sirius* with *Aldebaran*, or *Arcturus* with *Antares*. What an extraordinary difference in brightness!

There exists between the individual stars of one and the same magnitude a very considerable difference in brightness, and therefore these magnitudes are again divided into ten subdivisions, which are numbered from 0·1 to 0·9. The star *α Lyrae* (*Vega*) is generally taken as the standard of brightness.

It is important that in course of time we should develop a certain sensitiveness for these differences of brilliance, and this can only be attained by numerous estimations of the light values of neighbouring stars, or of those belonging to the same class of magnitude. With stars belonging to the first three magnitudes this presents no great difficulty, and we shall, after the selection of an adequate number of comparison stars of known brightness, soon reach a certain accuracy of estimation. The judgment of differences of brightness between stars of the third magnitude downwards will be found rather more difficult, since the eye is unable to recognise slight differences of brightness between very faint objects. Yet even here we can by practice attain good dexterity with the help of lists of stars such as most almanacs and yearbooks contain, and which give accurately the star's magnitude.

For later investigation, it is important that the observer should also make observation of the fixed stars from another point of view. At the first glance we directed towards the heavens, it appeared that all the stars were white, but we soon found that only one part of the stars visible to the naked eye are actually white in colour, as, for instance, *Vega*, *Spica*, *Regulus*, *Sirius*, and *Deneb*. Other stars appear quite differently coloured; thus *Arcturus*, *Altair*, *Procyon*, and β *Ursae Majoris* are yellow; *Aldebaran*, *Antares*, *Betelgeuse*, and especially *μ Cephei* are reddish or red. *Castor* shines with a slightly greenish tinge, while *η Lyrae* is bluish. For colour differences and gradations, our eye should be made receptive by the undertaking of numerous observations. This is best done by the aid of some colour scale, which we can settle for ourselves. In colour estimation particularly, the influence of personal comprehension of colour is unusually great. In order to represent such estimations by figures, the following scale can be taken as a basis :—

0 = White	6 = Slightly reddish yellow
1 = Slightly yellowish white	7 = Reddish yellow
2 = Yellowish	8 = Yellowish red
3 = Yellow	9 = Slightly yellowish red
4 = Topaz yellow	10 = Full red
5 = Orange	

Having now familiarised ourselves with the starry heavens, and given ourselves some training in the differentiation of brightness and colour, we may with a good conscience proceed to investigate the details of this infinitely wide field.

By this time no doubt our naked eye has come upon several parts of the heavens which are far more thickly strewn with stars than are others. Let us remember how extremely rich in stars are the neighbourhoods of the beautiful constellations of *Orion*, *Lyra*, and *Taurus*. Particularly in the latter many of the brighter stars are concentrated in a very small space, forming the well-known groups of the *Pleiades* and *Hyades*. Now it is scarcely probable that this clustering of stars is entirely fortuitous, and certainly it is *not* so in the case of some of those stars which appear to us to be arranged in pairs at no great distance from each other. They are——

CHAPTER V

DOUBLE STARS

ONE of the most striking examples of these is *Mizar*, the middle star in the tail of the Great Bear (ζ Ursae Majoris). A sharp eye can see, even without optical aid, close above it a fifth-magnitude star (80 Ursae Majoris), also known as *Alcor*, which in olden times was used as a test for keen eyesight. The distance between these stars is about eleven minutes of arc. Even with a moderately sized telescope we can distinguish that the chief star Mizar is itself double, and that it consists of two stars, of third and fifth magnitudes respectively, separated by a distance of fourteen seconds of arc. There are also, as we shall see, other double stars situated much more closely together, and therefore requiring higher magnification and a more powerful telescope, in order that they may appear as such to us. Occasionally they are separated from each other by merely a fraction of a second of arc.

At the same time, however, we cannot be absolutely certain that such stars are also placed *actually* near to each other, for it may be that they appear as a "double" merely by virtue of the fact that they accidentally stand almost in the same line of sight; so that, though showing themselves close together, the one may in reality be a vast distance behind the other, and have no further relation to it. Such stars as thus *appear* to us double we call "*optical doubles.*" Mizar and Alcor is such a pair.

But, should two stars stand close together, and at the same time belong to one and the same system, then we have what is called a "*physical double*," or more commonly a "*binary.*" These, then, are far-distant suns, revolving round their common centre of gravity; at distances which, though limited, may amount to many hundred millions of miles. The aforementioned companion star to Mizar, at a distance of fourteen seconds of arc, forms with its principal star a physical system.

Up to the present time there are known to exist over eleven thousand double and multiple stars, of which only a small portion have proved to be really optical doubles, while about eight hundred show relative movements, and about four hundred are recognised as definite physical doubles. In the case of many pairs, the orbit and the period of revolution of the companion star round the principal has been calculated. These periods naturally differ considerably for different pairs. Only in a few cases, up to the present, has the period of revolution been found to occupy less than one hundred years, and of the remainder only a few appear to have a period of less than three hundred years. For the majority of these double stars, it is thus a long time, often over one thousand years, and sometimes from ten thousand to thirty thousand years, before a complete revolution has been accomplished.

On this account accurate data of double star systems are obtainable only after a long space of time. The position of the companion star with regard to the principal star, in most cases, changes only extremely slowly, and is defined, for any moment, by the "position angle," *i.e.*, by the angle which the line joining both stars makes with the circle of declination of the principal star, and which is counted from 0 to 360 degrees from north through east, south, and west, back to north. Thereby it is possible for the observer to know at once at which side, right or left, above or below, he has to look for the companion star, and this is especially important when the object in question lies near the limit of the optical power of his instrument.

Equally important to the double-star observer is the statement of the distance separating the companion star from the principal; and he will thereby be placed in the position of being able to judge whether the separation of the double can be accomplished by means of his instrument, or not. The statement of the magnitudes of the component stars will of course be the chief point to be attended to, for only thereby can we tell whether the companion star is or is not too faint to be seen with our instrument, even when the principal star does not stand close enough to the companion to dim its light.

The consideration of the colours with which these double stars shine is unusually interesting. While in the single stars white is the ruling colour, yellow being fairly frequent, and red much more rare, we find that the companion stars in doubles are very frequently blue and green. Generally speaking the difference between their colouring is greater in direct proportion to the difference of magnitude between the two components. Very frequently we notice that they exhibit the complementary colours, such as red and green, or blue and orange, but there are also other colour combinations, yellow and white, white and blue, dull yellow and bright yellow, deep blue and light blue, yellow and blue, and green and blue, which present themselves more or less frequently.

It is not without interest to know that, to an observer, the colour of one star is considerably influenced by the proximity of another differently coloured one. It would, therefore, seem that the colours of the pairs of double stars are generally optical illusions, and make themselves apparent through the phenomenon of complementary colours. That is to say, if we bring an artificial star into the field of view of a photometer, and close enough to a white star to give the impression of a double star system, then, by giving the artifical star any desired colour, we shall be surprised to see that the white star assumes the complementary colour. We can, however, be quite sure that with most of the double stars their colour differences are not due to optical effect, but are actually as they appear. The simple test, by covering the principal star by means of a crosswire, or a bar diaphragm inside the telescope, has proved that the colouring must, in the greater part, be accepted as the actual colour of the companion. To the amateur who, at the beginning, has practised estimating the colours of the fixed stars, these double star systems offer a very wide field for increasing his skill therein.

We shall next proceed to select, from the exceedingly large number of these objects, those which offer the most interest to the amateur astronomer, and of these we shall first mention those which can be separated by an ordinary achromatic telescope of only one to two inches aperture.

After Mizar, of which mention has been already made at the beginning of this chapter, γ *Delphini* is an easily observed double star. The principal star is of fourth magnitude, and shines with a pale reddish light, the companion star, separated from the principal by eleven seconds of arc, is of sixth magnitude, and bright green in colour. On account of this interesting combination of colours, it is for the amateur a pretty and striking object. The companion moves extremely slowly—namely, only about $7\frac{1}{2}°$ in 100 years.

γ *Arietis* is separable even in the weakest instruments, and the difference between the magnitudes of the component stars is very little, for the principal is of 4 and the companion of 4·5 magnitude.

γ *Andromedae* is a very interesting object, and is triple. Its companions belong to magnitudes 6 and 8 respectively. The first is easily seen in a small telescope, while the second can only be seen in a superior instrument. Its appearance then is very fine indeed, because each component has a different colour. The principal is orange, the first companion is greenish, and the second companion shines with a bluish light.

ε *Equulei* is likewise a triple star, for the principal star, of magnitude 4, is itself a close double. The first companion is of magnitude 10, and easily seen, but it is not certain whether it is actually or only optically connected with the system. The larger companion, of magnitude 5, stands so close to the principal that their separation is possible only with powerful instruments. It is nevertheless of interest, because it possesses an extremely short period of revolution (11 years), which is very rare amongst the double stars.

ε *Lyrae* appears to a sharp eye to be double even without optical aid. Each of these stars is, however, seen to be double in small telescopes. All the stars shine with a yellowish white light. One of the most interesting objects in the northern skies. Between the two doubles are three other diminutive little stars.

β *Serpentis* is a wide double, for the

companion star stands 25 seconds of arc away from the principal. The principal star is of 3 and the companion of 9 magnitude.

φ Tauri. The principal is of 5 the companion of 8 magnitude, the former shining with a reddish and the latter with a bluish light. Also a very wide pair.

α Geminorum (*Castor*) is the brightest and most beautiful double in the northern skies, and can be separated with a 2-inch telescope. The principal star is of 2·5 and the companion of 3·5 magnitude; both shine with a greenish yellow light. It is of interest to know that it was from observation of this pair of stars that W. Herschel first arrived at the knowledge of the physical connection of the double stars.

ι Cancri, a pretty object, formed by a yellow star of 4 magnitude and a companion of 6 magnitude. More interesting, however, is the triple star

ζ Cancri, a white principal star of 5 magnitude and two yellow companions of 7 magnitude. In small telescopes the more distant companion only is visible. It shows a slow but irregular movement. The other companion is visible in more powerful instruments, moves regularly, and more rapidly than the other.

ν Scorpii is easily recognised in a small telescope as a double the companion is of 7 magnitude. In a powerful instrument, however, it shows itself as a quadruple star, since both the principal and the companion stars have each very close companions. Also the double β *Scorpii* is easily separated by small telescopes. The white principal star is of 2 magnitude, the greenish yellow companion of 5 magnitude. In a very powerful telescope the star appears triple. This other companion is very close to the principal star, and was discovered in 1879 by Burnham, whom we have to thank for a very large number of double star discoveries and measurements.

α^2 *Capricorni*, of the 3 magnitude, has a 4 magnitude companion, which can be seen even with an opera-glass. Both are bright yellow, and are slowly moving apart.

β and o *Capricorni* are likewise easily separated doubles.

ψ^1 *Aquarii* is a wide double, the components of which are 50 seconds of arc apart. The principal star is 4 and the companion 8·5 magnitude. In actuality the star is threefold, but the 36-inch telescope was the first to separate the companion of the smaller star.

ψ^1 *Piscium* is easily separable, but is of no further interest. Principal and companion are both of 5 magnitude.

ζ *Piscium*, likewise easily separated by small telescopes. Principal is of 4, companion of 5 magnitude. Separation 23 seconds of arc. Both white.

66 *Ceti.* Principal magnitude 6, companion 8 magnitude. Distance apart, 15 seconds of arc.

o^2 *Eridani*, a bright yellow principal star of 5 magnitude, with a pair of stars of 9 to 10 magnitude as companions; and is therefore triple. The large proper motion of the companion stars, namely 4 seconds of arc annually, is specially noteworthy.

32 *Eridani* is a very beautiful couple, and is worth closer consideration. The bright yellow principal star, of 4·5 magnitude, has a blue companion of 6 magnitude separated from it by 7 seconds of arc, and is therefore not easily separated by a small instrument. Of those double stars which require at least a 2-inch to 3-inch object-glass to separate them, the following will be mentioned :—

π *Boötis.* The principal star is of 5 and the companion of 6 magnitude. Separation 6 seconds of arc.

ζ *Coronae.* Principal of 4, companion of 5 magnitude. Separated by 6 seconds of arc.

γ *Virginis* has principal and companion both of 5 magnitude, separated by 5 seconds of arc. A very beautiful, noticeable object.

α *Herculis.* The principal star is of 3, the companion of 6 magnitude. Separation 4·7 seconds of arc.

ξ *Boötis.* A very beautiful double star. The principal, of 4·5 magnitude, is yellow, while the companion, of 6·5 magnitude, shines with a blue light. Separated by 4·2 seconds of arc. This pair is a good example of the doubles showing complementary colours. The companion makes a revolution round the principal star in 127 years.

ζ *Aquarii.* A very noteworthy double. The principal and companion stars are each of the 4 magnitude, and are separated by little more than 3 seconds of arc. A 2-inch telescope will scarcely separate them.

δ *Serpentis.* Just about the limit of separation for a 2-inch telescope. The stars appear in a telescope of this aperture in close contact, like a single elliptical star. Their separation amounts to 3·3 seconds of arc. The principal star is bluish and of 3·5 magnitude, while the companion is also blue and of 4 magnitude.

α *Piscium*, having a separation of only 2 seconds of arc, is no longer to be seen double with a 2-inch glass, but requires a more powerful telescope. The principal star is of 3 and the companion of 4 magnitude.

γ *Leonis*, an outstanding pair, which may be separated by a 2-inch telescope. The principal star is of 2 magnitude, and golden yellow in colour, while the companion is of 3·5 magnitude, and has a greenish yellow tint.

σ *Coronae* is a triple system. A 6 magnitude companion stands 4 seconds of arc from the principal 5 magnitude star. The second companion star belonging to this system is extremely faint (17 magnitude), and was declared by O. Struve to be one of the most severe tests, even for the most powerful telescopes.

ε *Boötis*. Separation 3 seconds of arc. The principal star is of 3 and the companion of 7·5 magnitude. The beauty of the colouring of this pair (orange and emerald green) has gained for it among astronomers the name of "Pulcherrima."

η *Cassiopeiae* is a most interesting double star, having a yellow principal star of 4 magnitude, while the companion is of 7 magnitude, and shimmers with a rose-coloured light. Struve attempted to calculate the period of revolution of the companion star, and found 147 years. From later investigations, and by taking into account all observations down to the year 1901, W. Doberck found the probable value to be 328 years. If the parallax found by O. Struve is correct, then, by using Doberck's elements, calculation gives the combined mass of the two component stars as being 2·17 times as great as the mass of our sun.

ε *Lyrae*, a double, of which each star is again double. The two principal stars are separated by 207 seconds of arc, and are of 4·5 and 5 magnitude respectively.

μ *Draconis.* Separation is possible with a

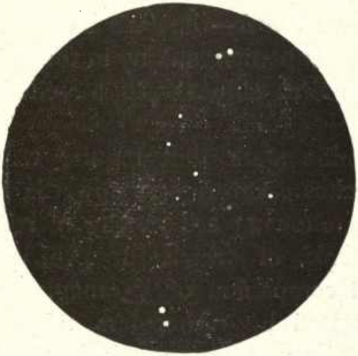

Fig. 20.—Double star ε Lyrae, as seen through a Telescope of 4-inch aperture.

3-inch telescope. The principal and companion stars, both of 5 magnitude, are about 2 seconds of arc apart. A beautiful pair. The somewhat brighter principal star is again a close double, but was discovered by Burnham in 1890 only with the 36-inch telescope. All three stars form a physical system, and show a common proper motion.

o *Draconis.* A golden yellow principal star of 5 magnitude, with a companion of 8 magnitude, which is blue.

ξ *Ursae Majoris* can also be seen only in telescopes of 3 inches aperture and upwards. The principal star is of 4 and the companion of 5 magnitude. Otherwise no interest attaches to it.

α *Ursae Minoris*—the *Pole Star*—is a double, and has a companion ranking in the 9 magnitude. The Pole Star shines with a yellowish white light.

Of double stars that require telescopes of 4 to 5 inches aperture and upwards for separation, the following are worthy of remark:—

τ *Ophiuchi*, of which the principal star is of 5 and companion of 5·5 magnitude. They are separated by rather less than 2 seconds of arc. The period of revolution is 218 years.

λ *Ophiuchi* has a companion of 6 magnitude situated 1·6 seconds of arc from the principal 4 magnitude star.

36 *Andromedae.* The principal star is of 6, the companion of 7 magnitude, and the separation of the two is 1·3 seconds of arc.

12 *Lyncis.* Principal star 5 magnitude and companion of 6 magnitude.

ε *Arietis*, with a principal star of 5·5 magnitude and a 6 magnitude companion.

γ *Ceti*, a 3 magnitude star, with a faint companion of 7 magnitude.

ζ *Boötis*, a very fine pair. The principal star is of 3·4 magnitude, and is separated from its 4 magnitude companion by only 0·8 second of arc. It requires a 5-inch object-glass to separate it.

49 *Cephei*, another difficult object. The components are of 5 and 6 magnitude respectively.

ι *Cassiopeiae*, a triple star. The principal star is of 4 magnitude, and shines with a golden yellow light. The more distant companion, being separated by 2 seconds of arc, may be seen in smaller instruments. It is bluish in colour. The closer 7 magnitude companion, is also blue, but demands a much more powerful instrument in order to be seen separate from the principal star.

β *Orionis* (*Rigel*), is another very beautiful object, which can easily be separated by a 5-inch telescope. The principal star, Rigel, is of 1 magnitude and yellowish in colour, while the 8 magnitude companion star shines with a bluish white light.

7 *Tauri* is also a double star worthy of remark, and requires a rather powerful instrument for its separation.

As examples of unusually close double stars, visible as such only in considerably larger telescopes, the following are given :—

μ Coronae. The extremely faint companion star stands very close to the principal, and completes a revolution round it in 95 years.

ζ Herculis is a specially notable and historically interesting double. It was the one by which W. Herschel was able for the first time to prove conclusively the occultation of one fixed star by another. In the year 1803 this great observer remarked: "My observations of this star furnish us with a phenomenon which is new in astronomy; it is the occultation of one star by another." The companion star was discovered by W. Herschel on July 18, 1782. He described it then as a fine object composed of two unequally bright stars, the brighter white and the other ashen in colour. After 1802 the companion star could not be seen on account of its proximity to the principal star. F. W. Struve, who made the observation of the double stars his special study, and whose labours in this field have formed the basis of all later work on double-star observation, saw it again in 1827, with his 9-inch refractor, at Dorpat. In the years from 1828 to 1831 it was too difficult even for this instrument, and trustworthy measures first begin again in 1834. Altogether, since its first discovery, the companion star has completed almost four revolutions round the principal star, and its period is therefore fairly accurately known. At the present time, when the companion is again very close to the principal, it is a very difficult object. Its distance is somewhat over 0·8 second of arc. The apparent magnitude of the principal star is 3·0, its colour yellow; the companion ranks about 6·5 magnitude and is of a bluish green tint. The period of revolution of this system is 33·9 years.

φ Ursae Majoris is also a very difficult object, and can be separated only by the more powerful instruments. The principal and companion stars are of 5·0 and 5·6 magnitude respectively, with a distance between them at present of only 0·3 second of arc.

θ Orionis, called the "Trapezium in Orion," as seen in a 4-inch telescope, consists of four stars, of which the brightest is of 4·7, the faintest of 8 magnitude. Struve discovered a fifth star of 11 magnitude; J. Herschel found a sixth of 13 magnitude; de Vico in 1839 discovered in addition two smaller stars. By Porro, in 1856, a ninth star was found. On January 6, 1866, Huggins saw all the nine stars at once. To those observers provided with very powerful telescopes *θ* Orionis can be highly recommended as an object worthy of very close observation.

σ *Orionis* is a rather complicated system, composed of two groups of quadruple stars, and is thus an eightfold system. The brightest stars are of 4·0, 5·5, 6·3, 6·8, and 9·5 magnitudes.

σ *Coronae*, to which we have already referred under the list of double stars for telescopes of 2 to 3 inches aperture, is really a triple star. The second companion, however, is most extremely faint (17 magnitude), and can only be seen with the most powerful telescopes, and even then only under the most favourable conditions and with very clear air. Struve has declared it to be one of the most severe tests of the space-penetrating power of a telescope.

We shall now desist from any further enumeration of double stars, but the student of the heavens, for whom this chapter will have a special interest, is referred to the detailed lists of double stars, which are generally to be found in the astronomical year books and almanacs. He will find enumerated there, in addition to these, a great number of pairs of fixed stars, which he can make the objects of his observation, even though his telescope is not one of the powerful instruments.

Before, however, leaving this section, the suspicion may occur to us that there may be double-star systems which even our most powerful telescopes cannot show separated, and in addition that dark companion stars may revolve round their principal stars, though we may never be able to verify their existence. So concluded that famous astronomer Bessel, who investigated with great care the proper motion of a number of fixed stars, and deduced from the observations that the movements of *Procyon* (*α Canis Minoris*) and of *Sirius* (*α Canis Majoris*) showed a deviation from the calculated positions far exceeding the possible errors of observation. He held it then to be exceedingly probable that both these stars had companions, with which they described an orbit round the common centre of gravity, and that, in revolving round this centre of gravity they must, with the lapse of time, occupy different positions with regard thereto. But since such a companion star could be seen neither beside Sirius nor beside Procyon, nothing remained but to take for granted that the companion must be a dark body. This assumption was held by other astronomers of his time to be rather a bold one, but he could not allow the innumerable visible stars to be evidence against the existence of invisible ones. He did not, however, attempt to undertake the calculation of the orbit of the companion star, because the material to hand did not seem to him to be sufficient for the purpose.

Such a task was, however, undertaken by the astronomer Peters, who found from Bessel's observations a period of revolution of fifty years. His calculations, and Bessel's hypothesis, were brilliantly confirmed, when Clark, at Cambridgeport, on January 31, 1862, succeeded in seeing the companion of Sirius, a faint little star, at a distance of 10 seconds of arc from Sirius. To-day the companion of Sirius is a well-known object of 9·5 magnitude, but nevertheless can only be seen in the larger or largest telescopes. At the Manora Observatory in Lussinpiccolo under air conditions far more favourable than generally exist in most places, it has been seen and measured by Director Brenner with his excellent 7-inch telescope. The companion of Procyon was also found, but much later, by Schaeberle at the Lick Observatory in 1896.

The number of those double stars, which, even with our most powerful telescopes, we can see either scarcely or not at all, has, during the last decade, become very considerable.

For this advance we have to thank the progress of spectrum analysis, which of late has raised astrophysics to such an important position in astronomy. With the help of the spectroscope it has been possible to recognise as double certain stars which even the most powerful telescopes in existence could never hope to show separated. They betray themselves on account of the fact that the oppositely directed movements of the components of such a double star round their common centre of gravity cause the lines in their spectrum to show periodical displacements. Such stars are known as *Spectroscopic binaries.*

At the present time close upon a hundred such stars are known, and no less than Spica, Algol, β Lyrae, Capella, and Aldebaran belong to this group, having been proved by spectroscopic, or in more recent times by spectro-photographic means, to be binaries.

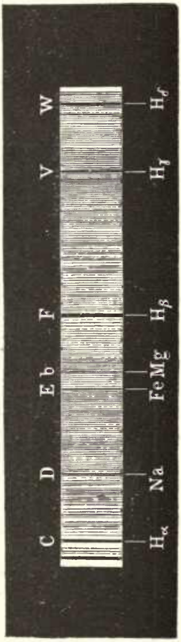

Fig. 21.—Spectrum of Sirius.

It would be beyond the limits of this little volume, and besides, it would be of no use to the amateur, if we were to go any further into this last group of the double stars. The student of the heavens will not as a rule be in a position to have at his disposal the instruments and apparatus generally used for investigations in spectrum analysis (Spectroscope, Spectrometer, Spectrograph).

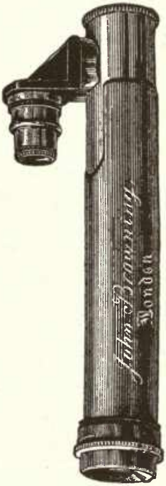

Fig. 22.—Browning's Pocket Spectroscope, with scale tube.

Fig. 23.—Browning's Pocket Spectroscope.

We must not, however, omit to strongly advise all those who wish to have an insight into the constitution of the universe, and into the physical nature of the heavenly bodies, to make themselves familiar with the principles of spectrum analysis, and with the fundamental laws of this method of research which must play so important a part in astronomy. It is, as a witty astronomer once expressed it, "the voice of the heavens," and deserves to be highly appreciated by the student of astronomy. By the help of a good book on the subject and a pocket spectroscope, we can carry out those laboratory experiments, which will then serve us as guides in this wide field, wherein of recent times almost every day brings some new discovery and conquest.

As a spectroscope for the amateur we should recommend Browning's pocket spectroscope, it being worthy of mention on account of its compact form, acknowledged quality, and cheap price. The small apparatus is fitted with a little micrometer scale for purposes of measurement.

We shall now leave the double stars and binaries, and turn ourselves towards a still wider field, which for both professional and amateur astronomers is a most interesting department—the star clusters and nebulæ.

CHAPTER VI

STAR CLUSTERS AND NEBULÆ

When we first attempted to learn our way among the separate groups and constellations in the heavenly vault, it did not escape our notice that the largest and brightest stars were scattered fairly regularly over the whole firmament, but that in the case of the smaller stars such a distribution was not always to be observed. We need only call to mind the well-known group of the Pleiades, where we saw with the naked eye seven stars gathered together in a comparatively speaking small area. By the aid of a telescope this number increases to more than one hundred. Let us also think of that wonderful faintly luminous band encircling the whole heavens like a gigantic belt, in places divided into two branches, and called by us the Milky Way. Let us direct our telescope towards it, and then its milky glimmer will be transformed into an innumerable army of densely packed little stars, of all the varying magnitudes down to the tiniest point of light. Yet even in its brighter portions there still remains some of that soft glimmer. Let us try a more powerful telescope, and the glimmer will resolve itself into a legion of new and fainter stars. But if we look attentively, we shall always be able to observe still some of that soft, faint glimmer. It is not really conceivable that this clustering of the stars should be merely an apparent one; on the contrary, we are convinced that these multitudes of stars have also a physical connection.

Even though the opinions at present held considerably differ regarding the configuration and structure of that stellar aggregation we call the Milky Way, yet we can nevertheless accept it as probable that our sun is likewise a star belonging to the swarm of stars in this Galaxy, or Milky Way, and that it lies not in, but rather out of the plane of the greatest extension of this stellar condensation. It does not, however, lie very far from this plane. The Galaxy is but a shining island in the depths of space, just like the many that we now take the opportunity of examining.

The form of the stellar clusters is, as a rule, circular, or rather spherical. The individual stars of which they are composed appear mostly to be of about equal magnitude, but occasionally either one or a few brighter stars are to be found in the central parts of these groups. Their appearance in some cases is overwhelmingly magnificent, especially in those groups where the stars are very small and closely crowded. These clusters mostly possess a globular form, and the individual stars become more and more condensed towards the centre, so that there they give the appearance of a ball of light. The number of stars that sometimes compose such clusters is absolutely astounding. Thus, Sir Wm. Herschel has estimated the number of stars in the cluster in *Centaur* at five thousand, and, when seen in the telescope, they appear like a scattered host of glittering diamonds.

Not unfrequently the stars in these clusters are arranged in curved lines, winding like a spiral, each line often commencing with a bright star.

In other clusters, stars of different magnitudes often appear interlaced with each other, and in such cases the cluster is generally not very sharply outlined, but seems to lose itself gradually. In many other clusters the stars are more sparsely distributed than in the already mentioned Pleiades and Hyades.

These stellar clusters appear to the naked eye, if they are visible to it at all, and if the individual stars are not so widely separated as in the Pleiades and Hyades, as dim, hazy forms; and many of them do not change this character even in the smaller telescopes. On the other hand, we can see many luminous, gaseous, cloud-like structures, which we cannot succeed in resolving into individual stars, and regarding which we were for a long time in doubt as to whether they should be included amongst the star clusters.

Sir William Herschel, who made these objects his special study, and who was possessed of an enormous optical instrument, was at first of opinion that these nebulous forms were also star clusters, because in many, even if not in all cases, he succeeded in resolving them into stars. Since then, however, though the continued investigation of the heavens has increased the number of these nebulæ to many thousands, yet the most powerful optical means have not been able to resolve these forms. It was reserved for spectrum analysis to reveal the true nature of these nebulæ. Whereas those clusters composed of actual stars gave a connected band of light as a spectrum, a so-called *continuous spectrum*, the nebulæ proper show us only a few coloured lines, a *line spectrum*, from which we must conclude that these nebulæ are really composed of gaseous masses. It is very probable that, in the nebulæ, we see far-distant solar systems, which have as yet attained only a very early stage of their development.

Respecting the form and systematic classification of these extremely interesting structures, it may be said that the large, extended nebulæ are, as a rule, so faint in their light, and so indefinite and undecided in their limits, that they are to be seen well only with very powerful telescopes. Large nebulæ present the appearance of an irregular, chaotic mass of luminous gas, as, for example, the Great Nebula in Orion. In large telescopes this nebula shows itself as a web-like structure of filaments, of brighter and dimmer streaks and bands, dark canaliform markings, and winding lines, and would overcome the

Fig. 24.—Earlier representation of the Nebula in Andromeda.

perseverance of the best draughtsman. But by the aid of celestial photography we are able to obtain on the sensitive plate the true representation of this chaos of a world to be.

Besides these great irregular nebulæ, others are to be seen, which have an expanse many times greater than the disc of the full moon, with more clearly defined outlines than those of the irregular nebulæ, and showing in places noticeably brighter portions, in which the light seems to concentrate. These brighter portions have received the names of "stars," "stellar condensations," or nuclei, while the whole structure is called a stellar nebula. In the constellation of Virgo are to be found whole crowds of such nebulæ, and the zone of these formations stretches from there right through Coma Berenices and Ursa Major, on to Andromeda.

Even in the most confused nebulæ traces of organised action may be recognised; and there is clearly to be seen a bright central portion, from which radiate several curved lines in the form of a spiral. These are called the *Spiral Nebulæ*. As these are so numerous, and as this spiral structure has been established by photography to be common to the great majority of nebulæ, it is questionable whether this form of nebula should be considered as a separate group at all. Above all, the oval and elliptical nebulæ—of which one of the finest representatives is the well-known Andromeda nebula, visible without aid to a sharp eye—show this spiral structure.

Fig. 25.—Planetary Nebulæ, after J. Herschel.
(1) In Pisces, (2) in Ursa Major, (3) in Andromeda.

The so-called *Planetary Nebulæ* constitute another group, and owe their name to the fact that, when seen through the telescope, their regular light and tolerably sharp outlines remind us of the appearance of a planetary disc. Planetary nebulæ, possessing a condensation towards the centre, form a transition group to the nebulous stars. These latter resemble planetary nebulæ which have their light so condensed in the centre that one or more stars seem to stand therein, but the spectroscope proves these condensations to be glowing masses of gas.

Much rarer than the foregoing types are those known as *Ring Nebulæ*, which appear to be merely a variety of planetary nebulæ, and which, as their name implies, are more faintly luminous in their central parts than they are on their sharply defined borders. The best known of these is the Ring Nebula in Lyra, and it is moreover, the only one of its kind that will show the characteristic form of its type in a moderate-sized telescope.

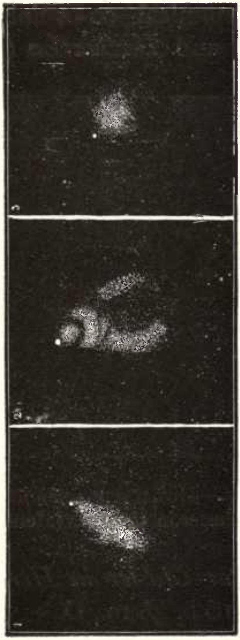

Fig. 26—Cometary Nebulæ, after Herschel and Rosse.

Nebulæ, which in their appearance more or less resemble the telescopic comets, were called by Herschel "*Cometary Nebulæ.*"

Of those star clusters and nebulæ which will have an especial interest for the amateur, and which once having seen he will gladly look for again and show to his friends, the following will now be mentioned, and the best examples of their kind will be described.

In order to facilitate the finding of these objects on the star map and in the heavens, their places will be definitely indicated by the astronomical co-ordinates of *Right Ascension* (Æ.) and *Declination* (D.).

Fig. 27.—Earlier representation of the star cluster in Hercules (Messier 13).

Declination north of the celestial equator will be shown by +, and that south of it by −.

The large scattered star clusters of η Tauri (Pleiades) and γ Tauri (Hyades) we have already become acquainted with. A very fine object is the

Star Cluster in Hercules, south of the star η (Æ. 16 h. 38 m., D. + 36° 39 m.), which is visible as a dim speck to the naked eye under favourable conditions. A telescope of fairly good aperture shows thousands of tiny points of light, which are so thickly crowded toward the centre that they cannot be distinguished separately. By employing a higher magnification, three dark rifts or canals are quite plainly visible in the midst of the group, while at the edges, especially towards the south-east, beautiful outlying rays show themselves. Altogether a most attractive object.

Star Cluster in Perseus (Æ. 2 h. 12 m., D. + 56° 42′) is likewise a magnificent, very large object, extremely rich in stars, in the neighbourhood of the star χ Persei. Quite close at hand and adjoining this is another

Star Cluster in Perseus, also extraordinarily rich in stars of 7 to 14 magnitudes.

Star Cluster in Cancer (Æ. 8 h. 35 m., D. + 20° 19′), known as "*Praesepe.*" This also may be seen with the naked eye, like a tiny cloud, and a very small telescope will easily resolve it. A second

Star Cluster in Cancer (Æ. 8 h. 46 m., D. + 12° 12′) is rather widely extended, and likewise very bright and rich in 10 to 15 magnitude stars.

Star Cluster in Cassiopeia (Æ. 1 h. 27 m., D. + 60° 10′), a bright, round, rich cluster of stars of 10 and 11 magnitudes.

Star Cluster in Auriga (Æ. 5 h. 30 m., D + (34° 4′), a very large and rich cluster of 9 to 11 magnitude stars. Another

Star Cluster in Auriga (Æ. 5 h. 47 m., D. +

32° 31′) is a very bright and beautiful object. The stars are smaller and more condensed than in the previously mentioned one, and are

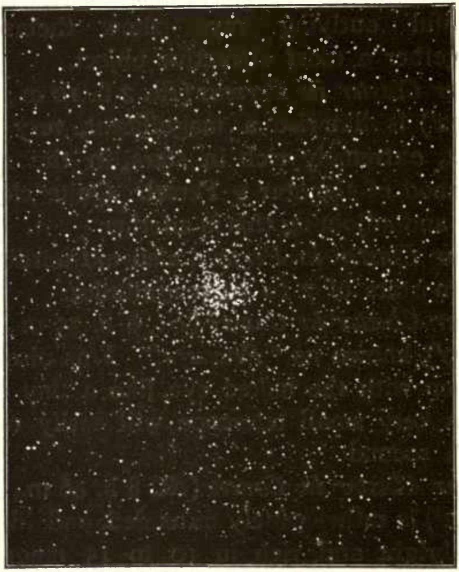

Fig. 28.—Star Cluster in Auriga.
(Photograph by Dr. Isaac Roberts.)

somewhat involved with nebulosity. Herschel termed it a noble object.

Star Cluster in Gemini (Æ. 6 h. 3 m., D. + 24° 20′), not far from the star η Geminorum, is visible to the naked eye as a very faint nebulous object, but in the telescope is so fascinating a sight that Lassell said, "No one can see it for the first time without an exclamation, and nothing but a sight of the object itself can convey an adequate idea of its exquisite beauty." It is, therefore, a much observed and often photographed cluster. Dr. Roberts obtained in a field of 26 minutes of arc no less than 620 stars.

Star Cluster in Argo (Æ. 7 h. 37 m., D. − 14° 35′). On account of its southerly position, this cluster is very difficult to observe in our latitudes. It is a large cluster, rich in a great number of small stars, and is situated in immediate proximity to the star 2 Argus, on the edge of the Milky Way. If a very powerful instrument is used, it shows itself as a very beautiful cluster of stars of 12 to 15 magnitudes. The whole cluster surrounds a small ring nebula.

Star Cluster in Canes Venatici (Æ. 13 h. 37 m., D. + 28° 53′). About 12° northward of Arcturus, and shows itself in small telescopes as a collection of hundreds of sparkling little stars. In larger instruments it gains greatly in extent, and is remarkable for the radiating lines of stars, which spread out from it on all sides.

Star Cluster in Libra (Æ. 15 h. 13 m., D. + 2° 27′) stands somewhat south of the star δ Serpentis, and is a globular, very compressed cluster of stars of 11 to 15 magnitudes. Photographs show this cluster to be greatly compressed in the centre.

Fig. 29.—Star Cluster in Cassiopeia.
(Photograph by Dr. Isaac Roberts.)

Star Cluster in Scorpio (Æ. 16 h. 11 m., D. – 22° 44′) is one of the richest and most condensed masses of stars in the firmament, but cannot be resolved by small telescopes, in which it seems to resemble a nebula. It is further notable from the fact that in May, 1860, a star of 7 magnitude suddenly blazed out in it, and a month later had entirely vanished. This cluster is not difficult to find; it lies midway between the two bright stars α (*Antares*) and β Scorpii.

Star Cluster in Ophiuchus (Æ. 16 h. 42 m., D. $-$ 1° 45′) between the stars δ and 41 of this constellation. In small instruments it appears to resemble a faint, round, starless nebula. A more powerful instrument, however, shows the stars quite clearly resolved right to the centre of the cluster.

Star Cluster in Ophiuchus (Æ. 16 h. 52 m., D. $-$ 3° 56′) is a very pretty, large, globular cluster, but rather difficult, however, for a small telescope. It is rich in stars of 10 to 15 magnitudes, of which some are arranged in curved lines.

Star Cluster in Cassiopeia (Æ. 23 h. 52 m., D. + 56° 10′). A large, rich, and strongly condensed cluster between the stars ρ and σ of this constellation, situated in a part of the Milky Way.

Star Cluster in Cameleopardalis (Æ. 3 h. 58 m., D. + 62° 3′) is visible even in an opera glass. By using a rather powerful telescope, it appears as a glittering, closely packed cluster of stars ranging from 10 magnitude downwards.

Star Cluster in Pegasus (Æ. 21 h. 24 m., D. + 11° 38′). A beautiful globular cluster, situated between the stars ε Pegasi and β Equulei. The central part of the cluster appears nebulous in the less powerful telescopes. The stars are arranged in lines and curves round the centre.

Star Cluster in Canis Major (Æ. 6 h. 43 m., D. – 20° 38′) is easily visible in a small instrument. It lies about 4° south of Sirius, and in this cluster also the stars appear to be arranged in curves. In the centre there is a ruddy star.

Of those objects which even our most powerful telescopes fail to resolve, and which spectrum analysis methods of investigation teach us are more or less dense masses of cosmic gases, we shall mention first the renowned

Nebula in Andromeda (Æ. 0 h. 37 m., D. + 40° 44′), beside the star ν Andromedae. This nebula appears in an opera-glass as a small, dim cloud; in small telescopes it has an elongated, lenticular form, and for years was so depicted in books on astronomy. Since the rise of celestial photography, it has engaged the attention and interest of astronomers to a very large extent, and has lately become a much-photographed object. On looking at such a photograph we see a central nebulous nucleus, surrounded by rings of nebulous matter which here and there show traces of condensation. The plane of the rings lies considerably obliquely to our line of sight, so that we do not get the benefit of a full view of the ring surface. Any further explanation of such a photograph is scarcely necessary; the disposition of the

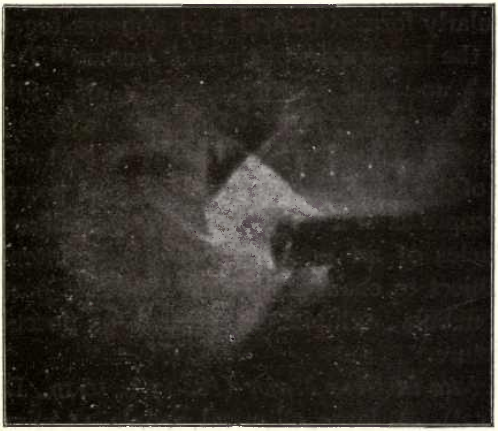

Fig. 30.—The Great Nebula in Orion (after Geo. Bond).

nebulous matter speaks in no ambiguous manner, but so completely bears out the theory of Laplace that any further explanation of its form would seem superfluous. It should, however, be mentioned, that in August, 1885, a new star, or "*Nova*," of the sixth magnitude blazed out in this nebula, and then again decreased in brilliancy, finally disappearing entirely in the course of 1886. A second famous object of this type is the

Great Nebula in Orion (Æ 5 h. 29 m., D. − 5° 28′), which may also be visible to an unusually sharp eye, under very favourable conditions, without optical aid. In a small telescope the bright, singularly formed central part appears together with the larger stars of the well-known "Trapezium" and the commencements of radially branching arms. The whole nebula occupies an area seventeen times as great as that of the disc of the full moon, and appears in powerful telescopes as of a very odd form, not unlike the tentacles of an octopus. The light intensity is subject to changes, but the brightest part of the nebula exhibits a curdled or flocculent structure.

Nebula in Ursa Major (Æ. 11 h. 10 m., D. + 55° 53′). A large, elliptical nebula, 15 minutes of arc in length and 6 in breadth, to the south-east of β Ursae Majoris.

Nebula in Virgo (Æ. 12 h. 26 m., D. + 14° 58′). A starless nebula between two small stars and a star of 6 magnitude. It has an elliptical form, and is somewhat condensed at the centre.

Nebula in Canes Venatici (Æ. 12 h. 46 m., D. + 41° 39′) is a planetary nebula, and has the brightness of a star of 8 magnitude. It is not large, but has a bright central-point. Rosse saw round the nucleus a bright ring, and believed the nebula to be of a spiral form.

Fig. 31.—Spiral Nebula in Ursa Major.
(Photograph by Dr. Roberts.)

Photographs show this ring, but also indicate that it is not of a spiraliform nature.

Spiral Nebula in Canes Venatici (Æ. 13 h. 26 m., D. + 47° 43′) and (Æ. 13 h. 26 m.,

D. + 47° 47′). A great nebulous spiral, of which both nuclei show a spiral formation, and are surrounded by dense nebulosity. The spirals

Fig. 32.—Spiral Nebula in Ursa Major.
(Photograph by Dr. Isaac Roberts.)

are in places interrupted by star-like condensation. It is noteworthy that Huggins found the spectrum to be continuous, from which we must conclude that here we have to do with a star system which with our former means of research could not have been recognised as such.

Nebula in Sagittarius (Æ. 17 h. 56 m., D. – 23° 2′) stands close to the star 4 of this

Fig. 33.—Spiral Nebula in Canes Venatici.
(Photograph by Dr. Isaac Roberts.)

constellation and is a large trifid nebulous group, traversed by dark rifts.

Omega Nebula in Sagittarius (Æ. 18 h. 15 m., D. – 16° 3′) is a very fine, large, and bright object. It has earned its title from the alleged resemblance of its form to the Greek letter Omega (Ω), which, however, does not appear evident from photographs. In a clear sky it can be quite easily seen with a small telescope.

Nebula in Sagittarius (Æ. 17 h. 58 m., D. – 24° 22′). Stands close to the 6·5 magnitude star 9 Sagittarii and in the Milky Way. It is oval, with its major axis lying in a north-east to south-west direction. In a small telescope it has the usual appearance of a nebula, but by using a more powerful instrument a host of small stars may be seen, showing actually as a scattered cluster in the midst of a bright, large, irregular mass of nebula.

Ring Nebula in Lyra (Æ. 18 h. 50 m., D. + 32° 54′). This is the only object of its class that can be seen by the smaller telescopes. It is very easy to find, standing as it does between the stars γ and β of this constellation. A small telescope shows it only as a rather sharply outlined ring. A more powerful instrument, however, shows that the central space of the nebulous ring is also filled with excessively delicate nebula, and very keen observers can also see in the centre of the apparently empty space a central condensation, somewhat resembling a faint star. Photographs of the nebula show that the interior space is distinctly nebulous, and this escapes our eye simply because in it the predominating light is ultra-violet, a colour invisible to the human eye, but which, nevertheless, has a powerful effect upon the sensitised film of the photographic plate.

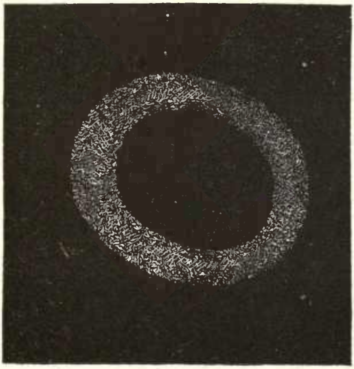

Fig. 34.—The Ring Nebula in the Constellation Lyra.
(From a drawing.)

"*Dumb-bell*" *Nebula in Vulpecula* (Æ. 19 h. 55 m., D. + 22° 26′). It stands somewhat south of the 5 magnitude star 14 Vulpeculae and appears in moderate-sized telescopes as two oval, hazy masses in contact, whence its name "Dumb-bell." In larger instruments and in photographs it shows as a much more irregularly formed mass, in many places exhibiting a floccular structure; the whole mass being, moreover, surrounded by a faint nebulous veil giving it an elliptical appearance.

Nebula in Aquarius (Æ. 20 h. 58 m., D. − 11° 45′). A beautiful, very bright planetary nebula of elliptical form, with short rays on either side of the centre, which gives it a striking resemblance to Saturn and his rings. It stands immediately beside the star γ of this constellation, and shines with a pale blue light.

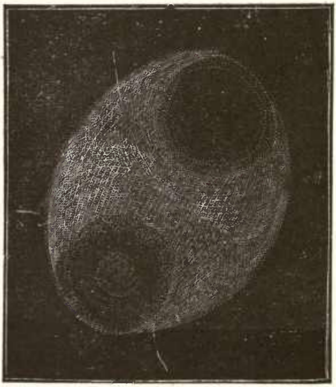

Fig. 35.—Dumb-bell Nebula.
(After a drawing by J. Herschel.)

Crab Nebula in Taurus (Æ. 5 h. 29 m., D. + 21° 57′) lies about 1° north of the star ζ Tauri, and is an irregular roundish mass of nebula, showing faint filamentous appendages, and numerous stars. W. Herschel described it as one of the most beautiful nebular objects in the heavens.

We shall now draw to a close our enumeration of those nebulæ and star clusters which are of special interest to the amateur, but we would remark that there are still many more of these objects that will be of interest to him,

Fig. 36.—Dumb-bell Nebula. Exposed 20 minutes.
(Enlargement of a photograph by W. E. Wilson.)

even though he has but a small telescope. All astronomical year books generally contain such lists, and to these the amateur is referred for additional objects to observe.

In recent times it has been principally celestial photography that we have had to thank for the large number of discoveries of new nebulæ, which were quite invisible even to our most powerful telescopes. Moreover, it alone gave us a correct knowledge of these gaseous formations appearing in the immeasur-

Fig. 37.—Reproduction of a drawing of the "Crab" Nebula.

able depths of space, and to-day we know that these represent solar systems, which are as yet in a very early stage of development. But no one can form any adequate idea of their remoteness in the depths of space. Sir John Herschel estimated the time that light would require to travel from the most distant nebulæ visible in the telescope to our earth as about twenty million years, and Mädler came to the conclusion, from other considerations, that this time might very well reach thirty million years.

Here human imagination is powerless. Yet even in those bounds where numbers convey no impression, in that infinity where giant worlds dwindle to tiny specks, there still exists the order of an eternal law. Even those worlds in the depths of space are arranged in some other great system, and the same natural law which causes the moon to revolve round the earth, the planets and comets round the sun, and the millions of suns round their centre, also causes these universes to revolve round their central system, in prescribed orbits and in measured times. Even the boldest mind among us earth-dwellers may well be giddy at such thoughts, and feel that in no earthly language are there words adequate to refer to such a subject. We abandon, even with the measuring rod of the velocity of the light ray at our disposal, the attempt to represent such infinities of space and time, that seem only to mock our numeral system, and we acknowledge frankly that here we stand at the utter limit, not of the universe, but of our knowledge.

Before, however, we return from these infinitely remote regions to our own solar system, for the purpose of observing the individual members thereof, we shall once again come back to the stars, and in this case to those stars which are of so much interest to all astronomers, on account of the fact that they appear sometimes brighter, sometimes fainter, and exhibit such distinct fluctuations in their brilliance.

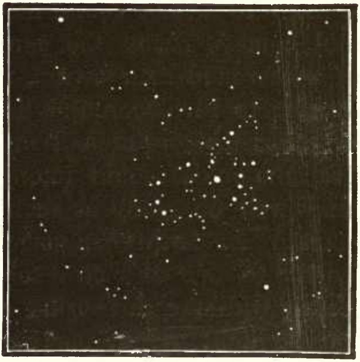

Fig. 38.—The group of the Pleiades in the Constellation Taurus (see p. 108).

CHAPTER VII

VARIABLE STARS

On August 13, 1596, David Fabricius saw in the neck of the Whale (Cetus) a third-magnitude star, which in October of the same year entirely vanished; but in the year 1603 Bayer represented in the same place a fourth-magnitude star, and only six years later Fabricius found it again on the 5th of February, without, however, following up the extraordinary observation. It was Professor Holwarda who, in the year 1639, recognised the variability of this star (which had been designated o Ceti by Bayer), after he had observed it in the year 1638, found it vanished in the middle of 1639, and seen it once more shining in December of that year. Because of the remarkable variation in its light, Hevelius gave the star the name of Mira ("The Wonderful"), and since then it has become famous as the representative star of its class. The light of Mira varies in rather irregular periods of $331\frac{1}{3}$ days from a maximum of second to a minimum of ninth magnitude, or in other words, from being as bright as the large stars of the Great Bear, to invisibility to the naked eye. For 42 days, on the average, the star increases to the maximum of its brilliancy, without, however, attaining at those periods the same degree of brilliancy, for occasionally it remains standing about the third or fourth magnitude, before its light fades to the minimum. Mira shows, like most of the variable stars, a rather ruddy light.

As opposed to this long period, there are other variables which at regular intervals, in a much shorter time, exhibit a rapid diminution in their light, lasting for only a few hours. In this category of variables stands the star *Algol*, (β Persei), with a period of 2 days 20 hours and 48 minutes. It was discovered by Montanari in 1669. For the greater part of this time, namely for 2 days 11 hours 30 minutes, it remains in its maximum of second magnitude, while in its minimum, of only 10 to 25 minutes, it shines as a star of the fourth magnitude; the remaining 9 hours it varies between these magnitudes, because it requires $4\frac{1}{2}$ hours for the decrease of its light, and likewise $4\frac{1}{2}$ hours for the increase. As a result of recent observations, it appears that the minima of brightness are occurring earlier, and therefore Algol is being attentively watched at the present time at many prominent institutions, regarding the variation of its light. The amateur can also very profitably lend his aid by making attentive and correct observations for the new control of these light changes of the star Algol, and this will be all the more

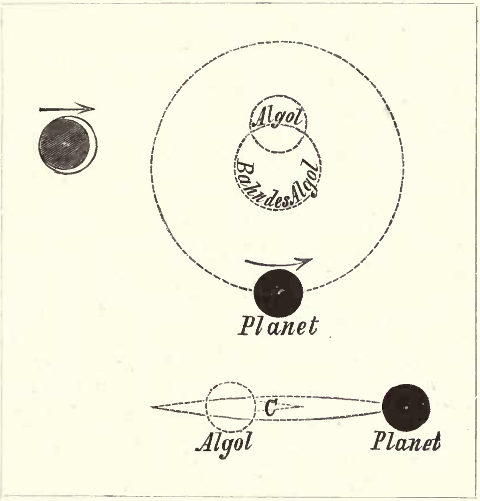

Fig. 39.—Explanation of the phenomenon of variability in stars of the "Algol" type. Translation of the German in the wood-cut: Bahn des Algol = Orbit of Algol.

easily accomplished, since the variations being from the 2·1 to the 3·2 magnitude may be watched with the naked eye.

Other variables of short period, as for example

β Lyrae, show regular variations in the diminutions, as also in the augmentations of the light, and thus show two maxima and two minima of different brilliance. This star thus, during a period of about 12 days $21\frac{3}{4}$ hours, changes its light in such a manner that its brilliance first increases for 3 days 2 hours, then falls again for 3 days 7 hours, thenceforward brightens till in 3 days 3 hours it reaches its greatest brilliance, which is 3·4 magnitude, and lastly fades again in 3 days 10 hours to its minimum, when it shines as a 4·5 magnitude star.

Many variables with very slight alterations in their light, as for example ε Aurigae, change their brightness so irregularly that no definite period can be assigned to them, and they are therefore termed "*irregular*" variables.

What we know to-day regarding the physical nature of these variable stars has been entirely due to the enlightenment given us by spectrum analysis. The first type of variability is caused by the rotation of the star, whereby differently shaded sides of the heavenly body in question are turned towards us, or else it may be caused by periodical emanations of light-absorbing vapour. The second type of variability consists of a more or less short period brought about by the eclipse of the star in question by a dark companion. Algol offers an example of such a star, and we name all the variables belonging to this group as variables of the "Algol type." The third group can be traced to outbursts of incandescence, which take place at quite irregular intervals.

As objects of observation for amateur astronomers, in addition to the four already mentioned stars, the following are recommended as well worthy of attentive observation :—

δ *Librae* (Æ. 14 h. 56 m., D. − 8° 7′) was known as a variable as early as 1859, and is specially notable on account of its short period of variation. The whole period of variability occupies 2 days 7 hours 51 minutes, but the alterations are accomplished within 12 hours, while during the remaining time nothing takes place. At the maximum it is of 4·8, at the minimum of 6·2 magnitude. It is of the Algol type. On January 1, 1908, a minimum occurred at 3 hours 20 minutes, from which by addition all following minima may be found.

λ *Tauri* (Æ. 3 h. 56 m., D. + 12° 12′) is likewise an Algol variable with a variation in light between 3·4 and 4·2 magnitudes in a period of 3 days 22 hours 52 minutes. The alterations, however, are completed within 10 hours. A minimum occurred on January 4, 1908, at 3 hours 47 minutes, from which others may be calculated.

δ *Cephei* (Æ. 22 h. 26 m., D. + 57° 54′), is also a double star, with a blue companion star of 5·5 magnitude situated 41 seconds of arc from the principal star. This principal shows a light variation in a period of 5 days 8 hours 47 minutes and 40 seconds. At the time of its maximum brightness it is of 3·7 magnitude, while at minimum the magnitude is 5·0. In the same constellation the star μ *Cephei* (Æ. 21 h. 40 m., D. + 58° 19′) is also an interesting variable, which appears to the naked eye intensely red in colour, and is known as the "*Garnet star.*" It varies its light from about 4 to about 5 magnitude, but in irregular periods.

η *Aquilae* (Æ. 19 h. 48 m., D. + 0° 45′). A star of yellowish colour; its variability was discovered by Pigott in 1784. At maxima its magnitude is 3·5, at minima 4·7. The period of light variation occupies 7 days 4 hours 14 minutes 4 seconds.

S *Cancri* (Æ. 8 h. 39 m., D. + 19° 24′) is likewise an Algol star, but with a variability observable only in good instruments. Within 9·485 days its brightness varies between 8 and 10 magnitudes.

ζ *Geminorum* (Æ. 6 h. 59 m., D. + 20° 43′) is also a double star. Its companion shines with a bluish light and is of 7 magnitude. The bright yellow principal is at times of maxima of 3·7 magnitude, and the period of its variation occupies 10 days 3 hours 43 minutes, during which time it falls to 4·5 magnitude. Both its duplicity and variability may be observed with a small telescope. The star η Geminorum is also a variable, and of 3·2 magnitude at its maximum. It belongs to the long-period variables, for its period occupies 231·4 days. At minima it may sink as low as 4·2 magnitude, but this is not always the case, for it sometimes declines to 3·7 magnitude only, slowly increasing again to its maximum brilliance.

β *Lyrae* (Æ. 18 h. 47 m., D. + 33° 15′) is when at its brightest of the 3·4 magnitude, but at minima only 4·5 magnitude, and has a period of 12 days 21 hours 51 minutes.

α *Cassiopeiae* (Æ. 0 h. 35 m., D. + 55° 59′) is a variable star with irregular period. Its brightness varies between the magnitudes 2·2 and 2·8.

α *Orionis* (*Betelgeuse*) (Æ. 5 h. 50 m., D. + 7° 23′). This bright star also shows irregularity in its variations in brilliance, the course of which variations is as yet very little known. Usually it shines as a reddish star of 1 magnitude, but declines occasionally to 1·4 magnitude. The period of its variations is also irregular.

R Leonis (Æ. 9 h. 43 m., D. + 11° 54′) shines in times of maxima as a 5·2 magnitude star, but declines at minima as low as 10 magnitude. Its variation period is 312·8 days.

χ *Cygni* (Æ. 19 h. 47 m., D. + 32° 40′) shows a period of 406 days. At maximum it is of 4·0, at minimum of 13·5 magnitudes. This constellation is, in addition to this, very rich in interesting variables. P *Cygni* (Æ. 20 h. 15 m., D. + 37° 43′) was observed by Jeanson Blaeu in 1600, and had in years following received the attention of many astronomers of old (Kepler, Cassini, Hevelius). Since 1665, when it sank to 5 magnitude, it has shown no further variation. Still more interesting is the variable Q *Cygni* (Æ. 21 h. 38 m., D. + 42° 20′) which was found, on November 24, 1876, by J. Schmidt, to be a 3 magnitude star of very noticeable reddish yellow colour, but since that time it has waned very rapidly, and is still waning, so that in the future even the most powerful instruments will have difficulty in finding it. At present it is of 15·7 magnitude.

β *Pegasi* (Æ. 22 h. 59 m., D. + 27° 32′) is a reddish yellow star, of which the light wanes from 2·2 to 2·7 magnitude in irregular periods.

R *Leporis* (Æ. 4 h. 55 m., D. − 14° 57′) is a notable variable, which Schmidt had recognised as such in 1855, after it had awakened the interest of astronomers a long time ago, on account of its intensely red colour. The variations of its light extend over a period of 436·1 days, during which the graduations in its brilliancy range from 6·0 to 9·5 magnitude.

R *Hydrae* (Æ. 13 h. 24 m., D. −22° 46′). The variability of this star was recognised by Maraldi in 1704. The period of this very red star to-day occupies about 338 days, while about thirty years ago it was 437 days, since when it has steadily decreased. The variations of its light lie between the 6·1 and 11·5 magnitudes.

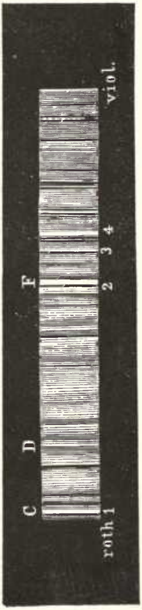

Fig. 40.—Spectrum of the temporary Star T Coronae Borealis.

Besides the variable stars, there are also stars that occasionally blaze out suddenly, and then fade again, without showing any recognisable period in these occurrences. They appear quite unexpectedly in the heavens, and either vanish again entirely in a comparatively short time, or else fade away to an extremely low degree of brightness. Such appearances have up to the present time been observed on not many more than thirty occasions. The very earliest phenomenon of this kind is known to us through the Chinese; and in 134 B.C., in the month of July, there appeared between the stars β and ρ Scorpii a star which caused Hipparchus to plan the formation of a star catalogue, whereby later astronomers might be in a position to prove whether new stars really appeared and existing ones vanished.

Another not less famous star was that which appeared in the year 1572, in Tycho's time, in the constellation of Cassiopeia, and caused a tremendous sensation. Its brilliance exceeded that of Jupiter, and was almost as great as that of Venus, so that it could be seen even in the daytime. When, however, its striking brightness began to diminish in December, it shone till March, 1573, as a first-magnitude star, but then faded slowly through all the magnitudes till in March, 1574, it was invisible to the naked eye. In star charts its place is still yet marked as B Cassiopeiae.

Kepler's star was discovered in Ophiuchus by Brunowski in October, 1604, as a star of the first magnitude. It was white, and shone brighter than Jupiter. After rapid changes in colour, it began in 1605 slowly to wane, and vanished about the end of March, 1606.

On June 26, 1670, Anthelm, a Carthusian friar, discovered a third magnitude star in Vulpecula, near β Cygni; the star vanished after five months, but appeared afresh in March, 1671, as a 4 magnitude star of very variable brilliance. At present it is of 6 magnitude, and is designated 11 Vulpeculae on the star maps.

On May 12, 1866, a new star of 5 or 6 magnitude was discovered by J. Birmingham and J. Schmidt, in the constellation Corona, and in a few hours it had risen to 2 magnitude, but by the beginning of July had decreased to a star of 9 to 10 magnitude.

Fig. 41.—The Andromeda Nebula with the new Star that appeared in August, 1885.

One of the most remarkable appearances was that which was visible in the Andromeda nebula from 1885 to 1886. In August, 1885, there flamed out in the centre of this nebula a new star of 6 magnitude, which thus stood just at the limit of visibility to the naked eye. By September it had already diminished to 8 magnitude, in the middle of October it had become 10 magnitude, in November 11 magnitude, in January, 1886, it was only 12 magnitude. It continued to fade during the ensuing months, and finally vanished entirely.

In January, 1892, a new star was discovered by Dr. T. D. Anderson, of Edinburgh, in the constellation of Auriga. When discovered it was of the 5 magnitude, but by the end of March it had diminished to 13 magnitude, and before its final extinction it was seen at the Lick Observatory as a minute star of the 14 magnitude.

Even to-day the astronomical world stands under the influence of that discovery, which was likewise made by the Scottish astronomer, Dr. Anderson, during the night of February 21 to 22, 1901, namely, the finding of *Nova Persei*, the new star in Perseus. At the time of its discovery it was of 2·7 magnitude, but increased till it outstripped in brightness the neighbouring star *Capella* (α Aurigae). Soon, however, it began to wane again, and on March 5th it once more equalled a star of barely 1 magnitude. The ruddy star faded and soon became telescopic; now it is scarcely visible in our most powerful telescopes. A phenomenon of quite exceptional interest was the nebula which later surrounded the star in numerous coils, and regarding which it has never been possible to establish whether this nebula showed a spiral formation, or was composed of separate rings with fainter portions, notwithstanding the fact that good photographic records of it were obtained.

This complicated mass of nebula seems to corroborate Professor Seeliger's hypothesis, according to which new stars are formed by cool or only faintly luminous suns coming in contact with extended cosmic nebulous masses of greater or less density, thus resembling the illumination of the shooting stars when they enter our atmosphere, inasmuch as the resultant friction gives rise to a new sun. It is clear that a sudden and enormous rise of temperature is the cause of the simultaneous blazing up of the star, and in the cases of these new stars we have to do with a celestial catastrophe which in all probability took place a thousand or more years ago, since the rays of light from it, which gave us the information, have been on their way towards us all that time.

Considering how rare an occurrence is the sudden appearance of a new star, it would therefore be an extremely thankless task for the amateur to proceed to hunt for such objects. Such a discovery is much more a matter of chance, and may be stated as so much the more likely to occur the more acquainted the observer is with the starry heavens. A newly formed star of the higher magnitudes disturbs the picture of the constellation impressed upon the memory, inasmuch as it appears very evident, and strikes the observer at once, if he is well acquainted with the constellations. In such a case we should immediately consult a good star map, and, if the star in question is not really indicated on it, we should give notice in the shortest and quickest way to the nearest observatory, giving accurate details of the place where the new star appeared, in order thus to assure for ourselves the priority of the discovery.

The observation of variables and temporary new stars is one of the chief points in the programme of the astrophysical observatories, which are equipped with all the necessary instruments for accurate measurement, such as Photometers, Spectroscopes, &c. As an example of such an institution may be taken the Observatory at Potsdam, or else the Observatory at Meudon, near Paris.

The measurements of the brightness of the stars are made with Astrophotometers, of which the Zöllner Polarising Astrophotometer is the most perfect instrument, for it allows the advantage of an absolute measurement. On account of its highly ingenious construction, it is possible with this instrument to form artificial stars of constant brightness, and to reflect them close beside the image of the actual star. By means of the revolution of two prisms and a plate of rock-crystal, the artificial star can be given the colour and brightness of the actual star. The brightness of the star then bears a known relation to the angle of revolution of the prisms.

The amateur in astronomy will, of course, scarcely be in a position to provide himself with perfect implements and instruments wherewith to observe the variable stars, but nevertheless he can obtain very fine and accurate results by employing the so-called method of relative comparison.

For example, should a variable be investigated for its light changes, then we should select for comparison a number of stars of which we know that they are subject to no fluctuations of light, and that they are, at the beginning of our observation, of equal or nearly equal brightness to the variable under investigation. These comparison stars, the brightness of which is known to us from the star catalogues, we should choose as far as is possible in the neighbourhood of our variable, in order to effect an easier comparison with respect to the differences in brightness. Now we have to make accurate and conscientious notes of the proportionate brightness of the variable at the time, to the comparison star selected by us, which can be most practically done by accurately noting when our variable star is equally bright to, or more or less bright than the comparison star. With regard to the waxing or waning of our star under observation, we should naturally select other brighter or less bright stars, as the case may be, as comparison stars. These comparative estimations of brightness must be continued over an adequate length of time, according as the variable star under observation is of long or short period. The more numerous the observations undertaken, and the greater the number of stars used for comparison purposes, the more accurate will be the results thus ascertained of the duration of the fluctuations, and therefore of the period and the light curve. In order to increase the accuracy of the results obtained, it is advisable to extend the observations over several periods.

It is now also clear why it was that, at the beginning, when learning the constellations, the value of a good training in the estimation of differences in the brightness of the stars was referred to. By long and continued practice at this subject, an attentive observer can gradually obtain such a training that his eye may become sensitive to such minute differences of brightness as, for example, 0·1 of a magnitude.

As a commencement, it will be of advantage for the amateur to make his investigations upon variables, the light fluctuations of which can be observed and followed with the naked eye, and then afterwards to go on to fainter objects that are telescopic only. Hand in hand with the estimations of brightness, when observing the variable stars, estimations of colour should also be made, for in many cases these latter exercise a very great control over the former.

Before leaving the fixed stars, and passing on to those bodies forming our own solar system, we shall learn so much concerning the colours and the physical constitution of the fixed stars as is indispensable to the observing amateur.

It has long been known that the colours of the stars are not in all cases permanent characteristics, but undoubtedly change within a longer or shorter interval of time. The first example of such a change of colour is shown by Sirius. The writers of former times unanimously refer to it as a red star. Seneca says of it that it was of a vivid red colour, much redder than Mars. Ptolemy also mentioned it as being a fiery red star, while to-day it is distinguished by its dazzling whiteness. Capella (α Aurigae) also was likewise included among the red stars by the olden writers, but to-day shows no ruddy tint.

The colours of the double stars particularly are liable to change, and often in very short spaces of time.

Zöllner has expressed the opinion that all the bodies known to us pass from the white to the redly glowing condition, and then finally to the non-luminous state; and that accordingly the fixed stars also, in the course of their evolution, change from the glowing gaseous to the glowing fluid condition, and eventually in the final stages develop a solid non-luminous crust, with which changes there is naturally connected a gradual diminution of light and a change of colour. For very many stars, especially for the already mentioned new stars, Zöllner's view has a high degree of probability, and has been confirmed by the investigations of spectrum analysis, so that it may be taken for granted. That other circumstances, however, must exercise an influence over the colours of the stars, is proved by the colour changes which have taken place in some cases in the opposite direction of the colour scale, from red to white, as was indicated in the cases of Sirius and Capella.

Our present knowledge of the physical and chemical conditions, which are really the causes of the colours and colour changes of the stars, is due to the researches of spectrum analysis.

Fraunhofer had already made the discovery that the spectra of the fixed stars bore a great resemblance to the spectrum of the sun, that

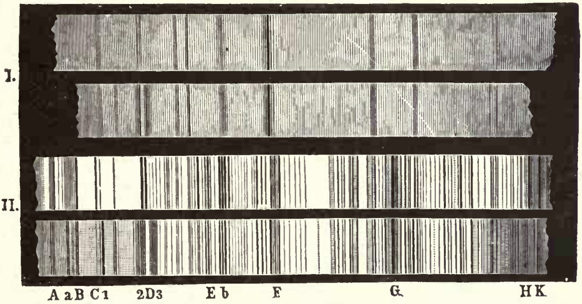

Fig. 42.—Spectrum of Sirius (I.).
Fig. 43.—Spectrum of the Sun (II.).

they were *continuous* spectra, crossed by dark lines. He also found that in the cases of some stars several of these lines coincided in their position and strength with certain lines in the sun's spectrum. Later, a number of distinguished investigators in this field, among whom may be mentioned Huggins and Miller (England), Janssen (France), H. C. Vogel (Germany), Secchi (Italy), succeeded in identifying these lines in the stellar spectra as being those belonging to substances known on our earth. One portion of the substances of our earth can be recognised also in the fixed stars, substances that they also have in common with our sun ; but there are other substances to be found on earth which as yet have not been found in the sun and stars.

For example, we find that a great portion of the elements present in our sun are also present in Aldebaran (α Tauri), but others, such as *Oxygen*, *Cadmium*, *Cobalt*, and *Barium*, though present in the sun, are not found in Aldebaran. On the other hand, Aldebaran shows the presence of substances such as *Mercury*, of which no trace can be found in our sun.

In Betelgeuse we meet with another peculiar phenomenon. All the elements which give indication of their presence in this star are found also in our sun, except that in Betelgeuse there can be found no *Hydrogen*, the element which plays so great a part in our sun, and in most of the heavenly bodies ; while on the other hand, *Thallium* in spite of its strong spectrum, cannot be established as present in our sun, but appears to be in such quantity in Betelgeuse that its absorption lines stand out quite plainly, in spite of the great distance of the star.

The spectrum of Sirius is distinguished by a large number of the Fraunhofer lines, which are uniformly spread throughout its whole length. Amongst these many fine lines, we find corresponding to elements known on our earth those of *Sodium*, *Magnesium*, *Hydrogen*, and *Iron*. An almost similar spectrum to that of Sirius is shown by Vega (α Lyrae).

Pollux (β Geminorum) or Arcturus (α Boötis) correspond less with the spectrum of our sun. Rather more do Deneb (α Cygni) and Procyon (α Canis Minoris). No spectrum, however, bears so much resemblance to that of our sun as does that of Capella, the brightest star in Auriga. This sun, therefore, bears a quite unusually similar chemical relationship to our own.

CHAPTER VIII

THE SUN

A SENSATION of grandeur and awe must come over us when we think of that heavenly body to which we owe our whole being. The sun is the giver of light and heat, and wherever in our solar system life is to be found, it exists only by the benefits conferred upon it by the sun. Owing to the preponderance of its mass it is able to hold fast the whole of the planets, and to compel them to revolve around it in unalterable orbits. It occupies, thanks to its size and mass, the most prominent place in our planetary system; it is the ruler, the "all-animating, pulsating heart," as Kepler termed it. Even the peoples of antiquity must have felt this, and reverenced it as the most worthy symbol of the Godhead, and even as the Godhead itself. To us earth-dwellers it is the regulator of our occupations, and in general of our time reckoning.

To the amateur, who, for any reason whatever, is prevented from making astronomical observations during the night-time, the continuous and systematic study of the sun and its surface will offer an occupation which will be both pleasing and instructive.

The light of our sun is so dazzling that it cannot be looked at with the naked eye, without serious inconvenience. We therefore employ coloured glasses, by which the violent intensity of the sunlight is so far mitigated that to look at the sun's disc is then quite bearable to the eye. Through such a coloured glass we see that the sun is by no means such a uniformly bright disc as was believed by people in olden times, who saw in it an image of spotless purity, but instead we see on its surface alternating bright and dark spots.

Still more will this become evident to us when we turn our telescope upon the sun. In doing so, we must, naturally, not forget to protect our eyes from the glare. Fittings for the purpose of observing the sun are generally supplied with all telescopes; they consist of coloured glasses, called "dark glasses," and are usually so arranged as to be fixed over the eyepiece, between that and the eye. So simple is their use and choice, that they should always be taken into consideration when procuring an instrument. With thin and light coloured glasses the eye gets quickly tired, while with thick and dark ones the observation of the fainter details on the sun's surface becomes more difficult.

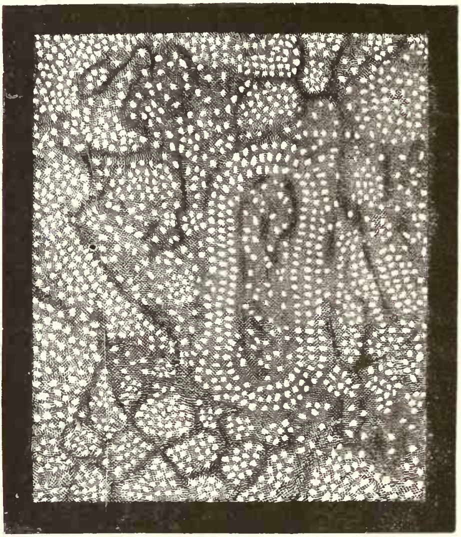

Fig. 44.—Surface of the Sun, showing granular structure (after W. Huggins).

Red coloured glasses are by far the most often used, but they transmit most of the heat rays. The best adapted for the purpose are dark yellow or dark green, and these have the additional advantage that they approach more closely to the actual colour of the sun's disc, and therefore make it appear whiter when observed through them than do the red glasses. The larger instruments are mostly fitted with the best and most modern appliances for this purpose, and the sun's light is toned down by polarisation, by using between the object-glass and eyepiece an arrangement consisting essentially of four dark plane mirrors.

In this case also the sun's image appears in its true colour, and the modification of the light can be regulated to the observer's liking.

With our eye thus protected, we see that the whole surface of the radiant sun is covered with innumerable light and dark densely crowded points, which often bear a resemblance to our cirrus and cirro-cumulus clouds. This fine marbled, or gravelly appearance we call the *granular structure* of the sun's surface.

Upon this very irregular ground we can often see larger or smaller black spots, which after a few days or weeks vanish; they are the so-called *sun-spots*. Such a spot may vary greatly in its area, and, though often very small, may frequently be many times greater in area than the whole earth. It consists essentially of a dark, almost black central nucleus, called the *umbra*, which is surrounded by a somewhat less dark edging, called the *penumbra*. The

Fig. 45.—Sun-spot. From a photograph taken at the Lick Observatory, August 8, 1893.

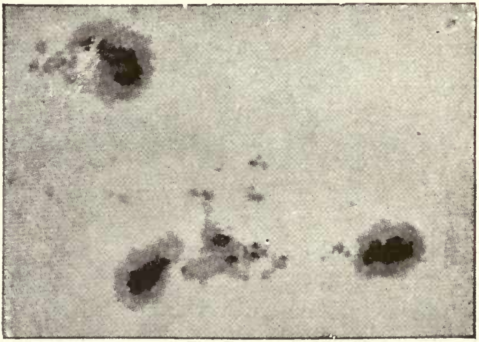

Fig. 46.—The Spot in Fig. 45 on August 31st.

dark umbra has usually an irregular, sometimes oval, sometimes torn and ragged form, while the penumbra surrounds it as a brighter ring, generally, but not always, showing a radial furrowing.

But the spot umbræ, which appear to us to be deep black, are in reality not so, and we are

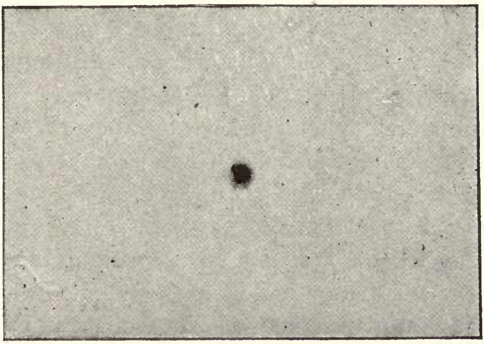

Fig. 47.—The Spot in Figs. 45 and 46 on September 27th.

best convinced of this when one of the interior planets, such as Mercury, passes across the sun's disc, and turns toward us its actually black unilluminated hemisphere. In comparison with the planet, even the darkest spot then appears of a deep greyish brown. This greyish brown or reddish brown colouring is also noticeable when the sun shines in a quiet air through so thick a mist that it can be observed without using a dark glass.

The penumbra has often, instead of a radial structure, a spiral one, which points to the rotatory movement of a vortex. Not uncommonly the penumbra traverses the umbra in several places. The umbra itself is also frequently crossed by one or more brightly shining bands, which have been named *bridges*. Often several spots stand very closely together, and thus form extended spot groups.

The amateur who makes the observation of the details of the solar surface his task, will do well to practise making drawings of the observed spots and spot groups. If we follow the course of a sun-spot for a considerable time, we shall see how it develops, assumes various forms, diminishes, and at last vanishes entirely.

These changes take place often in a surprisingly short time, only a few hours being needed in some cases; but on the other hand, we can observe spots lasting frequently for several weeks, without any substantial alteration in their form taking place. Generally the spots are seen appearing at the eastern limb of the sun in long, elliptical forms, and then slowly moving westwards. The closer they approach the central portions of the sun, the broader and more extended they appear, and when on the sun's central meridian they are often perfectly circular in form.

If we continue to follow the spot day by day, we shall be able to observe that it slowly advances towards the west, becoming narrower again, and when close to the sun's western limb it will again appear as a very elongated ellipse.

If we have taken note of the time when the spot appeared at the eastern limb, as well as that when it vanished at the western limb, we shall find that the spot has taken about thirteen and a half days to make the journey. Spots having a long duration appear again at the eastern edge thirteen and a half days after they have vanished at the western, and once again complete the same course across the visible hemisphere of the sun.

The perspective foreshortening which the spots exhibit, as soon as they approach the edges of the disc, offers the best proof of the spherical form of this mighty orb. From the movement of the spots we are thus in a position to deduce the rotation period of the sun—leaving out of account, of course, the proper motion of the spots. It really occupies not $13\frac{1}{2} + 13\frac{1}{2} = 27$ days, but only about 25 days 4 hours, and the rotation takes place in the same direction as it does in the case of the earth, namely, from west to east on the side turned away from us, and from east to west on the side turned to us.

The reason why the duration of the rotation does not occupy 27 days, as we have found from the observation of a spot, is explained by the fact that the earth, while we have been observing the spot, has advanced along its orbit. In order, therefore, that a point on the sun's disc should again occupy the same relative position to the earth, the sun must rotate a little further round, to make up for the distance the earth has in the meantime advanced, and to do so the sun takes about two days. That a sun-spot thus appears to us again only after 27½ days is analogous to the fact that the hands of a watch do not take up the same relative position after the lapse of an hour.

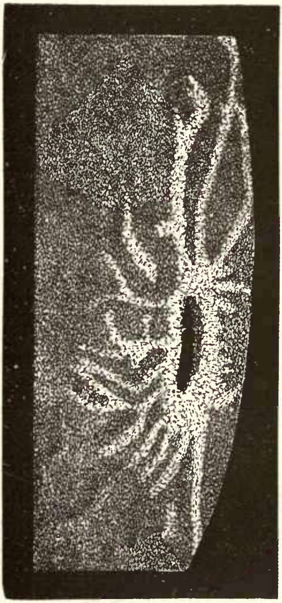

Fig. 48.—Sun-spot at the edge of the Sun's limb.

Even with a small telescope we can see that the form of the spots frequently changes during their growth and decline, and it often becomes difficult to recognise the same spot when it returns again to the eastern edge of the sun. In general we shall also find that spots which endure throughout a complete rotation of the sun are rare. But spots have been known which have lasted through several, sometimes even three or four, rotations of the sun.

The attentive observer who has been observing the sun for more than a year, will have noticed that the apparent path of the sun-spots throughout the course of a year is not the same. The sun-spot paths, which lie parallel to the sun's equator, have at different times of the year different directions. In March the paths of the spots are as elliptical as they can be. Later on the ellipses become narrower and narrower, till in the beginning of June the spots appear to cross the disc in perfectly straight lines. From June to September the curvature gradually appears again and increases, till in September the paths appear as elliptical as they did in March, but their position is reversed. Whereas the elliptical paths of the spots in March turned their convex sides to the north pole of the sun, in September they are convex towards the south pole. These long ellipses then change again slowly into straight lines, and in the first week of December the spots once again appear to cross the disc in straight lines. This apparent change of direction is the result of the varying position of the earth in its orbit, with reference to the plane of the sun's equator.

After some considerable study of the sun, it will not have escaped the notice of the amateur observer that also the distribution of the sun-spots over the surface of the disc is of a very peculiar kind. Very seldom do spots appear in the higher latitudes of the sun, that is between 50° and 70° north or south heliographic latitude. Nearer the poles no spot has ever been observed. They occur most frequently in two zones in the neighbourhood of the sun's equator between 10° and 30° north or south heliographic latitude.

The sun-spots are in general very frequent occurrences, but by no means are they always to be found. There often occur periods during which even the most attentive observer does not succeed in discovering a single spot; and again other periods when the sun is not free from spots for a single day. That these occurrences took place in regular succession was long suspected, but Schwabe was the first to discover the periodicity in 1826. On the basis of long-continued observations, we know to-day that the period of maximum sun-spot frequency occupies 11·1 years on an average. It may vary as much as 2·0 years from this number in either a positive or negative direction, thus occurring two years earlier or later. As a rule the spot maximum follows the preceding spot minimum after 4·5 years, while the minimum comes 6·5 years later than the maximum. The rise to the maximum is therefore more energetic than the decline to the minimum.

It appears, also, that these occurrences in the sun are not without influence upon the whole planetary system, and that this mighty autocrat of the planets exercises a decidedly perceptible effect upon them, even at their enormous distances. With the variations in the frequency of sun-spots, a similar variation in the frequency of auroræ, and the daily variation of the magnetic declination, seem to be intimately connected, since these two latter phenomena show the same periodicity; and the opinion is steadily and gradually gaining ground that the formation of a sun-spot simultaneously gives rise to a powerful magnetic disturbance which affects our earth. But the mystery which always surrounds the origin of these phenomena will not permit us to form any definite connection between them and the movements or the meteorology of our planet, although it is certain that some relation, particularly of the magnetic order, does exist towards these phenomena.

Fig. 49.—Sun-spot on August 15, 1894.

Unfortunately these relations are not yet sufficiently well known for us to be able to

Fig. 50.—The Sun-spot in Fig. 49 on August 17th.

predict, from the fact of the appearance of these huge spot groups, such happenings as volcanic outbreaks, earthquakes, cyclones, &c., though many have attempted to do so. Only a long series of carefully controlled observations will finally unriddle the nature of the astrophysical relations between the sun and the earth. Herein also the amateur, by the making of systematic and conscientious observations of the sun, can help considerably the professional astronomers.

The amateur astronomer who makes the

Fig. 51.—The Sun-spot in Fig. 49 on October 4th.

observation of the sun his task, must keep an accurate account of all appearances that he may see on the sun's surface. The number of the spots, and how many of them belong to a group, their type, and their extent, are especially the points of view from which the sun-spot observer has to make his notes. As already mentioned, the drawing of the observed spot on a previously prepared squared chart of the sun, with exact data of the time of observation, is highly recommendable. Such rationally conducted and continued observations of the sun's surface acquire so much higher a scientific value, the longer the space of time over which they are spread. Also the drawing of the spot

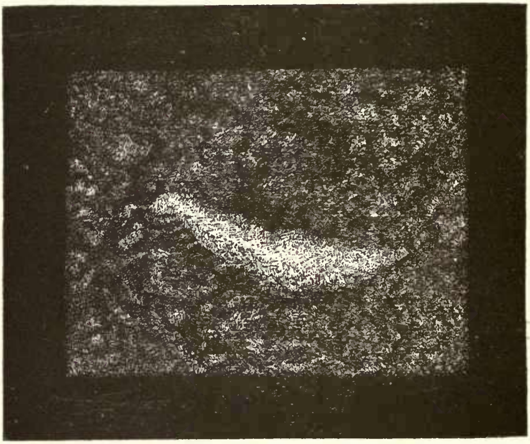

Fig. 52.—A Sun facula.

details, *i.e.*, the structure, penumbral edging, light-bridges, and surroundings, should be the task of every solar observer. In order to be able to correctly judge the changes in the character of a spot, it is advisable to make observations day by day, as far as the weather conditions will permit.

Yet one other appearance on the sun's disc should engage the attention of the observer at all times. Even the spotless portions of the sun's surface are by no means equally bright, but show on their mottled surfaces here and there places of greater brilliance than the surrounding parts; these are the *faculæ*. They are situated frequently in the neighbourhood of large spots or spot groups. A facula standing alone can, as a rule, be regarded as the precursor of a sun-spot forming at that place. In faculæ, also, rapid and violent changes take place, the constant observation of which should not be omitted.

Of the larger sun-spots of recent times, which specially attracted the attention of observers, the following will now be mentioned shortly. A large sun-spot showed itself on February 17, 1894, at the edge of the sun, and even at the beginning exhibited quite unusual dimensions. Unfavourable weather interfered with observations to begin with, but at last on February 20th a sudden clearing of the sky made it possible to continue observations. The spot then had an almost round form, a crater-like appearance, and the penumbra covered a great part of it. The development of this huge spot reached, on February 23rd, its maximum. Near the central point there united a number of brilliantly gleaming tongues and bands of light, yet in less than an hour substantial changes took place in its form, indicating movements of huge magnitude and of astonishing velocity.

Another spot also appeared on August 18, 1905, which presented a much sub-divided

Fig. 53.—The great Sun-spot of January, 1897.

appearance, and caused quite a sensation when seen through the telescope. In August, 1907, the sun exhibited unusually vigorous activity. On August 27th there appeared at the eastern edge of the sun's disc an enormous group of spots, situated very close to the sun's equator. This group passed the central meridian between the 3rd and 4th of September, and towards the 9th disappeared at the western edge. This group consisted of three main spots, two being close together towards the west, and one larger one towards the east, the three large spots being surrounded by quite a swarm of smaller ones. The total extent of the group was estimated

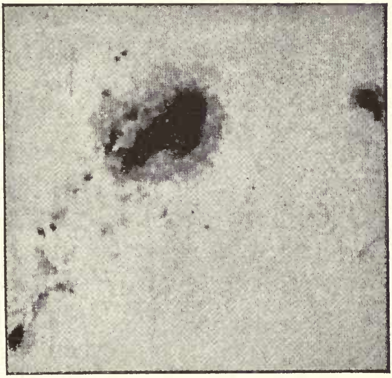

Fig. 54.—The great Sun-spot of January, 1897.

to be on the whole almost an eighth part of the diameter of the solar disc, which means that its extent was equal to about thirteen times the length of our earth's diameter. On account of these gigantic proportions, it was easily possible to see the vast group with a pair of opera-glasses, before the eyepieces of which a piece of darkened or smoked glass had been placed.

Regarding the nature of these sun-spots, and of the physical constitution of the sun, the most diverse opinions used to be held in the earliest times, and we shall revert to this subject at the close of this chapter. In the case of the sun, the conditions of observation are exactly the reverse of those attending the observation of all the other phenomena of the starry heavens, for these latter hide their last secrets in night and darkness. But that majestic ball of light renders itself unapproachable to the searching eye, because of its overwhelming brightness. But the immediate surroundings of the sun, which are invisible to us on account of its dazzling rays, are of the highest interest. The possibility of seeing it, and of more closely investigating it, is given to us when our earthly satellite cuts off the direct sunlight, or as we say, during a *total eclipse of the sun.* Then only is the background of the sky dark enough near the sun to throw into relief those softly luminous phenomena that offer such an interesting study to the observer of the sun.

Those lovers of nature, and particularly those of astronomy, who have the time at their disposal—even though it be but a short holiday—and who can also afford it, should never omit seeing that magnificent spectacle which is presented by a total eclipse of the sun. In such an eclipse the observer sees the moon advancing from the west, or right-hand side, across the solar disc. The eclipse proceeds gradually, till the last trace of the narrow crescent of the sun vanishes on the eastern side; that is the beginning of the total phase of the eclipse. Then

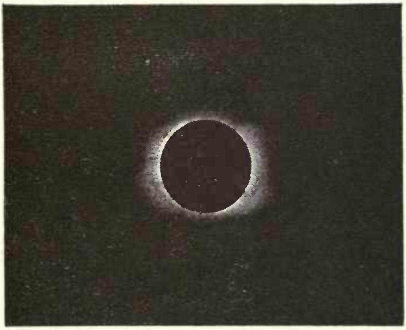

Fig. 55.—Total Eclipse of the Sun on January 1, 1889.

(Photographed by E. E. Barnard with a $3\frac{1}{2}$-inch Telescope. Enlargement from the original.)

soon a narrow crescent of the sun becomes visible on the western side, and marks the end of the total phase. Between these two times lie the few precious minutes, on account of which all the nations send out costly expeditions—if necessary, into the remotest parts of the earth—and on account of which the investigators willingly make the greatest efforts and endure many hardships. Only a very few

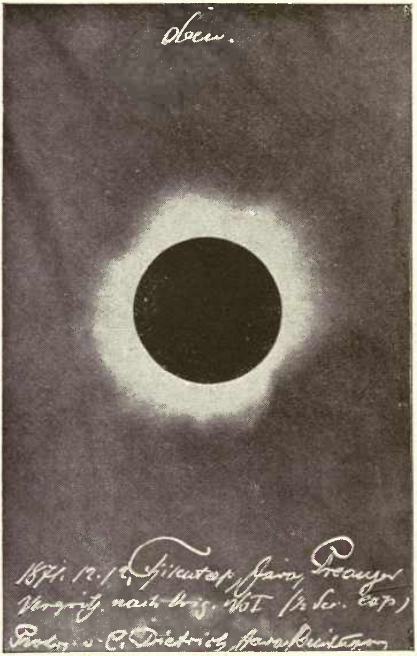

Fig. 56.—Photograph of the Total Solar Eclipse on December 12, 1871.

minutes—in favourable cases from three to five, in the most favourable about eight—are given to the observer to obtain all the hoped-for information, and one single cloud may render fruitless all the trouble and all the cost.

One phenomenon of especial magnificence,

Fig. 57.—Eruption in the Sun on July 11, 1892 (427,000 kilometres, or 265,000 miles high).

which has a powerful effect upon the mind of the most prosaic observer, is that halo of silvery white light surrounding the darkened body of the sun, and known as the *Corona*. In ordinary telescopes this has a milky and nebulous appearance.

It was always an extremely difficult task to represent its form correctly, for the duration of totality is usually far too short to obtain the contours accurately, and we should not have advanced so far with the investigation of the physical constitution of this brilliant phenomenon, if it had not been that celestial photography had assisted us over these difficulties. In the corona we can see, as it were, the extreme limits of the sun's atmosphere. The form of this shining halo is by no means circular, but rather angular, and besides, very irregular.

The direction of the individual streamers is also not exactly straight, but variously curved, and, moreover they are not radially directed away from the sun. Their extent is not the same at all points round the edge of the sun; they appear most strongly in the neighbourhood of the sun's equator. Spectrum analysis has taught us that the corona also partakes of the sun's rotation. In the spectrum of the corona there appears a bright line of a green colour, which belongs to no chemical element up to the present discovered on the earth, but which must presumably be an extremely light gas, and to which the name "Coronium" has been given.

Another very interesting appearance during total eclipses of the sun, which gives us so true an insight into the violent storm-like agitations

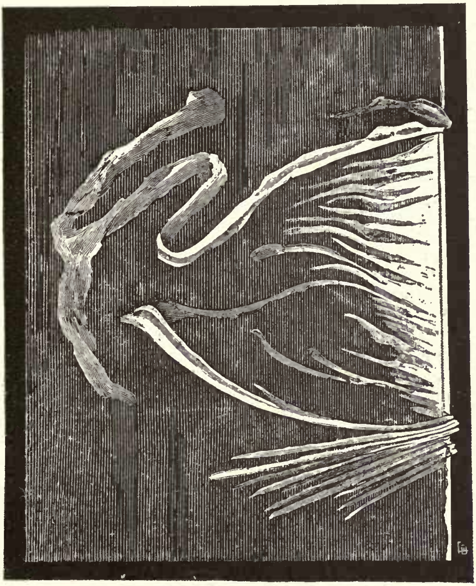

Fig. 58.—Eruption in the Sun on July 5, 1892.

which take place on the sun's surface and in its various layers, are those gigantic pillars of flame which are projected upwards to such astonishing heights above the edge of the sun, the so-called *prominences*. As a rule they do not stand isolated, but tower in connected groups over the edge of the sun. In instruments of low power, and even with the naked eye, these little ruddy prominences may be seen. These forms are liable to incredibly rapid changes. They may often be seen to suddenly and unexpectedly blaze up above the edge of the sun, and soon fall back again into the sun, where hydrogen, helium, and the gaseous metals, according to their density, mix with the various layers of the sun's atmosphere.

According to their form, Secchi, the famous observer of the sun, divided them into four groups:—

1. *Cloud-like*, or "*Cumulus*" protuberances. They are vague, cloud-like forms and elevations of the chromosphere, of quite a local nature, and seldom rise higher than 21,000 miles, remaining mostly below 16,000 miles. Such cloud-like protuberances appear most frequently in the regions of the faculæ, and their position on the edge of the sun may be approximately predicted for any coming total eclipse, if beforehand the arrangement and positions of the faculæ on the sun's surface are studied.

2. *Stratiform* protuberances. These are the most frequently met with, but are less brilliant, and their height varies between 53,000 and 80,000 miles. They have the appearance of a

stratiform cloud, sometimes connected with the chromosphere by their pillar-like stems.

3. *Ray-like* protuberances are unquestionably the most imposing, and also the most interesting appearances of their kind. In this type the violent eruption and the direction in which it is projected can easily be seen. At the base they have generally a narrow filamentous

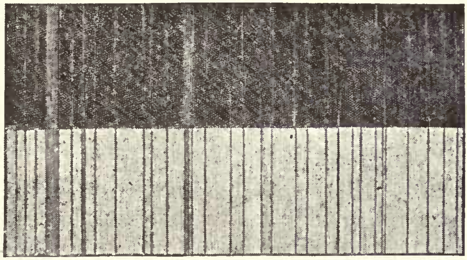

Fig. 59.—Young's observation of the Spectrum of Protuberances.

structure. The separate filaments shine so strongly with the brightest light, that their number may easily be ascertained. They become gradually broader at the upper part, assuming a cloud-like form, and afford the spectacle of a sheaf of fire of fascinating beauty, the separate parts of which fall back again in parabolic paths like rockets, and dissolve amidst a mass of incandescent vapours. The changes which take place in these prominences are so violent, that even after a few minutes their form may be completely altered.

4. *Wisp-like* protuberances, which are very similar to the previous type, but differ from them in being much less brilliant. They appear at much greater heights, are of larger extent, and are distinguished by greater permanence and longer duration. At their upper edges they often assume a cloud-like form.

Since the spectrum of the prominences shows particularly bright hydrogen lines, we must conclude that, being the chief constituent of the prominences, these latter must consist of hydrogen, the lightest of all gases, in an incandescent state, which naturally occupies the uppermost layers of the sun's surface.

The red colour of the prominences is to be attributed to the very bright C-line in the red part of the spectrum, and it is on this account that the outermost layer of the solar atmosphere, to which the prominences belong, has been named the *chromosphere.*

Many other bright lines of incandescent metallic vapours also enter into this spectrum; for example, those of Sodium, Calcium, Barium, Manganese, Magnesium, Iron, Titanium, and Nickel. In addition, there appears also that bright green line, of which mention has been already made in the corona.

Unfortunately, the opportunity of being a witness of a total eclipse of the sun and all its wonderful phenomena is very unlikely to come to the amateur astronomer. Whoever cares to take the trouble to look through the almanac, will find that total eclipses of the sun occur more frequently than do total eclipses of the moon, and yet, though almost every one of us has seen a total eclipse of the moon, we have very seldom or never at all had a sight of a total eclipse of the sun. The reason for this lies in the fact that, in a total eclipse of the moon, the sunlight is actually cut off from the moon by the earth, and the moon is therefore seen darkened wherever it is above the horizon—that is to say, over a whole hemisphere; and if we take into consideration that the duration of totality is more than an hour, the rotation of the earth will render it visible to rather more than half the earth. It will thus be possible for every inhabitant of the earth to be in a position to see, on an average, one-half of all the total eclipses of the moon that may take place during his lifetime. It is quite otherwise with the total eclipses of the sun, for here only one part of the earth's surface is robbed of light.

Since the umbral shadow of the moon is only about 140 miles broad in equatorial regions, and in polar latitudes about 930 miles broad, the zone of totality, even though the line of the eclipse may be thousands of miles in length, covers still only a very small portion of the earth's surface.

As it may be of interest to the amateur to know what total eclipses of the sun are expected to happen within the next few years, the time and place of the most important will here be stated.

In May, 1910, a total eclipse of the sun will take place, visible in the south polar regions, the observation of which will be all the more interesting, because at the time of totality there will be an opportunity of observing Halley's comet in the darkened sky near the sun, as it is now on its way to perihelion, which it is expected to reach on the 20th of April, 1910. The duration of the total phase, as seen from the southern end of Tasmania, where probably the greater number of the expeditions will set up their observing stations, will last about four minutes. Unfortunately, at the time of total eclipse the sun will be no higher than 10° above the horizon—a somewhat unfavourable circumstance.

The total eclipse of the sun on April 28, 1911, will take place under more favourable conditions. It will be visible in the Polynesian

Islands, and will be best seen from Norfolk Island, between New Caledonia and New Zealand. The expeditions equipped for its observation may also be stationed on Tonga Island. In Neiasu (longitude 173° 59′ W., latitude 18° 39′ S.) the total phase commences at 9 h. 37 m. local mean time, and will last for 3 minutes 37 seconds. The sun's altitude at the time will be 43°.

Of those total solar eclipses visible in Europe, the first to occur will be in the year 1912. It is, moreover, an annular eclipse, and will be total only for a very short part of its course. In Portugal the duration of the total phase will be only three seconds, and therefore any one could scarcely be seriously advised to journey thither for such a glimpse.

The following one takes place in August, 1914, and may be seen for the maximum duration of 2·4 minutes, along a line running over Scandinavia, the Gulf of Riga, and the Black Sea, into Persia. In Norway the eclipse will be able to be observed shortly after midday at a good altitude.

There will then be an interval till June 29, 1927, when the moon's shadow will traverse the whole length of England and Scandinavia. At Stonyhurst, totality will last for 20 seconds.

In Austria the first visible total solar eclipse will occur in the year 1961, and will be seen as total for 2·5 minutes at Pola.

In Central Europe, the total eclipse of the sun on August 11, 1999, will be visible at Vienna and other places as a total phase of 2·6 minutes' duration.

The phenomenon of a total eclipse of the sun, with all its attendant appearances, is so grand, and fills the mind with so rare a charm, that it becomes difficult to describe it in words. Those lovers of the heavens who can possibly find an opportunity of ever undertaking a journey into the zone of totality of an eclipse, will, if the weather be favourable, gladly forget all the labour and trouble accompanying a distant journey, and once they are back home again will never repent the trouble they have taken, and will never cease to speak of the deep impression made upon them by what they have seen. Here the amateur has the advantage over the professional, for he can allow the whole charm of the phenomenon to act upon him, while the professional has to occupy himself with one or other separate detail of the phenomenon. Many an astronomer, who has co-operated as a scientific observer at an eclipse of the sun, has given expression to the inward wish that he would like to be present at an eclipse, if only for once, as an ordinary spectator.

Even the prelude to this grand spectacle of nature powerfully affects the observer. Merrily the birds are fluttering amid the branches, and singing their joyous songs, but all imperceptibly, little by little, a slight but ever darkening veil spreads over the landscape, and it almost looks as if the evening twilight were coming on. Restlessly the birds now fly hither and thither, astonished and frightened at the premature ending of the day, their singing ceases, and timidly they fly to their nests in the trees.

Once the moon's disc has reached the centre of the sun, the light rapidly wanes; but when totality approaches, and when only a narrow and ever-narrowing crescent of the sun remains left, which we can easily look at now with the naked eye, then the fading of the light becomes positively alarming. Trees and bushes turn grey, the whole of nature changes colour, the yellowish green bordered heaven appears of a dark leaden grey hue, our complexion becomes ashy pale, the temperature falls and we begin to shiver. We see now only one last sharp ray of light, and suddenly it also vanishes.

At this moment the darkened orb of day suddenly appears surrounded by a halo of silvery light, from which long rays shoot out in all directions. Round the edge of the disc we see those little, bright, flesh-coloured forms of varying size and shape, the prominences. As if to glorify the event, the planets next the sun, Mercury and Venus, together with the brighter fixed stars, become visible—an exquisite, impressive spectacle, like a sign of the Creator's omnipotence. Then all at once, at the right side a ray of light bursts forth, all the glorious sights around the sun pale and vanish, and we recall the words of the Bible, "Let there be light." Like the rushing, foaming water of a gigantic waterfall, flows once more that mighty flood of brilliant light for which our hearts in secret yearned, and we breathe a deep relief. Everything rejoices at the return of daylight, and gradually the sun resumes its former brilliance, and life goes on in its old way.

If we cast a glance over the foregoing, to recapitulate all that we know with certainty regarding the physical constitution of our central orb, the results found are somewhat as follows :—

Beginning at the outside, we have first the corona, which may be composed of several layers, the lowest being a very bright, uniform ring of light of incandescent coronium and hydrogen gas, as the uppermost layer of the solar atmosphere. Next to this follows the chromosphere, also consisting of incandescent hydrogen, and this is the seat of the prominences. Deeper down in this chromosphere, we also find the incandescent vapours of various metals, such as iron and magnesium. Still further inwards the metallic vapours increase, and by their absorption of the sun's rays give rise to the dark lines in the solar spectrum. Beneath this layer is the photosphere, which for us is really the visible limit of the sun's nucleus, and therefore it is also the layer from which we derive light and heat. It surrounds the actual nucleus of the sun, into which neither telescope nor spectroscope can penetrate.

As regards the physical nature of the sun-spots, we shall shortly discuss the theories of two distinguished authorities. The famous physicist Kirchhoff, who has rendered so much service by his investigation of the solar spectrum, holds the sun-spots to be clouds which have formed in the solar atmosphere on account of local falls of temperature. They cut off the rays of heat proceeding outwards, and therefore cool those layers situated above them. These inwardly growing clouds become still colder, their temperature falls beneath the point of incandescence, they thereupon become opaque, and manifest themselves as the umbræ of sun-spots. Larger, but less dense clouds, lying above these umbræ in a stratiform manner, appear to us then as the surrounding penumbræ.

Zöllner holds the sun-spots to be the scoriform products of cooling, floating upon the incandescent fluid surface of the sun, which theory on the whole is only a modification of the previously mentioned one.

As the sun stands in the closest relation to our earth, it may be asked whether it will for all time continue to supply us with light and heat and other benefits, or whether its store of energy will become exhausted—an important consideration for us earth-dwellers. But all sources of energy, which already exist as heat, or may become heat at some future time, will not last for ever. Though millions of years may pass before any noticeable change takes place in the condition of the sun, yet the inexorable laws of mechanics show that one day these stores of energy must become exhausted. Our sun will no more eternally shine, than it has eternally shone; it has at one time sent forth its *first* rays, and will at some future time send forth its *last*.

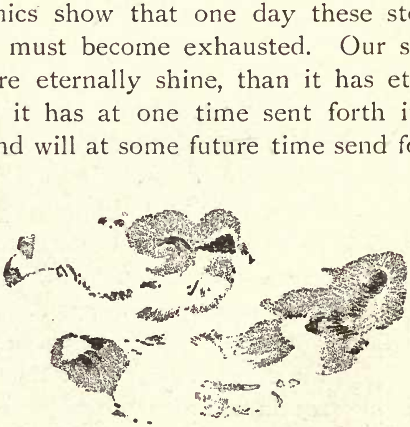

Fig. 60.—Sun-spot on May 14, 1894.

CHAPTER IX

THE MOON

THE nearest of all heavenly bodies, and the faithful companion of our earth, with which it is bound up in so many relations—the moon—offers both professional and amateur a wide field of observational work. While the fixed stars appear to our naked eye as mere points of light, star clusters as more or less vague nebulosities, and while the bright rays of the sun are far too strong for our delicate organ of sight, the moon shines with such an agreeably soft light, that we can easily see quite plainly the light and dark markings on its surface. The feeling, also, that with the moon's distance we have no more to reckon in millions upon millions of miles, but that we have only to do with thousands, positively demands our undertaking a searching study of this, comparatively speaking, close body.

Its size, its mass compared with the earth and other heavenly bodies, the form and position of its orbit, the nature of its motion round the earth, and its period of revolution will not here be discussed, as they are already generally well known. Those amateurs who, for the first time, are beginning to grapple with the celestial phenomena, are referred to the numerous works on popular astronomy for these particulars, regarding which complete and clear information may, at any time, be had therefrom.

We know that the rotation of our moon on its axis takes place in such a manner that it always turns towards us one and the same side of its surface, which is, however, not always fully illuminated (Full Moon), but, according to the relative position of the earth to that half of the lunar globe lit up by the sun, passes through all phases of illumination down to total invisibility of the disc (New Moon).

Since, therefore, the moon always presents to us one and the same side of its globe, we shall be able to become acquainted with only one half of it. But the attentive observer can hardly escape noticing, after studying the moon for a long period of time, that sometimes at the eastern edge of its disc, and sometimes at the western, there appear objects that he had not previously seen. In a similar manner both the north and south poles show us a little more of the surface at times. These facts, which we have to thank for thus being able to see more than half of the moon's surface, are called the *librations* of the moon.

As a matter of fact, the moon rotates at a uniform rate round its axis, but as it moves more rapidly in its orbit round the earth at perigee than it does at apogee, it thus allows us to see, sometimes to the right, sometimes to the left, small portions of its hinder surface. This change of front, the *libration in longitude*, amounts to 7° 53′ on either side, so that in the first case we are able to see 7° 53′ westward, and in the second case 7° 53′ eastward upon the side of the moon's surface turned away from us: we see thus about one-twelfth of the reverse side of the moon. As the axis of rotation of the moon is not always perpendicular to the plane of its orbit, this allows us to see sometimes beyond the north pole, and sometimes beyond the south pole of the moon; and the maximum variation amounting to 6° 47′, we see 6° 47′ further into the reverse side of the moon, alternately at the north polar regions and the south polar regions, in intervals of about fourteen days. The amount of the reverse side rendered visible to us by this *libration in latitude* amounts to about three-twentieths.

In addition to both the aforementioned librations, we can also observe a third, the so-called *diurnal libration*. This is caused by the fact that the earth's diameter is by no means a vanishing quantity compared with the distance of the moon. Those observers living at different places on the earth's surface do not, therefore, see the same point as centre of the lunar disc. This libration varies in the course of the day, and attains a maximum amount of 1° 2′. The collective effect of all these librations is such that we can see round four-sevenths of the lunar surface, while three-sevenths remain for ever concealed from our sight.

On account of the librations, objects on the moon at different times appear to us under different angles of view, and their form is, to some extent, altered thereby. The amateur making lunar topography his study, will find it important to clearly understand this by attentive observation, in order not to mistake these apparent changes for actual ones—if such take place at all.

As a matter of course, the effect of libration is not to our eyes the same upon all parts of the lunar surface. It makes itself least noticeable in the neighbourhood of the edges of the disc, for the observer sees these parts of the surface always obliquely and therefore foreshortened. Those parts of the hemisphere turned away from us, which are brought into view only by means of the libration, can really

Fig. 61.—First Quarter of the Moon.

(Photograph by Loewy and Puiseux, of the National Observatory, Paris, on March 14, 1894, at 6 h. 33 m. 57 s. sidereal time. After a copy by L. Weinek.)

never be observed under favourable conditions.

The very first glance directed at the moon through a telescope at once shows the observer that those bright and dark spots, which he saw with the naked eye, are, in reality, mountains and valleys. Upon that side of the moon lying opposite to the sun, the mountains throw very sharp shadows, which are so much the longer as the mountain is higher, and as the sun is closer to the horizon of the lunar locality which is being observed. At the terminator, where the illuminated portion of the moon is separated from the unilluminated one, are situated all those places where the sun is just rising or setting, and it is here also that the shadows cast by the mountain summits or the crater walls are at their longest. The higher the sun rises for any locality on the moon, the shorter become the shadows, and at the time of full moon they are generally imperceptible.

From what has been said, it is evident that for the observer of the moon the time of full moon is not at all favourable for observations. He would be far better to wait, if he wishes to observe and draw the various objects and details, for that time when the object in question is situated exactly on, or close to the edge of the illuminated portion, that is to say, on the terminator. It is only here, close on the boundary of light, that the conditions are favourable to the mapping of topographic details, and the amateur can, even with a small telescope, make out the little hills, mountains, and craters, and draw them in correct proportions. For each lunar landscape this favour-opportunity occurs twice during a lunar day—that is to say, twice in 29½ earthly days, namely, once when the sun is just rising on this landscape, which occurs at the waxing of the moon, and once when the sun is just setting, at the waning of the moon.

In order to obtain a correct idea of the true form of a lunar landscape, it is necessary to observe and draw it, both at sunrise and at sunset (as seen from the moon). But for the regions at the eastern edge of the moon, this will be possible only if the observing amateur is able to make use of the early morning hours, when the waning crescent of the moon is in the sky, for his observations.

In a moderately powerful telescope it can be seen that the line of the terminator is not uniformly straight, but appears indented and sinuous, on account of the elevations and depressions of the lunar surface. But also in those regions still dark, but close to the terminator, the observer will find many isolated, brightly shining points, which look like little islands. These are nothing but the summits of mountains lit up by the rising sun, before the sun's rays are able to reach the foot of the mountains. It will also not be a difficult matter for the zealous lunar observer, fairly well acquainted with the lunar surface, to tell the names of those mountains, upon the summits of which the rising sun is just striking.

All the various lunar markings, elevations, and depressions have in the course of time received names, and we are able to say that our knowledge of the topographical character of the lunar regions is much further advanced than that of many parts of our own earth. The amateur astronomer must by degrees familiarise himself with the individual objects and their names. This can best be done by the aid of a good map of the moon. To begin with, the lunar maps on a small scale, such as are found in almost all popular astronomy books, will suffice. Still better is the series of maps already referred to in Ball's "Popular Guide to the Heavens." Those observers who have occupied themselves with the moon for some considerable time, should not neglect to procure a large work on selenography. The work that appeared in 1874, by Nasmyth and Carpenter, entitled, "The Moon Considered as a Planet, a World, and a Satellite," was compiled as the result of thirty years' labour in drawings. One of the most comprehensive works on selenography is Neison's "The Moon and the Condition and Configurations of its Surface," which appeared in 1876, an atlas of twenty-two sections, a general map of the full moon, five special maps in colour, and three in line. Graphically these maps are certainly behind the others, but the detail is decidedly greater. The text, to be sure, is not popular, like that of the aforementioned work, but written for the professional; yet the amateur, who has studied the lunar surface for some time, should soon manage to understand it. Among the more recent works in lunar cartography is the map produced under the direction of C. Flammarion, of about 25 inches diameter, which, on account of the short shadows, furnishes a very good representation, and is especially adapted as a guide map to the uninitiated.

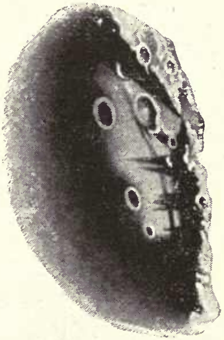

Fig. 62.—Mare Crisium.

The most perfect possible representation that could be had in the drawing of lunar objects has been produced by the director of the Prague observatory, Dr. Ladislaus Weinek, one of the foremost selenographers of the present time. His "Photographic Atlas of the Moon," consisting of two hundred plates drawn to a scale of a 10 feet lunar diameter, from the focal negatives of the Lick Observatory, surpasses entirely everything that could be demanded of such a work. Also the "Atlas of the Moon" of J. N. Krieger, the former proprietor and eminent observer of the Pia Observatory in Trieste, has met with universal approval, on account of its masterly delineation of lunar objects.[1]

The character of the moon's surface is excessively mountainous and jagged. The large grey areas, which can be seen with the naked eye, show a relatively smooth, even surface, and were formerly believed to be seas, and accordingly received the name of *Mare*.

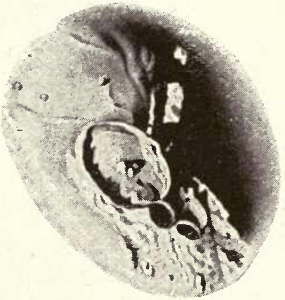
Fig. 63.—Gassendi.

Though we have long known that cavities containing water cannot exist upon the moon, yet this designation has been retained. With

[1] The illustrations of this section dealing with the moon are, with the exception of Figs. 76, 77, 78, and 82, reproduced after the masterly drawings of Professor L. Weinek, Director of the Imperial Observatory in Prague.

more powerful instruments it can, moreover, be seen that these surfaces are also often very irregularly formed. Only two of these "seas" appear to be completely bounded in themselves; they are the Mare Crisium (the Sea of Crises) in the north-west quadrant, and the Mare Humorum (the Sea of Humours) in the south-east quadrant of the moon. The other maria are only partially bounded, and stand connected with each other exactly like the oceans on our earth. They also often extend into the brighter neighbouring landscape, and form gulfs, which have been termed *Sinus*. Smaller and rather brighter surfaces, resembling the "seas" also, bear the names *Lacus* and *Palus*. The large maria, showing themselves of a greyish tint, occupy a considerable portion of the lunar surface. The most important is the Oceanus Procellarum (Ocean of Tempests) in the east.

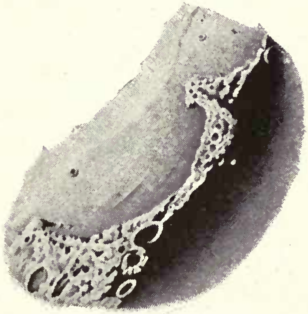

Fig. 64.—Sinus Iridum.

In the north-east extends the great Mare Imbrium (Sea of Rains); in the north-west quadrant besides the Mare Crisium, towards the centre of the lunar disc is the Mare Vaporum (Sea of Vapours), and adjoining it are the Mare Tranquillitatis (Sea of Tranquillity) and the Mare Serenitatis (Sea of Serenity). In the south-west quadrant lie the Mare Fœcunditatis (Sea of Fecundity) and the Mare Nectaris (Sea of Nectar). In the south-east lie the Mare Nubium (Sea of Clouds) and Mare Humorum (Sea of Humours). Near the north pole lies the Mare Frigoris (Sea of Cold), much elongated laterally.

Smaller basins are the Palus Putredinis (to the north of the Apennines), Lacus Somniorum (north of Posidonius), and Lacus Mortis (near Hercules). The larger gulfs of the seas are the Sinus Roris (of the Oceanus Procellarum), the Sinus Iridum (of the Mare Imbrium), the Sinus Medii (in the centre of the lunar disc), the Sinus Aestuum, and others. Mention should also be made of the Palus Nebularum, between the Mare Serenitatis and the Mare Imbrium, and of the Palus Somnii near the Mare Crisium.

The other brighter portions of the moon's surface, the elevations of the ground, show very varied forms. They may be divided into two essentially different classes—the *crater formations* and the *mountains.* The circular form is characteristic of them all, and the ring form is specially predominant. Neison divided the crater formations into nine classes and the mountain formations into twelve, but many of the subdivisions are not sharply separated from one another. We shall here follow the classification of the selenographer A. Schmidt, regarding the mountain formations.

Fig. 65.—South-west portion of the Mare Crisium.

1. *Walled plains.* These have a diameter of from 45 to 170 miles, and are surrounded by an irregular, often interrupted, wall or boundary. The interior is frequently divided into two parts by mountain spurs, but is, as a rule, comparatively flat, or occupied by a few irregular mountains. Terrace-formed gradations within the ring are either imperfect or quite absent. Most of the walled plains are situated on the southern hemisphere of the moon, and the observer may often find here several of these close together in a row. With the walled plains are naturally connected the mountain rings, which may be regarded as ruined members of the former class.

2. *Transitional forms* was the name given by Schmidt to those colossal structures having the central plain so much depressed that they closely approach the crater form, but nevertheless resemble the walled plains in the great irregularity and ruined condition of their mountain ramparts.

To the transitional form belongs, for instance, *Clavius*, near the southern edge of the moon, in

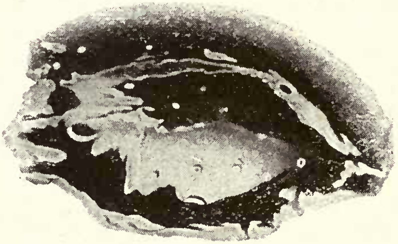

Fig. 65.—Schickard.

13° east longitude and 58° south latitude. (These lunar co-ordinates will be written thus: long. 13° E., lat. − 58°.)

3. *Large Craters.* These are the ramparts which have a smaller diameter than the walled plains and are characterised by their ring-formed walls. They usually enclose a deep hollow, in the centre of which stands not unfrequently a high, steep mountain, the central cone, which in most cases shows only one

summit, but occasionally may have several. It never, however, attains the height of the surrounding rampart. These craters have often a diameter of between 50 and 60 miles, and have in very few cases been disturbed by later crater formations, but show an intact form throughout. The inner slope of the wall descends frequently in terraces, of which there may be from two to five, and this slope is much steeper than the outer one, and often much deeper as well, so that the elevation of the wall above the inner surface is two or three times as great as it is over the outer surroundings. The great craters, or ring mountains as they are sometimes called, are specially distinguished by the fact that the upper edge of the rampart wall is extraordinarily bright, and from it bright rays, many isolated, but for the most part belonging to a regular system of rays, diverge radially. The largest of these systems of rays is possessed by *Tycho* (long. 12° E., lat. −43°). It is so evident that at the time of full moon almost one-fourth of the visible lunar disc is traversed by it, and it can even be seen by a sharp, unaided eye. This mighty crater is almost 60 miles in diameter. Around Tycho lie a large number of formations, part of which are irregular structures, and part also walled plains. In addition, an enormous number of crater-like depressions and crater cavities may be seen in this neighbourhood by the observer.

On account of the huge number of objects surrounding Tycho, it may often be troublesome for the observer to find it, as he cannot, so to speak, see the wood for the trees, and may seek for the crater for some time, especially in the case of the moon having a phase illumination. According to Schmidt, the relative altitude — for only a *relative* height can be spoken of on a waterless moon—of the crater walls is, in the case of the south-west wall inside, 13,800 feet, the west wall 14,800 feet, the north-west wall 19,100 feet, and the north-east wall 16,100 feet. To the east of Tycho the ground is so broken that a mean level at that part cannot be obtained.

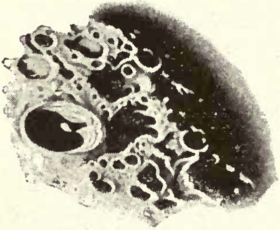

Fig. 67.—Tycho.

Copernicus (long. 20° E., lat. + 8°) is perhaps the finest and grandest crater, and measures about 60 miles in diameter. The not quite circular walls are crowned by numerous bright peaks, which under good illumination conditions appear like a sparkling diadem on the dark background. On the inner side the walls fall in steep terraces, but outside it is not so steep. The wall reaches its greatest height in the west; it amounts there to 14,800 feet. Inside the ring the observer can easily distinguish several central cones, of which the most easterly and the most westerly are of about equal height, some 2,030 feet. Their summits lie therefore over 5,080 feet below the mean level of the lunar surface, and about 12,600 feet below the summit of the west wall. In Copernicus also the bright ray system is very striking. The bright streaks appear even broader and more distinct than in the case of Tycho.

Theophilus (long. 26° W., lat. – 12°) is a large ringed plain of over 60 miles diameter, which appears to be of later formation than the two large walled plains of *Cyrillus* and *Catharina* which immediately adjoin it. The western wall of Theophilus towers up to a height of over 18,000 feet, the eastern to 15,100 feet. In the inner chasm lies a large, bright, central peak, the summit of which is 6,100 feet above the central surface.

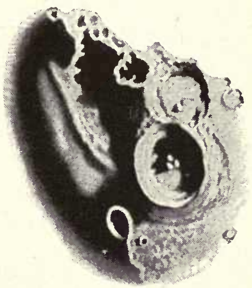

Fig. 68.—Theophilus.

Southwards from the wall a well-marked ridge runs across the Mare Nectaris to the little ringed plain *Beaumont.* The little ringed plain west of Theophilus is the elevation known by the name of *Mädler.* Both the walled plains *Cyrillus* and *Catharina* belong to the most distinctive formations of this order. The very irregular walls rise to terrific heights. The number of small craters in this region is extraordinarily great, especially towards the east, while the Mare Nectaris shows the observer very few details of this type.

Archimedes (long. 5° E., lat. + 30°). One of the most beautifully regular ring mountains on the moon. The diameter is about fifty miles. A many-terraced wall, out of which individual considerable peaks rise, surrounds an unusually level interior surface. Towards the south a rugged mountain mass adjoins it, from which rise likewise considerable peaks. On the eastern side may be seen little twin craters, which bear the name of *Beer*, and which have an exceedingly great internal depth. The two large ringed plains westward of Archimedes, *Autolycus* (southerly) and *Aristillus* (northerly)

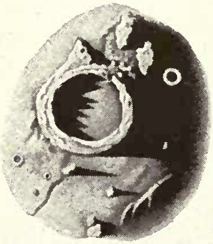

Fig. 69.—Archimedes.

have on the inner plains central peaks of great height. From their walls stretch in all directions numerous chains of hills and mountain ridges. These fine ringed mountains, on account of their condition, belong to the finest on the whole lunar surface.

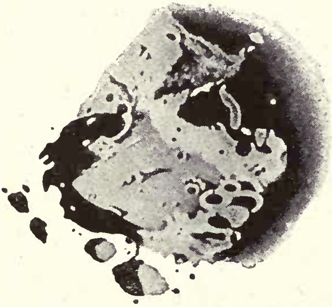

Fig. 70.—Maginus.

Aristoteles and *Eudoxus* (long. 17° W., lat. + 50°, and long. 16° W., lat. + 43°). Two huge ring mountains of 60 and 50 miles diameter respectively. The surface surrounding them is strewn with small craters, crater hollows, and radiating chains of hills. The crater of Aristoteles is at all parts almost uniformly bright, and therefore at full moon, in spite of its great circumference, it is a very difficult object to observe. The peculiar ringed plain of rhomboidal form eastward of Aristoteles bears the name *Egede*. Eudoxus, the more southerly of the two, is a most interesting object for the lunar observer. Its walls are not so unusually low and narrow as those of Aristoteles, which are on these grounds observable only at about 15° to 20° from the terminator.

Yet another magnificent line of great craters may be cited in this group. We shall mention the fine ring mountains of *Anaxagoras* (long. 15° E., lat. + 67°) and *Kepler* (long. 37° E., lat. + 8°).

4. *Medium-sized Craters.* These have many characteristics of the foregoing group. Their diameter amounts to between 20 and 30 miles. They depart very rarely from the circular form, and exhibit on the inner side steep terraced slopes. If a central peak is present, this usually shows only a single summit. The walls of these much less extensive ring mountains also show very brilliantly. A few objects belonging to this group have already been mentioned in connection with the larger objects in the foregoing. Many others in addition belong thereto, which the diligent lunar observer may recognise by the aid of the map, such as *Aristarchus* (long. 45° E., lat. + 23°) on the northern boundary of the Oceanus Procellarum, and *Herodotus* (long. 49° E., lat. + 24°), a little to the east of Aristarchus.

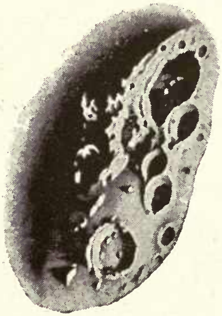

Fig. 71.—Colombo, Magelhaens.

5. *Smaller Craters.* The number of smaller

and very small craters on the visible hemisphere of the moon is simply enormous. They are to be found in all regions without exception, as well on the plains as in the mountain regions. They even are to be found situated on the edges of the highest ring mountains. A well-known astronomical writer says of them: "They appear in hundreds and thousands, breaking through all the other formations of the lunar surface, transforming this into a downright sieve. In the maria, their little cones run in rows like warts, which under a high sun appear as tiny, unimportant points of light; they appear like knobs on the great ring walls, they break out on the slopes, and open themselves even on the summits of the high central peaks." They have mostly a diameter of half a mile to a mile, or even less. The already mentioned ring mountains Eudoxus and Aristoteles are examples of the accumulation of this lunar feature.

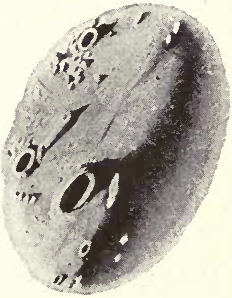

Fig. 72.—Harpalus and Foucault.

6. *Rills*. By close observation of the moon's surface through a telescope of medium power, we can scarcely fail to see those peculiar

Fig. 73.—Guttemberg.

furrows, clefts, and fissures which show themselves very distinctly in many regions. They run across walled plains and craters, ramifying and intersecting each other repeatedly. To-day over a thousand of these formations are known, and their number is steadily increasing through new discoveries. Their length often runs up to 300 miles, and their breadth up to $2\frac{1}{2}$ miles, while in some cases they are over 1,300 feet deep. The finest examples of this type are:—

The Rill System of Triesnecker (long. 4° W., lat. + 4°). Under the oblique rays of the sun they present a marvellous appearance. In this system the ramification and intersection of the various rills stand out very plainly. Two

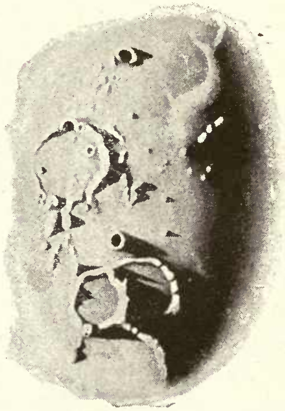

Fig. 74.—Guerikė and Parry.

pairs of rills run parallel for some considerable distance.

The Rill of Hyginus (long. 5° W., lat. + 8°) is a very easily visible rill, which pursues its course through ten small craters as well as through Hyginus itself. The rill traverses Hyginus by breaking through its wall, and continuing its course across the inner floor.

Fig. 75.—Schiller and Bayer.

Later on we shall refer again to this region of the moon.

The Rills of Hippalus (long. 30° E., lat. − 28°), which are strongly curved, and run parallel to one another.

The Rill in Petavius (long. 58° W., lat. − 26°) is also a fine typical object of this class.

The Rills near Fra Mauro, Parry and Bonpland (long. 16° E., lat. − 8°) are almost parallel ravines which have broken through the three combined walls of the three ringed mountains.

Many more of these rills lie strewn in all possible regions of the moon, and the amateur can easily identify them by means of the lunar map.

With this group should also be included those other objects of the lunar surface, which

Fig. 76.—South-east end of the Apennines, with Eratosthenes.

are visible only on account of their great power of light reflection, and which are neither elevations nor depressions of the surface. They appear as narrow, bright streaks, lying on the level of the plains like veins of light.

7. *Mountain Masses and Chains.* These have

undoubtedly the greatest similarity to our earthly mountains of all the lunar formations. They are mountain masses, grouped rather irregularly, and occupying a comparatively small area of the moon's surface. Long-extended ridges, lateral valleys, and crests are,

Fig. 77.—Plato.

by way of contrast to terrestrial mountain formations, entirely lacking. But we do often see hundreds of miles of continuous mountain sides and declivities, which certainly remind us to some extent of the terrestrial mountain chains. They have also been given the names of earthly mountains.

The most important are :—

The Apennines (long. 0°, lat. + 20°), 18,000 feet in height, at the southern border of the Mare Imbrium. Near them lie the craters of *Hadley*, *Bradley*, *Huygens*, and *Eratosthenes.*

The Caucasus (long. 6° W., lat. + 40°), 18,300

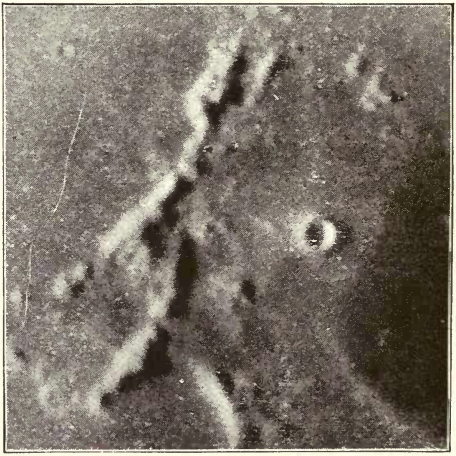

Fig. 78.—Riphaean Mountains and Euclides.

feet high, on the north-east border of the Mare Serenitatis. Close at hand lies the crater *Linné*, of which more hereafter, and *Calippus.*

The Alps (long. 10° E., lat. + 45°), 11,900 high, on the north-west border of the Mare Imbrium. At the eastern end of these mountains rises the great walled plain of *Plato*, the outer slope of which descends in many terraces. In the interior are several small crater cavities, which are among the smallest of objects, and can be seen only with the more powerful instruments.

Fig. 79.—Philolaus.

The Carpathians (long. 20° E., lat. + 15°), 6,400 feet in height, to the west of the Oceanus Procellarum. On the eastern slope of this rugged and torn mountain mass rises the fine crater *Mayer*.

The Hæmus (long. 15° W., lat. + 17°), 6,900 feet, between the Mare Vaporum and the Mare Serenitatis. Close by stands the ring mountain *Menelaus*.

The Hercynian Mountains (long. 73° E., lat. + 25°), 3,800 feet, close to the eastern limb of the moon.

The Pyrenees (long. 42° W., lat. – 13°), 11,900 feet, stretch in a southerly direction along the western edge of the Mare Nectaris. Between this range and the moon's limb rises *Vendelinus*. At the southern edge of the Pyrenees stands the crater *Fracastorius*.

The Cordilleras (long. 86° E., lat. – 15°), a small range on the extreme eastern limb.

The Altai Mountains (long. 24° W., lat. – 25°), 13,300 feet, with the crater *Zagut* to the north.

The Taurus Mountains (long. 33° W., lat. + 24°), 9,000 feet in height, between the Mare Serenitatis and the Mare Crisium.

The Riphæan Mountains (long. 27° E., lat. – 8°), a small and short range. To the north lies the crater *Landsberg*, to the west *Parry*. With regard to the heights mentioned here, it must be noted that they can make no particular claim to exactitude, for reasons that can be easily understood. They are given relatively to the height above the level of the immediate neighbourhood, since a uniformly level surface, such as the surface of the sea is to the earth, is not to be had on the moon. The highest mountain on the visible surface is *Curtius*, near the south pole, of about 29,000 feet, just about the same height as the highest elevations on the earth.

Upon the geological conditions of the moon different opinions are held.

Mädler sought to trace all the various formations to a volcanic source. The selenographers Nasmyth and Carpenter also explained the formations by volcanic activity, and this may be accepted as fairly certain in most cases, especially those of the central cones. But in the case of the ring mountains and walled plains, this assumption does not hold good. Celestial photography has herein also been of great service, and has furnished a suitable basis for the geological study of the lunar surface.

Fig. 80.—Vendelinus.

The question as to whether the great upheavals, which formerly took place on the lunar surface, have already reached an end, and whether the moon has by this time become an entirely cooled body, upon which no changes of form whatever can any longer take place, is not yet definitely decided. Both in earlier and more recent times we have had definite information of some changes

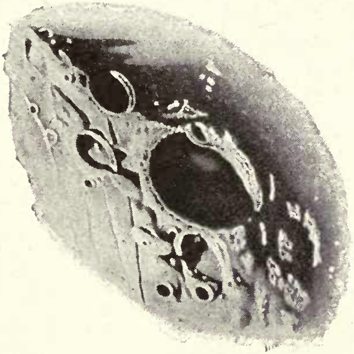

Fig. 81.– Mersenius.

which had just occurred in some particular detail of the moon, and it appears that these phenomena are not, as is often maintained, only illusions due to variable illumination, but that, on the contrary, a certain amount of reality cannot be denied.

Fig. 82.—Posidonius.

One of the earliest observations of this kind was made by Schröter in the great crater of *Posidonius* (long. 29° W., lat. + 32°). The second case relates to the crater *Linné* (long. 10° E., lat. + 30°), which was accurately figured and described by Lohrmann and Mädler, and was seen in the same form by Schmidt in 1840. In the year 1866 the last named could no longer find it, and at the present time even with the most powerful instruments, only a low hill beside a shallow depression can be seen.

A third example of physical change is offered by *Messier* (long. 50° W., lat. – 2°). This ring mountain, which, together with another crater close beside it, lie quite isolated in the Mare Fœcunditatis, was in earlier times of the same form and size as the neighbouring crater. To-day this equality no longer exists. The one crater is now not only distinctly larger, but also of quite different form, and situated in another place. Further discoveries of this kind are due to the lunar investigations of Klein. In one case it concerns the formation of a new rill system in the vicinity of the crater *Ramsden* (long. 26° E., lat. – 36°), in others, new rills and craters near *Aristarchus*. But the most important discovery of this investigator is that of the new object which he found near *Hyginus*, and which neither the earlier nor the later observers seem to have seen. This crater, designated by "N," close to the north-west of *Hyginus*, may be seen with a 2-inch telescope, and it is hardly probable that an object so evidently visible should have escaped the notice of former observers.

The amateur astronomer who takes up the observation of lunar details can, as we see, by the making of accurate drawings and sketches, aid the professional in many respects. The possible field of observation on the lunar surface is so wide, and contains so many interesting details, that a whole lifetime is scarcely sufficient to enable one to make observations on every part of the moon's surface, and even the longest experienced investigator of the moon will scarcely find himself in any difficulty as to which detail he will next make the object of his observation.

Before we part from this heavenly body, which brightens our nights with its soft and pleasing light, it will be necessary to discuss a few other phenomena of an astronomical nature, which are due to this faithful companion of our earth. The first is the phenomena of the lunar eclipse, which, as is well known, is caused by the moon, at the time of full moon, passing through the cone of shadow thrown by the earth. If in such a case the whole disc of the moon is darkened, then we have the phenomenon of a *total* eclipse, but if only a part of the disc is darkened, then we have a *partial* eclipse. Since the moon as well as the earth's shadow move from right to left across the heavens, that is from west to east, and since the earth's shadow is slower in its movement than is the moon, it follows that the moon meets the shadow, and thus in a total eclipse the darkening commences at the eastern limb of the moon, and totality ends there also.

An eclipse of the moon offers the astronomer far less interest than is afforded by an eclipse of the sun, yet these phenomena should by no means be allowed to pass without observation. As a rule, it is the moment of the moon's entry into and emersion from the shadow that is the chief object of the observation.

In addition, we observe the entry and the emersion of the various lunar mountains, as well as the extent of penetration of the shadow into the moon's disc. The times of these observations cannot, however, be given with the same exactitude as is the case with the solar eclipses, since the earth's shadow shows no sharp contour but is undecided, and, therefore, is prejudicial to the exactness of the observation. Since the eclipse of the moon can be observed in every place where the moon is at the time above the horizon, these eclipses were formerly used for ascertaining the geographical longitude of the different places of observation. Accurate determinations of longitude cannot, however, be made in this way, on account of the want of sharpness in the earth's shadow.

The colour phenomena during lunar eclipses are worthy of attention. As a rule the darkened portion of the moon shows itself of a grey colour, with a ruddy gleam, which colouring becomes deeper the further the moon advances into the shadow. In the centre of the shadow the moon appears almost entirely unilluminated. In general, however, the eclipsed lunar disc does not vanish entirely from the heavens, and even the most superficial observer cannot fail to see it. Often the naked eye can make out the usual spotted detail on the moon in spite of a total eclipse. In contrast thereto stand the eclipses of the years 1642, 1764, 1816, and in recent times that of April 11, 1903, wherein total in-visibility of the eclipsed moon existed from entry till emersion.

Another phenomenon, upon which the observer will gladly bestow his attention, are the so called *Star Occultations*. On its apparent course through the heavens it naturally frequently happens that the moon passes over sometimes brighter, sometimes fainter, fixed stars, and thus deprives us of their sparkling light. Here also the moon meets the star in question with its eastern edge and leaves it at the western limb, the star emerging sometimes more northerly and sometimes more southerly. Especially favourable are the observations of these phenomena at the dark limb of the moon, because at the illuminated limb the moonlight is very disturbing. The disappearances can thus be well observed at the time of waxing

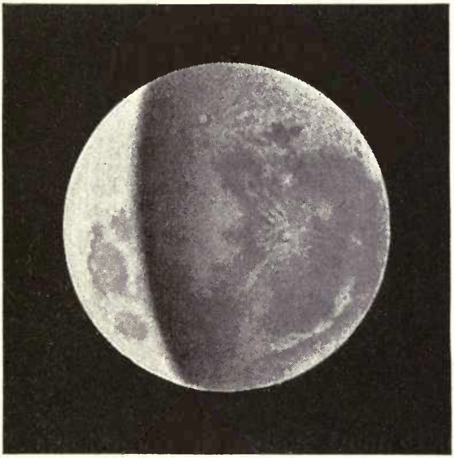

Fig. 83.—Eclipse of the Moon on January 28, 1888.
(After a water-colour drawing by Prof. L. Weinek.)

moon, and the reappearances at the time of waning moon. The astronomical year books, almanacs, and periodicals usually give the brighter fixed stars which will in the course of a year be occulted by the moon. The exact times of these occurrences, as well as the place and magnitude of the star, and the places of disappearance and reappearance according to the position angle of the moon, are accurately given.

The amateur is in a position, on account of occasional phenomena of this kind, and knowing the geographical position of his place of obser-

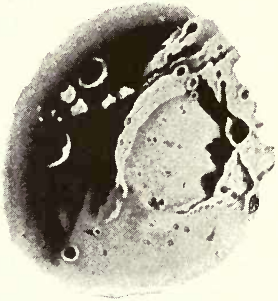

Fig. 84.—Fracastorius.

vation, to most accurately control his clocks and chronometers thereby. Since the moonlight at the time of full moon is very intense, the occultations of stars of the 4 and 5 magnitude will be very difficult to observe. Stars of the higher magnitudes, such as 1 and 2, can often be observed with the naked eye or with a very small telescope. Of those stars which may be occulted by the moon, on account of the position of its path in the heavens, the following chief ones may be mentioned :—

Aldebaran, the *Pleiades*, *Regulus*, *Spica*, and *Antares*.

The disappearance of the star behind the lunar disc takes place rapidly and suddenly, without any gradual decrease of light, and just as suddenly it appears at its emersion at the other limb. This is a proof that our moon is not, like our earth, surrounded by an atmosphere, at least by nothing worthy of the name, because the presence of such an atmosphere would reveal itself by the refraction of the light rays, and therefore by a gradual decrease and increase of light at disappearance and reappearance of a star.

CHAPTER X

THE PLANETS

ON the very night when we for the first time directed our observant gaze towards the heavens we saw one, or even several stars, which were equally as brilliant as the brightest fixed stars, or even considerably surpassed them, but which were not indicated on our star map. If we focus our telescope upon these objects, it will immediately become clear to us that we have not here to do with those brilliantly sparkling points of light, the fixed stars, but instead we plainly see, according to the power of our telescope, a more or less large body, of disc form, shining with a steady light.

These heavenly bodies, situated at great distances from us, but no longer at such immense and incomprehensible distances as the fixed stars, are *members of our solar system*, which, like our earth, revolve round the mighty central body. That they carry out a movement we can easily see, if we continue observing these heavenly bodies for some time. For example, let us note the apparent place of such a body, which can best be done by making a note of its position among the stars of that particular constellation in which it is situated, then usually after some short time we shall be able to prove that it has advanced or receded some distance among the stars marked on the map. But that this path is one directed round the sun will not at once become evident to us from continued observation. Quite otherwise! Their apparent paths in the heavens are by no means so uniform and even as we may perhaps have thought to begin with. We notice that the planet we are observing moves now faster, now more slowly, among the fixed stars, at times perhaps appears stationary, and often actually moves in a direction opposite to that in which it first moved. In the cases of some planets we can also observe that, in changing its motion from one apparent direction to another, the planet does not advance along the same path as formerly, but that the later path intersects the earlier one at some point. Loops are thus formed in the planet's apparent path, near the place where the planet appeared to be stationary.

The astronomers of ancient times, who would not give up their ideas of the uniform and even motion of the heavenly bodies, could not explain the peculiarities just mentioned in a simple manner. That was also the reason why the actual knowledge of the true structure of the solar system remained veiled in darkness down to the time of Copernicus. Since this time, however, we know that not the earth, but the sun is the centre of our planetary system, and that while we are observing the positions and paths of these planets, our earth itself is also advancing perpetually in its orbit, whereby the irregular and complicated apparent paths of these planets are simply explained.

Of all the eight large planets that we know, there are only two—*Mercury* and *Venus*—which stand closer to the sun than does our earth, and execute their movements round the sun in smaller orbits than the earth's. They are called *interior planets.* The orbits of the others—*Mars*, *Jupiter*, *Saturn*, *Uranus*, and *Neptune*, lie outside that of the earth, and they are therefore termed *exterior planets.*

Certain positions taken up by the planets with regard to the earth and the sun have been designated by special technical terms. For example, if a planet happens to lie in one straight line with the earth and the sun, so that the earth is between the planet and the sun, then the planet is said to be in *opposition* to the sun, but if the sun and the planet are both on the same side of the earth, then the planet is said to be in *conjunction* with the sun. It is evident that the interior planets, Mercury and Venus, can never be in opposition, because the earth, being further off from the sun than they are, can never lie between either of these planets and the sun. On the other hand, in the case of these two planets, we can distinguish two kinds of conjunctions—one an *inferior conjunction* when the planet is between the sun and the earth, and another a *superior conjunction*, when the planet is on the other side of the sun. Other positions also have special terms. Thus, when in the triangle sun—earth—planet, the angle at the sun is a right angle, then the planet is said to be in quadrature.

It is easily explicable that many amateur astronomers will turn themselves to the study of the surfaces of the planets, since there lies within us all the desire to know how all these heavenly bodies are constituted, and whether they show any similarity in physical constitution to our earth. It should also be mentioned, however, that the observation of the planets, so far as relates to their superficial details, is rather difficult. Apart from the fact that for a successful study the amateur must have a superior instrument at his disposal, long schooling and practice will be necessary before scientific value can be imparted to such observations. The observer must first learn to see and know how to distinguish between the actual and the merely apparent. It frequently occurs that even professionals can only with great difficulty free themselves from the influence of imagination in such observations. The individuality of each observer also plays a great part, especially when what is seen has to be rendered in a drawing, and it is often hardly credible how very diverse may be the conceptions of even practised observers regarding certain delicate details that stand just on the verge of visibility. So much the more, then, is the amateur astronomer advised, when studying the surface details of any planet, to be very strict with himself, and at all times to call himself to account over what he has seen.

To search for a planet, the place of which in the heavens is for the moment unknown to the observer, can be done by looking up its apparent place in an astronomical almanac. This contains the positions of all the planets for each day, or interval of days, in the co-ordinates of right ascension and declination; and all that is necessary is to find this given place on the star-map or planisphere, and then the planet may easily be found in the starry heavens. It occasionally happens, of course, that a planet is not in the evening sky, but in the daylight sky, or sets immediately after the sun, when it is naturally impossible to observe it for the brilliant rays of the sun.

Those planets which, when they are visible at all, do not rise long before, nor set long after the sun, are the interior planets, Mercury and Venus, with which we shall begin the discussion of the planetary members of our solar system.

Mercury.

Mercury is the smallest of all the great planets, and stands closest of all to the sun. It is, therefore, very difficult to observe, and appears, when visible at all, low down on the horizon in the rays of the rising or setting sun. In the best cases it can be seen setting about two hours after sunset and rising about two hours before sunrise. When visible, it is easily seen on account of its brilliant white light. Through the telescope we see very little of its condition, but can easily make out that it shows light phases like the moon, because it turns sometimes its illuminated and sometimes its dark side towards our earth. From his observations of some markings on its surface—which, however, are extremely difficult to see, and require powerful instruments and the very best air conditions—the well known Italian astronomer Schiaparelli has found that Mercury makes one rotation on its axis in the course of one revolution round the sun, and thus re-

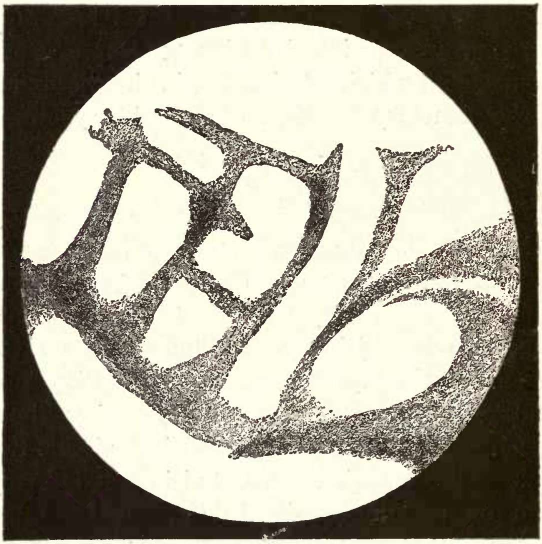

Fig. 85.—Markings on Mercury.
(After G. Schiaparelli.)

sembles the moon in its course round our earth. The spectrum of Mercury, with the exception of a few absorption lines, resembles that of the sun, from which it receives its light just as the earth does. We have to thank spectrum analysis that we know to-day that this planet possesses a fairly dense atmosphere, like the earth. Also, the markings, so uncertain in details and difficult of observation, are manifestly of atmospheric origin.

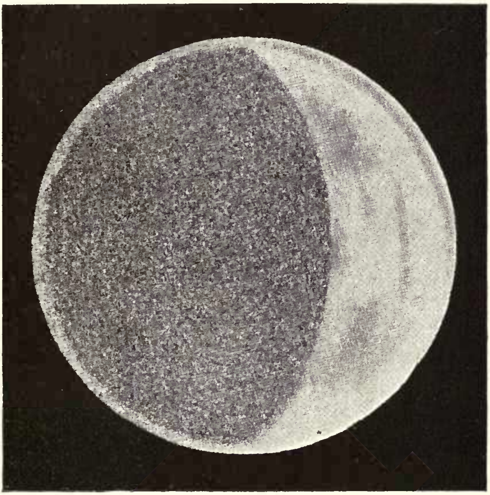

Fig. 86.—Ashen light of the disc of Venus.

Other phenomena which Mercury shows us from time to time are the so-called transits, the observations of which are of no small interest to the amateur. Such a transit, when the planet passes across the sun's disc, takes place thirteen times in a century, and occurs either in May or November.

The amateur astronomer will know from time to time, by reference to the almanacs or year books, at what time such a transit will occur, and these books also give the position on the sun's edge where first and last contact is to be expected. The mean duration of such a passage across the sun's disc amounts to five hours. Mercury appears, when projected upon the sun's disc, of a deep black colour, and can therefore be easily distinguished from sun-spots. From various perturbations in the movements of this planet, Leverrier thought they indicated the existence of a small planet between Mercury and the sun. The most recent investigations regarding such an intra-Mercurial planet, namely, the photography of the sun at the times of total eclipse, have demonstrated that such a planet most probably does not exist.

Venus.

Venus is certainly the best known of all the planets, for it surpasses them all in brilliance. Its dazzling white light is often so intense that small objects upon which it shines on moonless nights cast quite a distinct shadow. Like Mercury, Venus is always near the sun, and likewise exhibits phases. In "first quarter" or "last quarter" it appears to us in the most favourable phase, and its light is then at times so bright that the crescent form may be visible

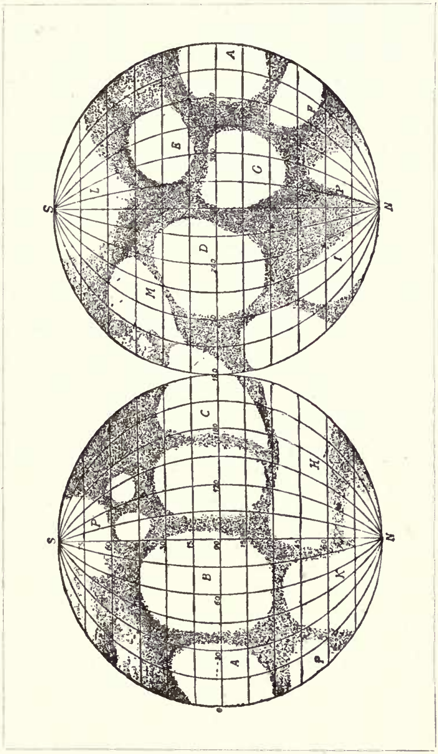

Fig. 87.—Map of the planet Venus.
(After Niesten and Steywaert.)

even to the naked eye. This is especially the case if Venus is at its farthest from the sun, when the earth is at its nearest thereto, which takes place approximately every eight years, whereby the two planets are as close as possible to each other.

By telescopic observation the amateur will soon find out that he cannot expose his eye to its radiant brilliance for very long, and it is advisable to lessen the intensity of the light somewhat. The line of separation of the illuminated and unilluminated parts of the phase, or the *terminator* as it is called, is not so sharp as in the case of the moon, but more hazy and vague, which gives evidence of a dense atmosphere, and this is borne out by spectrum analysis.

The observation of the surface of this planet also is one of the most difficult tasks. Certain conditions of illumination, the nature of which is yet unknown to us, give rise to optical illusions on the dark side of this planet, which are scarcely to be distinguished from actual appearances, and are often enough wrongly interpreted. The difficulties attending the observation of the surface of Venus, which are especially caused by the great difficulty of distinguishing atmospheric appearances from actual surface markings, are also the reason why a dispute arose about the period of this planet's rotation, and continued for years, because some decided in favour of a long period, while others maintained a short period, similar to the earth's. Only in recent times have the observations of Leo Brenner, the director of the Manora Observatory in Lussinpiccolo, who made them under unusually favourable conditions of air, shown that the rotation period of this planet does not differ greatly from 24 hours; and this has more recently been confirmed by the spectroscopic investigations of A. Belopolsky at the Pulkowa Observatory.

Since the orbit of Venus, being that of an interior planet, lies within that of the earth, then this planet, just the same as Mercury, must transit across the sun from time to time. These transits are of very great importance to astronomers, for they give us the most certain and accurate means of determining the distance of the sun from the earth, and therefore the measuring scale for all distances in the planetary system, and generally for the whole of space. Unfortunately these phenomena are very rare, for they occur twice only in every century. The next transits of Venus will take place on June 8, 2004, June 6, 2012, December 11, 2117, and December 8, 2125.

In earlier times several observers thought they had found a satellite to Venus. All these observations were merely illusions of some kind, because in recent times, in spite of the high perfection of optical means, no further trace of a moon to Venus has been found.

Mars.

Mars is the nearest to the sun of all the exterior group, and under good conditions appears to the observer as a striking ruddy star, shining with a brilliance exceeded only by Venus and Jupiter. But this planet is not always so favourably situated for observation, for its brightness may decline to that of a third-magnitude star, when the planet is far distant from the earth. This difference is explained by the fact that the orbit of this planet departs considerably from the circular form, and therefore at a favourable opposition the earth may approach to within about 33,500,000 miles of the planet, while at the time of conjunction the distance may amount to as much as 249,500,000 miles.

In a moderately powerful telescope the observer may recognise on Mars certain dark and bright markings, and in fact, no planet has laid bare the natural conditions of its surface to the observer's eye so plainly as Mars. We cannot, therefore, wonder that, favoured by the rapid developments in optical instruments, a large number of professional as well as amateur astronomers should have devoted themselves entirely during the last decade to the study of the topographical details of this planet. But we must not imagine the observation of this planet's surface to be a simple matter. The concurrence of so many conditions, which are usually so rare, is necessary for the purpose, that in reality there are only a few who can admire with their own eye these interesting and enigmatical markings on the Martian surface. A favourable position of the planet with regard to the earth, the very best air conditions, a powerful telescope, a steady eye, patience, and perseverance, these are the factors, without which a successful view of this far-distant world is not to be obtained.

The bright and dark markings, which show themselves in a telescope to the observer, have at the first glance the appearance of continents and oceans, the former appearing as bright reddish yellow areas, and the latter as dark greenish grey or bluish grey shadings. At the poles, the observer can see very bright white rounded spots, which are the so-called polar caps. By continued observation it may be seen that, at the time of the Martian winter, these polar caps distinctly increase in extent, but with the coming of summer they decrease and dwindle to comparatively small spots. At this time it may then be seen that surrounding the white caps is a sort of greyish border, which continues to increase in breadth. The explanation of these occurrences is quite plain; we have here the accumulation of polar snows

South.

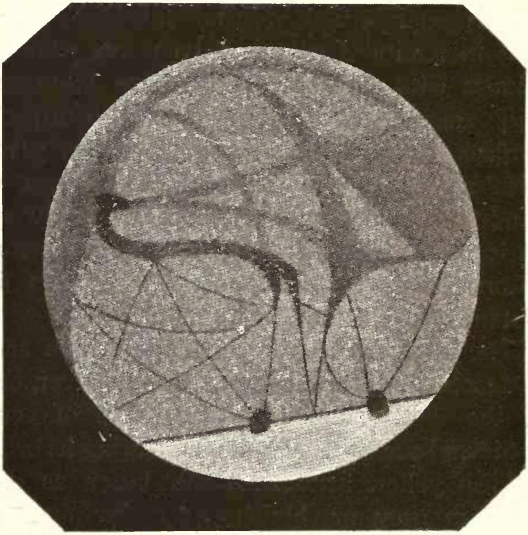

Fig. 88.—Mars on January 2, 1897.

in the winter, and the melting of this mass during the summer half of the year. Coincidently therewith, unmistakable inundations take place, since those parts which first appeared as continental formations gradually fade, or vanish altogether, as if in some manner they were inundated. *It snows and freezes and thaws also on Mars ; that we know.*

By far the most striking and most peculiar appearances on the surface of this planet are those straight or very slightly curved narrow lines, which connect the bluish green and bluish grey areas with each other, and which have received the name of *canals.* Their breadth varies from 18 to 185 miles, but they maintain the same breadth throughout their whole length unaltered, and widen into a sort of estuary only where they leave and enter the seas. Their length varies from about 300 miles to one-third of the entire circumference of the planet, and even a tolerably attentive glance can scarcely fail to notice with what evident design and systematic arrangement these lines traverse and intersect the entire Martian globe. But these canals bears a permanent character throughout, and continue to be seen from one opposition to another; their existence does not change, though their aspect, and especially their colour, may detract from, or increase their visibility. For at the time when the snow melts and the polar caps gradually shrink, those canals nearest the poles acquire a darker tint and broader form, and the region round the pole becomes a region of islands. As soon, however, as the time of year imposes a check upon the melting of the snow, the water gradually disappears from the canals, which then again become narrower and brighter, and slowly the land resumes its earlier appearance.

South.

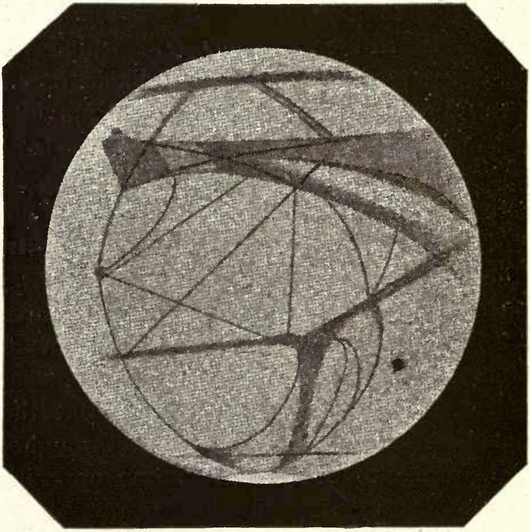

Fig. 89.—Mars on January 19, 1897.

Still more noteworthy than the canals themselves is that phenomenon which was first observed in the commencement of the year 1882 by Schiaparelli, the famous observer of Mars. He saw that these dark canaliform lines became double within the space of a few weeks, and that the planet then presented a decidedly altered appearance. Since then these occurrences have been repeatedly observed. With the arrival of a particular time of the year, a certain number of these canals become duplicated, so that then two straight dark lines, instead of the original single one, running quite close to each other, establish the connection of one water area to another. The duplication along the whole length of the canal takes place very rapidly, even in the course of a few days, or perhaps hours, in which form they usually continue during the whole season.

A satisfactory explanation of these facts has not been given up to the present day, yet it should be mentioned that of late years, in professional circles, opinion inclines towards considering that these appearances lack a foundation of fact, and should be ascribed to optical illusions, perhaps diffraction phenomena.

In the same degree, however, all doubt vanishes regarding the existence of these canals, and from what has been said the unprejudiced conclusion may be drawn that, from the aspect of the geometrical regularity of this network of canals, we have to do with the productions of a highly developed intelligence, beside which all human skill and power appears insignificant. What it was that compelled or still compels the inhabitants of Mars to carry out those huge works we cannot tell; perhaps it was the necessity of making the utmost possible use of the comparatively very small quantity of water which exists on the planet. But whether we shall ever be convinced of the existence of life on this neighbouring world is very questionable; one thing only is certain, that is, on this planet the conditions of life, for such organisms as exist on earth, are rendered similar by the presence of light, air, and water.

Mars is attended by two moons, which were first discovered by Hall, at Washington, in August, 1877, with the largest telescope then existing in the world. They are amongst the smallest heavenly bodies that we know of, and can be seen only with extremely powerful telescopes. They both have a diameter of not more than ten miles. The outer one, named *Deimos*, is slightly the smaller. Their distance from Mars is also very small. The inner moon, *Phobos*, is only about 3,700 miles from the planet's surface. On account of this proximity they move unusually rapidly round their central planet; Phobos completes a revolution in 7 hours 39 minutes, that is, three times within a Martian day, which lasts 24 hours 37 minutes. Thereby the inhabitants of Mars, if there be such, will have the unusual phenomenon of this moon rising in the west, and setting in the east, quite contrary to the rule which otherwise all heavenly bodies follow. Deimos also completes a revolution in the unusually short time of 1 day 6 hours 18 minutes.

The Asteroids.

In that region of space between Mars and the next exterior planet, the mighty Jupiter, revolve many of the smallest heavenly bodies in their orbits round the sun, and their diameters are so small that they can be measured only in a few cases, and that by such telescopes as the great Lick 36-inch. Photometric methods, *i.e.*, the comparison of their brightness, has been employed to obtain approximate determinations. Their number is perfectly enormous, and thanks to celestial photography quite a number are yearly added to the large membership. The seventh hundred is almost reached.

The observation of these asteroids can present no interest whatever to the amateur, because the great majority are so faint that they can only be found with difficulty, and even in powerful telescopes have the appearance of stars of the smallest magnitudes. But should the amateur so desire, on account of an irrepressible interest, to turn his telescope upon an asteroid, then he will do well to select one somewhat distinguished from the other tiny planets by its brightness, and of which the place for that particular time is given in the astronomical almanacs, just as are those of the larger planets. There are those which naturally were the first to be discovered, namely: *Ceres* (1), *Pallas* (2), *Juno* (3), *Vesta* (4), and *Hebe* (6). Of these Ceres shines at opposition as a star of 7 magnitude, the others as stars of 8 magnitude or rather less, and may be easily found if their apparent position is accurately known, even with small instruments. As we see, these asteroids, or planetoids as they are also called, bear names, and are from the beginning onwards, according to the order of their discovery, designated by numbers, which are attached to the asteroid's name, and enclosed in a circle. How extremely small the masses of these heavenly bodies are, when compared to those of the larger planets, may be understood when the diameters of the above mentioned five, which belong to the largest of them all, are respectively 485, 304, 118, 243, and 176 miles. The majority of these asteroids are much smaller; for example, *Gallia* (148), is about 62 miles in diameter, and *Irma* (177) only 40 miles, yet these do not come by any means among the smallest of the asteroids. On the contrary, the diameter is very frequently less than 30 miles, and the smallest value has been found to be about 7 miles.

As already mentioned, celestial photography above all has led to the discovery of this great host of planetoids. The first who brought this method into use was Dr. Max Wolf, of Heidelberg. The proceeding is very simple. The photographic telescope is directed towards a definite region of the heavens, and exposed for several hours. By means of the clockwork driving mechanism the stars appear on the plate as points. But if traces of light impression are found which are drawn out in length, then the object in question has doubtless moved during the time of exposure, and must therefore be an asteroid. In this manner the greater number of the asteroids have been found. But even by visual observation alone a very considerable number of these objects have been discovered. Thus J. Palisa, the present director of the Vienna Observatory, has succeeded up to the present time in discovering nearly 90 asteroids by the visual method alone.

There yet remains as worthy of mention the fact that many of these planetoids, according to the most recent observations, show that their light is subject to periodical variation. These light changes are explained by these asteroids,

South.

Fig. 90.—Jupiter.
(Photographed at the Lick Observatory on August 19, 1891.)

which, just like any other heavenly body, rotate round their axes, showing an unequal reflective power on different parts of their surface. These variations of brilliancy are particularly shown by the asteroid *Eros* (433), but also by *Hertha* (135), *Iris* (7), *Sirona* (116), and *Tercidina* (345).

JUPITER.

This planet, which at times emulates Venus in brilliance, is the largest by far of all the bodies composing our solar system, the sun itself excepted, and, were the sun suddenly to

South.

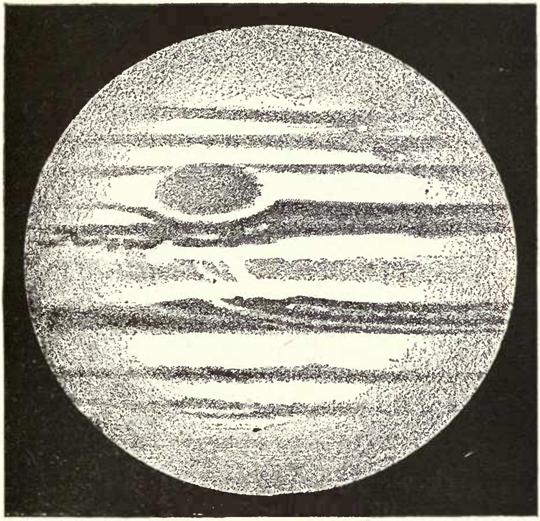

Fig. 91.—Jupiter on July 11, 1888, 12 h. 3 m.
(Lick Observatory.)

cease to exist, then all the planets would have to revolve in orbits round Jupiter. Jupiter is easily recognisable by its intense, steady, yellowish white light. The amateur who has but a moderately powerful telescope, of about 3 to 5 inches aperture, can successfully observe the appearances on its surface.

But even those amateurs who have but very small telescopes, will find many phenomena that may be followed with interest.

South.

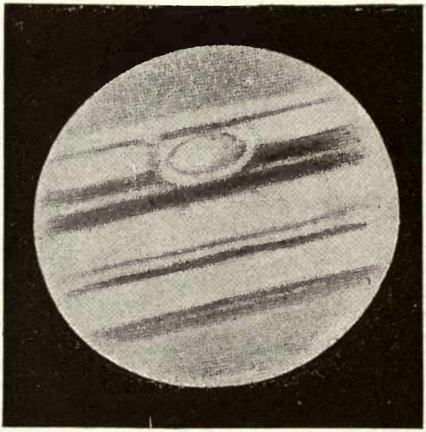

Fig. 92.—Jupiter on February 14, 1896.
(10 h. 10 min., long. = 6°.)

The surface of this planet will show, with sufficient optical aid, small dark spots, and long narrow bands lying parallel to the equator of the planet.

Often also dense almond-shaped markings may be observed, which are extraordinarily bright, and apparently reflect sunlight to an unusual degree. At times the surface in the equatorial regions shows a ruddy colouring.

All these appearances, however, do not belong to the planet itself, but are, as we now know,

South.

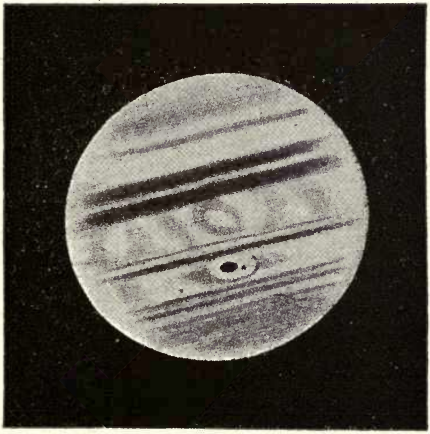

Fig 93.—Jupiter on April 23, 1896 (9 h. 8 m., long. = 253°).

in part due to its atmosphere, even though they show in many cases an astonishing consistency and stability.

Especially interesting was the appearance of a great red spot in August, 1878, but which almost disappeared six years later. In the year

1890 this "red spot" again became distinctly visible, but afterwards gradually fainter.

Such occurrences clearly point to violent disturbances, and the opinion has long been held that the surface of this planet is not yet completely cooled down, but is at present in a state of cooling.

South.

Fig. 94.—Jupiter on April 24, 1896 (7 h. 57 m., long. = 0°).

So far as we at present know, Jupiter is accompanied by eight satellites, four of which, however, are to be seen only under exceptionally favourable conditions, and only with the most powerful instruments. The remaining four are of such magnitude, and are so far separated from their central planet, that they might be visible to the naked eye, were it not for the powerful brilliance of Jupiter hiding them from view. These four larger moons are designated by the numbers I., II., III., IV., according to their distance from Jupiter. The brightest of the moons is the third one—it shines with the brilliance of a 5·2 magnitude star; the first moon is equal to a star of 5·6 magnitude, the second to one of 5·8 magnitude. The faintest moon is the fourth, which only equals in brightness a 6·4 magnitude star. Since their orbits are inclined only very slightly to the plane of Jupiter's equator, this frequently causes eclipses to take place, and in the course of almost every revolution the moons I., II., and III. are eclipsed by the shadow of the planet; the fourth moon also occasionally passes through the shadow. Also transits of the moons across the planet's disc are very frequent phenomena. The observer sees the satellite in question just going on to the edge of the disc, and notices it as a bright, round little disc, easily distinguishable from the planet's surface. As soon, however, as it approaches the central portion of the planet's disc, it gradually becomes less noticeable, till it vanishes from the observer's view. But when it approaches the eastern edge of the planet, it again becomes visible, and then passes completely off Jupiter's disc.

Sometimes, however, it happens that the moon passing across the planet's disc appears darker than the surface of Jupiter, and it can then be seen during its entire passage across the

South.

Fig. 95.—Jupiter on May 13, 1896
(9 h. 30 m., long. 28°).

disc. These are the so-called "*dark transits*," and in the case of moons III. and IV. are not unusual occurrences. As the satellites appear on the disc of Jupiter at these transits, they can also—for the earthly observer—disappear behind the planet without his seeing them enter the planet's shadow. The observer can also follow the occurrence of an eclipse of the sun on Jupiter. These phenomena, which as a rule take place at the same time as the already mentioned transits of the moons, happen very frequently, and the observer very distinctly sees the satellite's shadow passing over the disc of Jupiter.

All these eclipses, occultations, transits, and transits of shadows, which occur in the course of a year and are observable, are given in the astronomical almanacs, with the date, hour, and minute, of disappearance and reappearance, or ingress and egress as the case may be ; and the amateur is thereby thoroughly acquainted with such phenomena of this kind as will take place every evening or night upon which Jupiter may be seen at all. There is also in these books a table giving the configurations of Jupiter's satellites, *i.e.*, showing the relative positions of the satellites to Jupiter at a certain hour on every day that the planet may be observed.

SATURN.

Saturn is the second largest planet of our solar system, and bears considerable resemblance to Jupiter as regards the appearance of its surface. Since, on account of its very great distance from the sun, it moves forward very slowly in its orbit, and may sojourn in the same constellation for 2½ years, it is very easy to find again once it has been found, for it can always be seen near the same place, in which it was seen weeks or months beforehand. It appears to us as a dull yellowish star, and if its disc is examined with a sufficiently powerful telescope, it may be seen to be banded with dark and bright zones similar to those of Jupiter.

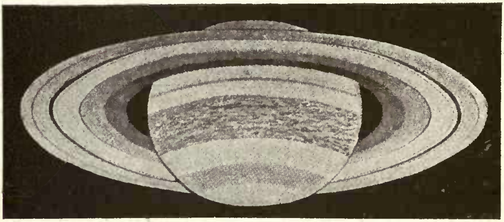

Fig. 96.—Saturn on April 26, 1896.
(Lussinpiccolo Observatory.)

Without doubt these bands belong also to the atmosphere of Saturn, and from their variations, which, notwithstanding the vast distance of the planet, may be quite distinctly seen by us, we can draw the conclusion that violent disturbances are taking place in this atmosphere.

Even in a small telescope it may be noticed that Saturn considerably departs from the round form of the other heavenly bodies, in that it shows the form of an ellipse, and thus appears to be very much flattered at the poles. But what distinguishes Saturn from all other planets, and makes it the most wonderful sight in the whole solar system, is that system of rings which encircles its globe without being attached thereto, and which may be distinctly seen by the observer with a small telescope. As this system of rings lies in the same plane as the planet's equator, and moves with the planet round the sun, and as it receives its light from the sun, then, at those points where the plane of the rings passes through the sun, the rings will be illuminated only on the edge, and to the observer on the earth they will appear as a line running straight across the disc of Saturn, but will be visible only by their dark shadow if at all. Beyond the sides of the globe they will be invisible, until the increasing inclination of the rings shows them as slender lines of light. But when Saturn is situated at those points in its orbit which are 90° from the previously mentioned points, the surface of the rings will be illuminated, and we shall see the ring system opened to its widest extent. These phenomena are repeated approximately every twenty-nine years, and during this time the ring is twice visible as a fine line, if visible at all, and twice visible with the greatest distinctness when opened at its widest;

but in these later cases we see at one time the northern side of the ring, and at the second the southern side. In order to know the position of the ring at any time, without having to observe it, we may note that Saturn appears without the ring when situated in the easterly portion of the constellations Leo and Aquarius, and that the ring system is widest open and may be best observed when this planet is in the easterly part of the constellation Taurus, or between the constellations Scorpio and Sagittarius.

Thus, for example, in 1907 the ring disappeared, or could be seen only as an extremely faint line with the most powerful telescopes; in 1914 the ring will be open to its greatest possible extent, and we shall then see the southern side of the ring; in 1921 the ring will again have vanished, and in 1928 we shall see the northern side of the ring open at its widest.

With a powerful telescope it is not difficult to see that the ring is not single, but composed of concentric rings, separated from each other by a dark space. That the rings themselves are dark and opaque is shown by the shadows which they throw upon the globe of Saturn. But this is not the case with all the members of this ring system. On the inner side of the inner bright ring, and merging gradually into it, is another dusky ring—the *crape* ring as it is called—which has the property of being semi-transparent, for the globe of Saturn may be distinctly seen showing through it.

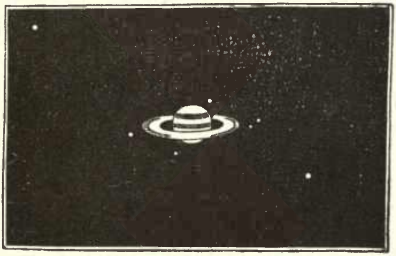

Fig. 97.—Saturn and its Satellites.

As far as we are at present aware, Saturn is accompanied on his way round the sun by ten moons, which are, however, so faint that

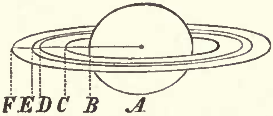

Fig. 98.—Proportions of Saturn and its Rings.

they can be observed only with powerful instruments. The names of these satellites are here given, beginning with that nearest the planet and proceeding outwards: *Mimas*, *Enceladus*

Tethys, *Dione*, *Rhea*, *Titan*, *Themis*, *Hyperion*, *Iapetus*, *Phœbe*. Of these, only Titan and Iapetus are observable in the smaller telescopes, the first appearing as a star of 7 magnitude, the others can be seen only with powerful instruments. Transits of these moons across the disc of Saturn are rare occurrences, on account of the inclination of the plane of their orbit. It is worthy of mention that some of these moons, particularly Hyperion and Iapetus, exhibit a very considerable variation of light, since when on the western side of the planet they appear very bright, but when situated at the eastern side they show a considerable falling off in their brillance, and become almost invisible, from which phenomenon the conclusion must be drawn that the surfaces of these moons have a varying power of reflecting light.

URANUS.

The discovery of this planet was made by W. Herschel on March 13, 1781, and doubled the distance of the limits of the solar system as then known. It is so far from the centre of the planetary system that it requires more than eighty-four earthly years to complete a revolution round the sun. It shines with a greenish-white light as a star of 6 to 7 magnitude, and may, therefore, if conditions are specially good, and if its apparent place is accurately known, be just seen by a sharp, unaided eye. On account of its great distance, it appears even in the largest telescopes as a small, pale disc, upon which, very rarely, and under favourable conditions only, there may be seen faint markings. This planet is attended by four moons, *Ariel*, *Umbriel*, *Titania*, and *Oberon*, which possess the peculiar property of having a retrograde motion round the planet—that is to say, they move from east to west.

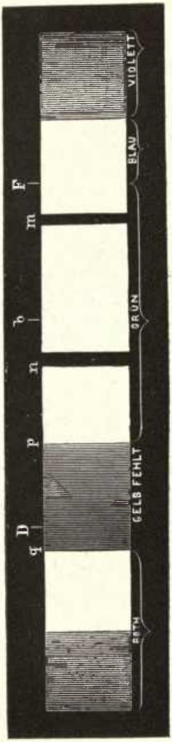

Fig. 99.—The Spectrum of Uranus.

Translation of German words:—
Red Yellow missing Green Blue Violet.

Neptune.

This planet forms the outer limit of our solar system, and thus gives the extent of our system a diameter of about 5,580 million miles. Certainly this is a plane of enormous extent, but still only a very small colony in the depths of space. Of all the planets, Neptune is the fourth largest, but its distance is so huge that

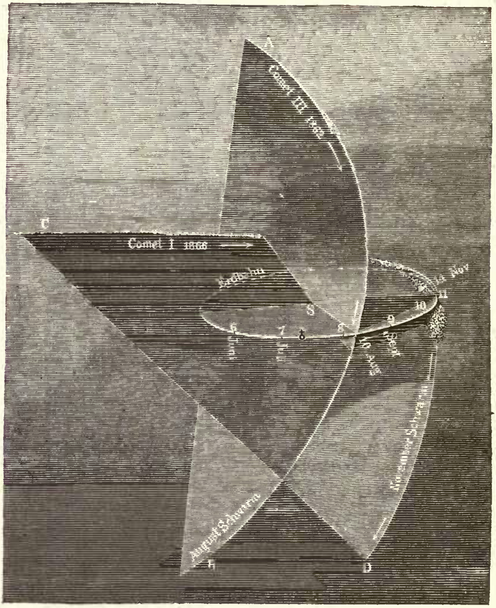

Fig. 100.—The paths of the August and November Meteor swarms. (The orbits of Comet III., 1862, and Comet I., 1866.)

(In the figure Erdbahn = Earth's orbit.)

even the most powerful telescopes show it only as a tiny little disc, and therefore nothing is known regarding the constitution of its surface and its rotation. Its discovery was one of the most brilliant triumphs that astronomy ever achieved. Its existence was discovered, not by visual observation, but, so to speak, "at the desk," which is a proof of the unity of logical thinking with the harmony of the universe. From perturbations in the movements of Uranus, Adams in England and Leverrier in France independently calculated the position of the unknown planet producing the disturbances. On September 23, 1846, Professor Galle, then observer at the Berlin Observatory, received by letter from Leverrier the final results, together with the probable position of the yet unknown planet, and that very night Professor Galle succeeded in finding the planet near the calculated position, as a star of the eighth magnitude. Neptune is accompanied by one moon, which, like the moons of Uranus, performs its revolution round the planet in a retrograde manner. It appears as a star of magnitude 14, and can only be seen with very powerful instruments.

CHAPTER XI

THE COMETS

THE heavenly bodies to which we have devoted our attention in the foregoing section all move round the central orb, our sun, in orbits which closely approach the circular form, and which are but slightly inclined to the ecliptic. But the kingdom of this mighty ruler is not restricted to the planets and their satellites, for it exercises its sway over a great number of bodies, which travel round it in the most varied orbits, and are known as *comets.*

Some of these describe closed orbits round the sun, just as the planets do, and therefore belong to our solar system, and can be observed at every return to the sun by us earth-dwellers when they are favourably situated; these are called *periodic comets.* Others, however, move along in parabolic or hyperbolic orbits, drawn to our sun only by its powerful and far-reaching gravitational attraction, and after having, as it were, made their obeisance to this influential ruler lose themselves once more in the infinite depths of space, perhaps after countless thousands of years to hasten forward to some other fixed star like a veritable "globe-trotter" of the universe. They come and go, we know not whence nor whither. Perhaps they are the residue of that primordial substance which has found no opportunity to attach itself to some larger heavenly body. Restlessly they wander through the depths of space, strangers everywhere. Should they accidentally come, in the course of their wanderings, in proximity to some sun, then at times it may happen that, by the attraction of this sun or its planets, they may become so far diverted from their original paths that henceforth they may gravitate round this sun in limited and closed orbits, thus becoming as it were, a naturalised member of this new kingdom, and a periodic comet.

The number of these heavenly bodies is absolutely enormous, but we are not in a position to see all that come at least within range of our sun, partly because the weather was perhaps dull during their proximity to the sun, or they came so close to the sun that they stood in the sky during daytime only, and partly because they are too small and faint to be seen at all. The great majority of the comets are quite invisible to the naked eye, and can be seen only in the largest telescopes, wherefore they are called *telescopic comets.*

To attempt to discover a comet is therefore rather a thankless task, and the amateur astronomer, who is rarely able to provide himself with the most suitable instruments for the purpose, will scarcely occupy himself in earnest with such a task. In professional circles, for the inspection of the sky for comets the *comet-seeker* is utilised—an instrument with a large objective aperture, comparatively short focal length, and large field of view. Of late years the search after comets has been very greatly aided by celestial photography, and we have to thank this method alone for the discovery of so many comets in recent years.

As soon as a discovered comet, which is at once notified in astronomical publications, has so closely approached the sun, and therefore also the earth, that it may be seen in medium or small telescopes, then it also becomes an object for the amateur astronomer.

So long as comets are telescopic—many of them remain so throughout their whole appearance—only a hazy, globular outline can be seen, which in appearance strongly resembles the small nebulæ and nebulous stars. With their gradual approach to the sun, the appearance acquires more form, and a shining nucleus may then be distinctly discerned, surrounded by a more or less bright nebulous envelope. Should circumstances be favourable, a long, broad, sometimes straight, sometimes curved band of light—the *tail* of the comet—may be seen proceeding outwards as a continuation of the nebulous envelope. This tail is often single, but at times composed of several separate bands, and is always found on that side of the comet turned away from the sun. The nebulous envelope, the coma, and also the tail are so tenuous that the stars shine through them with undiminished lustre.

Shortly after the epoch when the comet, according to the form of its orbit, is at its nearest to the sun, or, as we say, after its *perihelion* passage, the extent of its tail, if it ever had such an appendage, is at its greatest. Very interesting phenomena, which are very frequently seen in the larger comets, are certain changes of form in the head, whereby brilliant layer-like masses become detached, accompanied at the same time by the emission of brilliant rays. Such occurrences take place in the shortest time, so that the comet's head, after the lapse of even a few hours, may present quite an altered appearance.

Those comets which move round our sun

in closed orbits, and are therefore periodic, are divided into three groups by astronomers.

To the first group belong those comets of *short period*, which have a period of revolution of between $3\frac{1}{3}$ and $7\frac{1}{2}$ years; to the second group those that have a period of

Fig. 101.—Encke's Comet on December 7, 1828.

from 69 to 76 years; and lastly, to the third group, those comets that describe their paths in long spaces of time, which calculation often shows to be hundreds of thousands of years. They are called comets of *long period*.

Of those comets of short period, which are likely to be of interest to the amateur, the following should be mentioned.

Encke's Comet has the shortest period of all the periodic comets known. It completes its orbit round the sun in 3·3 years, and in 1908 it returned to perihelion for the twenty-eighth time since its discovery in November, 1818, by Pons. Since Encke calculated its orbit it has always been seen in a favourable position at its approach to the sun. At its last return it was found by photography at the Königsstuhl Observatory in Heidelberg. It belongs to the small and faint class of objects, and shows a nucleus very eccentrically placed. This comet approaches to within about 31 million miles, and at aphelion is as far off as 380 million miles.

Biela's Comet was discovered by Captain Biela on February 27, 1826, and calculation gave a period of 6·6 years. The comet appeared also in 1832, 1839, 1845, and 1852. At its return in 1852 it presented the curious feature of being divided into two separate comets a few degrees apart. This pair of comets was never seen again after this, but more will be said of it in another place.

Faye's Comet was discovered by Faye in 1843, at Paris, and its orbit was calculated by Leverrier. Its period is 7·6 years. It was last seen in 1896.

Brorsen's Comet. The discovery of this comet was made in the year 1846. Period 5·5 years. It has not been seen again since 1879.

Holmes' Comet was first seen in 1892, then again in 1899 and 1906, but with steadily diminishing brightness. Its period is 6·9 years.

Fig. 102.—Giacobini's Comet on December 29, 1905.

(Reproduced from a photograhic negative, wherefore the Comet and Stars appear black and the Sky bright.)

Winnecke's Comet was discovered in 1819, by Pons, at Marseilles. It was not seen again till 1858. When on March 8th in that year Winnecke discovered a comet, it soon proved that this comet was identical with the one discovered by Pons in 1819. In 1863 it could not be observed on account of its unfavourable position, but it was seen again in 1869 and 1875. In 1881 it was not found because at its perihelion passage, as seen from the earth, it was too close to the sun. Its return in 1886, 1892, and 1898 were confirmed, but in 1904 it was sought for in vain.

It has, however, been found again by Dr. Porro at La Plata on October 31, 1909.

Tuttle's Comet. Its first appearance was in the year 1790. It was again seen in 1858, 1871, 1885, and 1899, and should again be seen on its return to perihelion in the beginning of 1913.

Of the comets belonging to the second group—

Halley's Comet has a period of about 76 years. It has a very striking appearance, and was the first of all comets for which a return was predicted. The astronomer Halley investigated a large number of cometary orbits, and arrived at the important result that three of these computed orbits so closely agreed that they must belong to one and the same comet. Halley, therefore, announced its return at the end of the year 1758 or the beginning of 1759, a prophecy which was brilliantly fulfilled. On December 15, 1758, a peasant named Palitzsch, in Dresden, first succeeded in seeing the comet. Since then this comet has also appeared in 1835.

It has now once again been found, and is expected to make its perihelion passage on April 20, 1910.

About the time when this comet will be nearest the earth, which will be in May, 1910, it will not be visible for observation, for at this time it will be in conjunction with the sun. All the more interesting, then, should be the total

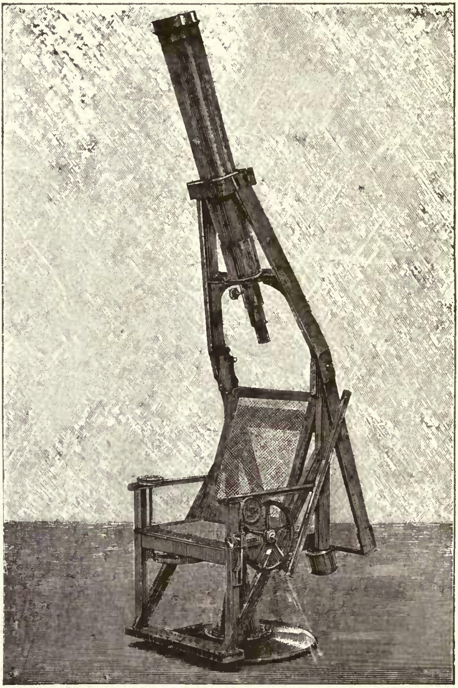

Fig. 103.—Comet-seeker. Objective aperture, 6½ inches; focal length, 4 feet.

eclipse of the sun on May 8, 1910, for during totality this bright comet should be observed quite close to the sun. Unfortunately, the zone of total eclipse falls almost entirely in the southern polar regions, and the South Cape of Tasmania will be about the only available station for observation.

In the case of the comets of long period, which often require several thousand years for their period of revolution, it must be remembered that these estimations are merely the results of calculation, and that their return cannot be predicted with anything like the confidence that is usually the case with the comets of short period. To the most brilliant of this group belong—

Donati's Comet, which was discovered in Florence by Donati on June 2, 1858, as a faint nebula, visible only with powerful telescopes, and which was situated in the constellation of Leo. By the end of August it had become visible to the naked eye, and the intensity of its light rapidly increased through the formation of a splendid tail. On September 4th the tail began to divide from the head outwards, whereupon brilliant concentric envelopes detached themselves from the nucleus. On October 5th this comet reached its greatest brilliance, and its tail reached from near the star Mizar in the Great Bear, while its head stood near Arcturus. Although the nucleus gradually decreased in brightness, the tail continued to increase in length, and on October 10th had an extent of 60 degrees, which implied a length of about fifty million

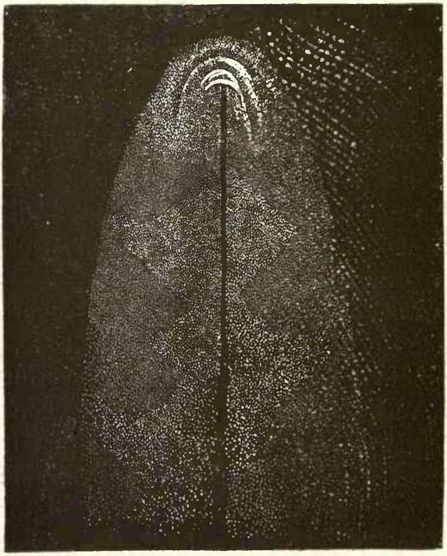

Fig. 104. —Coggia's Comet, July, 1874.

miles. The comet could still be seen up to March 1, 1859, at the Observatory of Santiago, in Chili. Asten and Hill calculated for it a period of 1,800 to 1,900 years. This large and brilliant comet has had very few rivals in splendour of appearance. The great bright comet of 1811, for which a period of 3,010 years was calculated, has up to the present been its only rival.

The comet of 1882 has a period of 772 years, and is at the same time one of the most brilliant

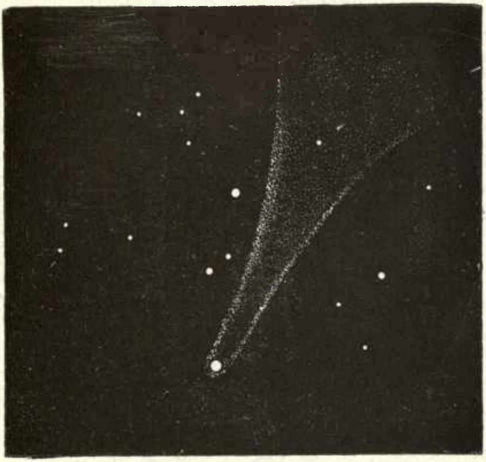

Fig. 105.—Comet of September 10, 1811.

comets of its kind. It appeared suddenly in the southern skies, and developed there unique splendour. It will always remain an epoch-making phenomenon in astronomical history, on account of the large number of peculiar characteristics, such as had never before been seen, that it possessed.

Of the comets of later years which were also visible to the naked eye there are *Daniel's Comet*, which was discovered on June 9, 1907, in Princetown, U.S.A., with the brightness of a star of 11 magnitude. In the middle

Fig. 106.—Comet of December 7, 1895.

of August it had reached a brightness of quite magnitude 2, and showed a tail of about 10° in length and 2° in breadth. It was for a long time, also, the object of observation of many amateurs. Unfortunately it showed itself in a rather unfavourable position, being in the early morning sky, so that it could never be observed at its best. In the beginning of 1908 its position in the sky was more favourable, but then its brilliance was rapidly diminishing. The elements of its orbit show that it moved round the sun in a parabolic path, and thus will not return again.

Comet 1907 V., which was discovered by Mellish on October 13th at Madison, U.S.A., could not be seen with the naked eye, but was quite distinctly visible with an opera-glass, and thus it belonged to the bright telescopic comets. Its brightness increased till near the middle of November, and then declined rapidly, as was to be expected.

Comet Morehouse was discovered on September 1, 1908, at the Yerkes Observatory. This comet was also the object of much observation in amateur circles, but was not a "popular" comet, as it did not present an imposing appearance to the naked eye. In professional circles it was for a long time the object of much spectroscopic investigation, and it is to be expected that we may obtain important information upon the physical constitution of these bodies from the observations of this comet.

If we now draw to a close our enumeration of these heavenly bodies, we should not omit to mention that, though not by any means all of

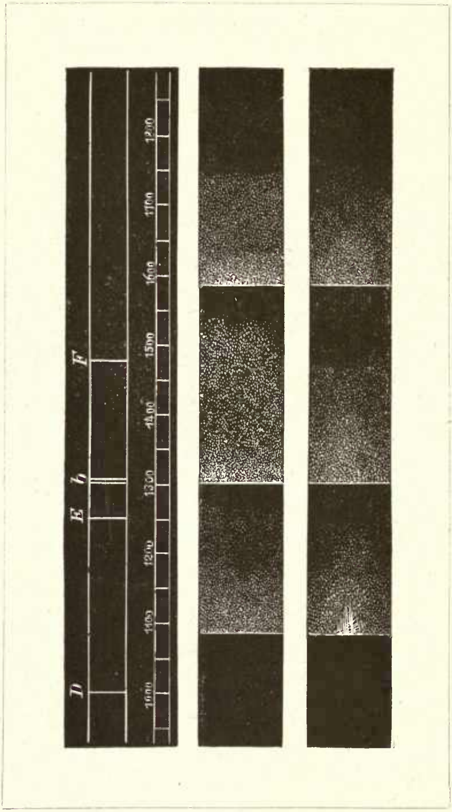

Fig. 107.— Similarity of the Cometary Spectrum to that of the Hydro-carbons.

these comets show similarity in their orbits, yet nevertheless a certain number of them do so, and therefore point to the fact that they belong to *one* group and have a common origin. Thus, for instance, the elements and the positions of aphelion were so similar in the cases of the comets 1860 III., 1863 I., and 1863 IV., that it appears almost certain that these comets, though certainly not identical, had nevertheless a common origin. A similar case is that of the comets 1881 IV. and 1898 X., and also of the comets 1896 VIII. and the already mentioned Biela's Comet. It seems that, in these cases, some great cometary body has at some time from some cause separated itself into two or more portions, just as happened before our eyes to Biela's Comet in 1845. This inclination towards sub-division, or even breaking up altogether, is one of the chief characteristics of all cometary bodies, and the manner in which it shows itself as such to us earth-dwellers on occasions in a very striking way, will be related in the next chapter.

CHAPTER XII

SHOOTING STARS AND METEORITES

We have all of us often observed that suddenly one of the many stars seemed to detach itself from the multitude of others, shot across the firmament with great rapidity, but usually in a few moments became extinguished; and if we look up towards the starry heavens on certain evenings of the year, we shall not have long to wait in order to become a witness of such an appearance.

These *shooting stars*, however, have no connection with those fixed stars in the immeasurable depths, but are astronomical occurrences taking place, comparatively speaking, in our immediate neighbourhood, the earth's atmosphere. Within the confines of our solar system, in addition to the planets, asteroids, periodical comets, and such occasional comets as may visit our system, there revolves an enormous number of the very tiniest cosmic bodies, which move in their orbits partly scattered, and partly in more condensed masses. Should, then, one of these small bodies encounter our earth, it will be strongly attracted by the earth, and its velocity will be so retarded by

Fig. 108.—Exterior appearance of the Lesves Meteorite.

traversing the earth's atmosphere, that it will glow with the heat thus generated, and become visible thereby.

According to their size, and to certain phenomena accompanying them, they have been divided into *shooting stars* or *meteorites.* Whereas the shooting stars appear for a brief moment and are noiseless, flying through the

Fig. 109.—Interior structure of the Lesves Meteorite.

atmosphere in their glowing state, becoming rapidly extinguished, and sending none of their substance to the earth, the meteorites, on the other hand, usually blaze up most brilliantly, remain visible for a longer time, and at the end of their course frequently explode, sending not always, but very often, one or more pieces of their substance to the earth. The fallen bodies are known as aerolites, and are termed by us meteoric iron, or meteoric stone, according to their composition.

Recent investigations, especially the meritorious labours of Professor von Niessl, an authority on the department of meteoric astronomy, have shown that really no fact exists which necessitates our looking upon shooting stars and meteorites as heavenly bodies of different classes, and that rather both phenomena represent the limits of one connected class.

There are not many phenomena for the investigation of which the astronomer depends so much upon the support of attentive friends of nature, as with those of meteoric astronomy. The professional astronomers, who devote their whole lives to the investigation of the manifold wonders shown us by the infinite universe of stars, will readily welcome the co-operation of amateurs, notwithstanding the fact that they have the help of trained staffs.

The observation of these celestial phenomena may be either accidental or intentional. Accidental ones are usually those rare cases when a large meteor, brilliantly shining, passes over our neighbourhood. Fortunately, of late such occasional observations are more taken notice of in lay circles, and accordingly news of the occurrence obtains publicity in most cases through the daily Press. It is then a problem for the astronomical institutions to trace these announcements, which are for the most part uncertain and untrustworthy in details, and to make them as perfect and accurate as possible, in order that they may become of scientific value.

In order to make a good observation of such a meteoric phenomenon, two things are necessary: first, to clearly *grasp* the details of the appearance, and second, to *describe* it accurately. Correct details can only be obtained during the observation of the meteorite; the fuller description can be given later, but the sooner the better. The circumstances that an amateur should bear in mind particularly, in order to ensure that such an observation may be of use scientifically, will here be discussed.

As in all astronomical observations, the *time of observation* should be given with the greatest possible accuracy. Owing to the unforeseen nature of these phenomena, the observer will in most cases have to refer to a pocket chronometer or watch, and therefore he should not neglect to compare his own time with that of a standard-time clock or the midday time signal, and to correct the time of his observation accordingly.

The name of the *place of observation*, its approximate geographical position, as well as the exact details of the standpoint of the observer during the phenomenon, should always be given in announcing such an observation.

Concerning the apparent place of the meteorite in the heavens, it will first depend upon whether the time of the observation fell in the evening or night-time, or whether it was observed in the twilight or bright daylight. At night-time the indication of the observed track of the meteor may best be given with reference to the visible stars in the neighbourhood. But as the observer is seldom in a position to bring into immediate use star-maps or globes for accurate orientation, it is advisable, even when the observer is well acquainted with the heavens, to make a small sketch, on which the meteor's track is shown with reference to the fixed stars. Especially important is the point at which the meteor lit up, and that at which it ended. The lighting-up point will only be observable in very rare cases, because the observer in such accidental phenomena usually only becomes aware of the meteor after it has been for some little time on its way, and sees it then for some reason or other, generally on account of its increased brilliance. Of incomparably greater importance is the exact determination of the apparent end, or stopping-point. Here also it may happen that this cannot be observed accurately, especially when the meteorite has so closely approached the observer's horizon that surrounding objects, such as houses or trees, &c., conceal the ending point from view. In general it must serve as sufficient that only that part of the apparent path which was actually seen should be drawn.

In phenomena which take place in the twilight or in daylight, the course of the meteor should be noted, as far as is possible, with regard to earthly objects, especial attention being paid to whether the meteor appeared at any edge or corner of a building, or whether it disappeared behind the same, and in every such case to note well the standpoint taken during the observation, in order to find it again later on.

As to the apparent heights of the commencing and ending points, these will be rather more difficult to retain in the memory; yet even in these cases, if no heavenly object, such as sun or moon, facilitates the marking of the point, the foregoing comparison with earthly objects lying in the direction in question will contribute much towards retaining it vividly in the memory. The amateur astronomer who has already acquired some practice in the estimation of degrees, will soon be able to correctly judge the heights of the commencing and ending points. It is of great importance in estimating these heights not to do so too highly, for it has been established by many experiments that the errors of estimation are very considerable, often exceeding the actual heights by two-thirds. Subsequently, with the help of a compass, or still better, by the aid of a sextant, which was specially mentioned in the beginning of this book in connection with these measurements, the observer will have to measure the accurate celestial bearing of the commencing and ending points of the meteor or to put it better, the angular distance of these points from the southern point of the horizon, the so-called *azimuth*.

Also the amateur will measure again the apparent heights of the beginning and ending points with this instrument, and so verify the first rough estimations.

It must be particularly borne in mind that all these estimations and measurements are to be taken from the same standpoint where the observer first saw the meteor. A simple sketch, indicated by a few rough lines of the local surroundings, with the corresponding apparent track of the meteor drawn in, will render excellent service in later scientific accounts of the details, especially with meteoric phenomena in daytime.

The foregoing remarks were chiefly concerned with the *position of the path* of the meteor observed. Of considerable importance, too, is an incidental statement of the *duration* from the first appearance of the meteor till its disappearance. Here also it is of advantage to make a note of it immediately. Even to those who are practised, it is at times difficult in such an unexpected fine appearance, to determine the desired duration by counting the seconds during the course of the phenomena. In most cases the observer must satisfy himself with an estimation of the duration made subsequently, which should likewise be done as soon as possible, while the impression is still fresh. This can be done by comparison with the ticking of a watch, and it can be ascertained afterwards how many ticks the watch makes per minute. The duration may also be estimated by pulse-beats, or by steady paces, which may later be compared with seconds of time.

Further particulars of such a phenomenon will be of a more descriptive nature, but are certainly not without value. Thus the observer can give details of the head of the travelling meteor, as regards its form, size, the colour of its light, and its brightness. Not infrequently the larger meteors leave behind a distinct smoke-like train, which often remains visible for some time, changing its form meanwhile. The description of such a phenomenon will be simplified by the observer having time, on account of the long duration of the appearance, to make sketches of the various phases.

If the meteor is not too far distant, and is at the same time one with an ending of a more or less explosive character, its detonation can also be observed. A short space of time will then elapse between the flash and the sound, just as with lightning and thunder, but which in the case of the meteor is a much longer interval, and seldom less than a minute. It is also recommended, after observing the phenomenon, to wait for five or eight minutes more, and to listen for a possible sound, generally a dull report or like a thunder-clap. In such a case an incidental note of this interval and of the kind of detonation will admirably complete the observation.

A report of the appearance of a meteor made in this fashion may be of high value for a subsequent calculation of its path. This latter is, however, only possible when the phenomenon is observed from at least two places, not too close to each other, and when described by both observers in the aforementioned manner. Such a report gives us information of the true path of the meteor, its distance above the earth's surface at the moments of appearance and disappearance, as well as of the direction of its arrival from space.

The institution called "Sammelstelle für Meteormeldungen," founded lately in Kronstadt (Siebenbürgen), has made it its task to collect, to register, and to hand over such observations in properly grouped form, to the great astronomical institutions for scientific purposes.

The observations of those smaller meteors, which are designated "shooting stars," have the same end in view, and form quite as worthy and important a branch of observational astronomy, for they are of very great value concerning our knowledge of the construction of our solar system.

Here is now an opportunity for the useful co-operation of the lovers of nature, and especially the lovers of astronomy, and a wide field is here opened to them, in which, by their aid, they can help towards the solution of numerous questions as yet insufficiently answered or not answered at all; for only through a large number of willing co-workers is it possible to furnish the material for accurate statistics, and thereby for a successful investigation.

That the frequency of shooting stars is not always the same throughout the course of a year, has perhaps struck even those who are not astronomical observers. But the number

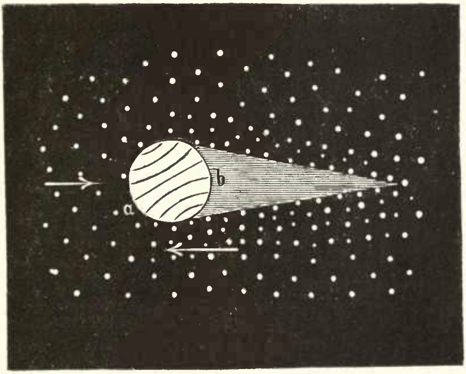

Fig. 110.—Entrance of the earth into a meteoric shower.

of shooting stars at any place is not the same throughout the course of the night, but gradually increases in the later hours, and reaches its maximum towards six o'clock in the morning. This circumstance is, at the same time, the best proof that the shooting stars are cosmic phenomena, and therefore come to us from outer space.

If the earth possessed no other motion than that of rotation round its axis, and if the shooting stars came to us with the same frequency from all points of the heavens, then the same number of shooting stars would be seen at all places. But since the earth moves along its orbit in space with a velocity of about 18·5 miles a second, it would naturally intercept considerably more shooting stars on its advancing hemisphere, *i.e.*, on the hemisphere which lies in the direction of its motion.

The favourable time for such observations is, therefore, the time when the point towards which the earth is moving, the so-called *Apex* (Fig. 110), is above the horizon. Before the rising and after the setting of this imaginary point, which has also been termed the *meteoric sun*, the frequency of shooting stars will be less ; it is at its greatest when the apex stands highest above the horizon, and at its least when this point is at its lowest beneath the horizon.

As the orbit of our earth round the sun departs only very slightly from a circular path, the direction of the earth's motion therein is almost always perpendicular to the direction of the sun ; the apex therefore lies in the course of the year always very nearly 90°, or six hours of time, west of the sun, and precedes the sun by six hours, therefore passing the meridian at 6 o'clock in the morning, being then at its highest, and it is for this reason that the greatest frequency of shooting stars occurs at this hour, whereby we naturally assume that the meteoric bodies are distributed evenly in space.

But this distribution holds good only in general, for it has long been noticed that the

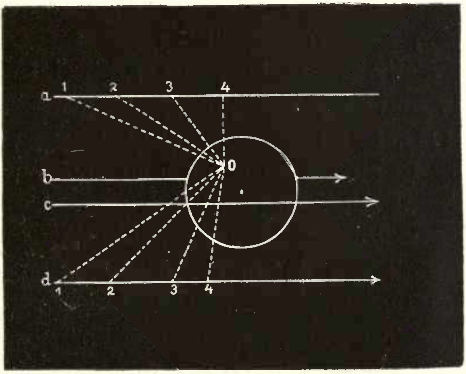

Fig. 111.—True paths of Shooting Stars.

shooting stars appear in unusual numbers on certain days in the year, from which we must conclude that in these cases the meteorites are more densely thronged and are concentrated in swarms and groups, moving round the sun in their orbits, like the planets and comets. Should, then, the earth in its course meet with one of these swarms, we may expect a more or less brilliant shower of meteorites.

This phenomenon is shown us, for instance, by the annual return, on the nights of the 9th to 12th of August, of the meteoric shower of the *Perseids*, as they are called, because they appear to come from the constellation of Perseus. This streaming from one particular point or small area in all directions has been termed *radiation*, and is caused by the meteorites, which really travel in paths parallel to one another and enter our atmosphere accordingly (Fig. 111), being caused by the laws of perspective to appear to come from one and the same point (Fig. 112).

The shooting stars of the November swarm have a radiant point in the constellation Leo, and are therefore called the *Leonids*. This shower showed itself in extraordinary splendour and abundance in the night of 12th to 13th of November, 1799, when over the whole northern hemisphere meteorites were seen to fall in such a quantity, that the whole phenomenon resembled a dense fall of snowflakes. This fine spectacle repeated itself on the 12th of November, 1833, and in the night of 13th to 14th of November, 1866. The fall of shooting stars in 1866, had been announced as imminent by astronomers, and their actual occurrence confirmed in a brilliant manner the periodicity of this swarm.

As the length of the cycle was thirty-three years, it was definitely expected that the next maximum would occur on the morning of the 15th of November, 1899. As is known, the

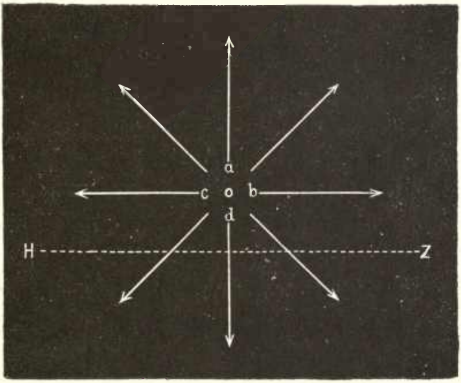

Fig. 112.—Apparent paths of Shooting Stars. Rising of the radiant point.

hopes which had been placed upon the return of this shower were bitterly disappointed. Instead of a great fall of meteorites, only a very moderate repetition of the phenomenon was shown. The causes of this non-appearance are probably to be found in the perturbations which the great planets Jupiter and Saturn had exerted upon the swarm.

The periodic nature of this swarm had already caused the celebrated astronomer Schiaparelli, of Milan, to form the idea that between the meteoric systems and the comets there stood a close connection, and a comparison of the calculated cometary orbits with the paths of the meteoric swarms as deduced from the radiant points led to the startling discovery that the Perseids form a constituent part of the great comet 1862 III., and that the Leonids stood in close relationship to the comet 1866 I. Later still, E. Weiss, Director of the Imperial University Observatory in Vienna, successfully compared other periodic meteor showers with the orbits of certain comets. From these investigations we know to-day that the periodically appearing meteoric showers are nothing other than the products of the breaking up of comets, and that for the return of these meteoric showers we have to thank the circumstance that the orbit of our earth intersects the orbit of a periodic comet at some point or other. In this manner the originating comets of a large number of meteoric showers have become known. Thus the meteorites appearing between the 19th and 23rd of April, in the constellation of Lyra—the *Lyrids*—are the remains of the comet 1861 I. The shooting stars of the 25th of April are connected with the comet 1748 II., those of the 28th of July with the comet 1737 II.

Of special interest are also those meteors which appear annually on the nights of the 27th to the 29th of November, in the constellation of Andromeda. It had long been known that the orbit of Biela's Comet, about the separation of which into two portions at its penultimate appearance in 1845 we have already heard, intersected the orbit of the earth at the point where the latter is situated towards the end of November. Already in 1798 and 1838 this radiant-point in Andromeda had yielded some noticeable shooting stars, though by no means specially numerous; but when in the year 1872 a great meteoric shower fell from this radiant-point, the opinion was held that the shower was associated with that comet of Biela's which commenced its disintegration so rapidly before our eyes, and calculation afforded a striking confirmation of this opinion.

Other important meteoric showers which the amateur will have the opportunity of observing during the course of a year, provided the weather conditions will allow of it and the bright moonlight does not hinder observation, are the following:—

January. In this month falls the brilliant shower of the *Quadrantids.* The maximum of this meteoric shower occurs on January 2nd, when the meteors appear to radiate from a point in α: (Right Ascension:) 230°, δ: (Declination:) + 53°. A large number of shooting stars stream down on January 29th, from the constellations of the Crown and the Great Bear; the former are known as the α *Coronids* and have a radiant point in α: 236°, δ: + 25°. Also on January 18th a radiant shows itself in the Crown (α : 232°, δ : + 36°), which in 1869 gave a specially brilliant fall; they are the δ *Coronids.* In addition, in this month there are the ξ *Leonids* and the ν *Leonids*, the meteors of which appear to come from near the stars ξ and ν Leonis. Large meteors may be expected from the 6th to the 15th, then again from the 23rd to the 29th.

February is not specially rich in meteoric showers. From the 5th to the 16th the observer's attention may be directed to the α *Aurigids* (near Capella). The radiant-points are situated about α : 74°, δ : 48°, and α : 75°, δ : 41°. Several observers have also noticed the feeble activity of a radiant point in Orion (α : 80°, δ + 6°), and another in Boötes (α : 208°, δ : + 17°). In meteorites of the larger type February is, on the other hand, unusually rich. They stream down at this time frequently from the constellations of Hercules (near ρ), Draco (near ν), Corona (near δ) and Monoceros.

March. This month can be stated at once as being poor in shooting stars. The most important shower is decidedly that of the *March Draconids.* Larger meteors, however, appear very frequently, especially during the first week of the month, from the constellations of Draco, Hercules, Virgo, and Andromeda.

April is for the meteor observer one of the most interesting months. It is characterised by the fairly bright shower of the *Lyrids,* which are visible from the 19th to the 22nd, and which have a large number of secondary showers as companions. This swarm, which is closely related to the comet 1861 I., has its radiant point in α: 271°, δ: + 30°, on the boundaries of the constellations Lyra and Hercules, and usually exhibits rapidly moving meteors. Besides this, during this month, many others in the constellations of Hercules, Draco, Ursa Major, Coma Berenices, and Virgo make themselves noticeable through comparatively rich showers. Larger meteors appear chiefly on the 11th and 12th from the constellations Lynx and Ursa Major.

May. Although otherwise rather poor in meteoric showers, this month offers special interest through the shower of the η *Aquarids* (at α: 338°, δ: − 2° in the constellation Aquarius), the meteorites of which seem to have some original connection with Halley's comet, which is calculated to make its perihelion passage in April, 1910. Since their discovery by Tupman in the year 1870, the Aquarids have not, however, shown a brilliant shower. The meteors of this radiant appear in the last days of April and the first days of May are mostly very strong and brilliant, and move in fine long paths. In the larger meteors May is, as a rule, poor.

June. The number of known active radiant points in this month is comparatively small. The reason for this lies in the fact that material for observation is lacking, for which the short nights in our latitudes are to blame. The amateur engaged in meteor observation is therefore recommended to continue his watching into the early morning hours. In the first week the δ *Bootids* (α: 215°, δ: + 55°) are visible, then come the α *Scorpiids* (α: 253°, δ: − 24°). Attention may also be given to the activity of some longer known radiant points, such as those near η Serpentis (Comet 1618 III.), and η Ursae Minoris, which are active from the 14th to the 21st. Radiant points of the larger meteors are to be found in Auriga, Scorpio, and Lynx. Particularly June 13th and 17th have been formerly noted for the appearance of large meteors.

July. With the increasing length of the nights, the hourly number of observed meteors also increases. From this time onwards a very decided increase in the shooting-star showers is noticeable, and even in the second week of July the first precursors of the chief swarm of the Perseids show themselves, and continue to fall till well into August, being the dominant meteoric phenomenon of that month. Besides these first of the Perseids, there come in evidence other rich showers, active from July 25th to 30th. Chief among them are the *July Aquarids* (α: 339°, δ: − 11°), and the meteors from Piscis Australis (α: 339°, δ: − 27°). Large meteors are to be expected particularly on the 16th, 22nd, and 25th, from the radiants in Scorpio and Aquila.

August is the month which furnishes us with the greatest number of shooting stars. The already mentioned Perseids have their maximum frequency on the 10th and 11th; their radiant point, which is somewhat variable, has its position in α: 45°, δ: + 57°. Among the numerous radiant points which show their activity at the same time, or earlier, or later than the main body of the Perseids, we may mention the δ *Cygnids*, σ *Draconids*, λ *Cassiopeids*, β *Cetids*, and γ *Pegasids.*

September. On account of the increased length of the nights, and the generally mild temperature, September may be said to be an exceptionally favourable month for meteoric observation. Fine meteorites stream from the constellation of Auriga between the 6th and 25th, and are known as the α and β *Aurigids*. Other radiant points, such as those on the 4th of the δ *Aquarids*, on the 7th of the α *Pegasids*, ζ *Ursids*, β *Piscids*, on the 12th to 22nd of the α *Cepheids* and α *Cassiopeids*, develop a more or less noticeable frequency.

October. In the period from October 18th to 20th there begins the fall of the *Orionids* (α: 92°, δ: + 15°), displaying a very vigorous activity, the meteors from this radiant usually being strong and brilliant. From October 14th to 15th occurs the fall of the ξ *Arietids*, from the 11th to 24th that of the ε *Arietids* meteorites, which come from the constellation Aries. The γ *Andromedes* from the 17th to the 23rd, the γ and δ *Geminids* from October 12th to November 12th, and the α *Triangulids* show themselves on many occasions in unusual brilliance. Large meteors may be looked for during this month, principally on the 13th and 23rd, from the radiant in Capricornus.

November may be described as one of the most interesting months for meteoric astronomy. Two brilliant showers, those of the Leonids and

Andromedes are specially noteworthy, since their meteorites, as we have already seen, move in the orbits of the comets of *Tempel* and *Biela* respectively. The Leonids, the maximum of which occurs on the 14th, have their radiant point in $\alpha : 150^\circ, \delta : +22^\circ$. The radiant of the Andromedes, which mostly gives meteorites moving very slowly and leaving trains behind them, is more extended, and lies in an area about $\alpha : 25^\circ, \delta : +43^\circ$. Of other radiant points, the β *Leonids* on the 13th, and the μ *Leonids* from the 1st to the 15th, should be named. The γ *Andromedes* ($\alpha : 24^\circ, \delta : +43^\circ$) and the α *Orionids* ($\alpha : 81^\circ, \delta : +5^\circ$) are also active at the same time as the principal swarm of the Leonids. Towards the end of the month the great *Geminids* shower—the maximum of which takes place from the 10th to 12th of December—commences its activity. November is also very abundant in large meteors, and such appearances are to be looked for from the constellation Cetus.

December. The *Geminids*, which show themselves towards the end of November, come from a radiant point about $\alpha : 108^\circ, \delta : +33^\circ$. They are generally short and swift meteorites, and it requires particular attention and presence of mind in order to be able to fix their paths on star maps. An important shower, active at the beginning of the month, is the ζ *Taurid*, then from the 2nd to the 13th the α *Aurigids*, on the 11th the β *Aurigids*, on the 27th to the 28th the ι *Aurigids*. The important radiant points of the γ and α *Orionids*, generally swift meteorites with long paths, are situated about $\alpha : 90°, \delta : +18°$, and $\alpha : 70°, \delta : +18°$. The days from the 10th to 13th of December have often been marked by the appearance of brilliant large meteors, which have already been alluded to by Arago, Schmidt, and Denning.

A detailed list of meteoric showers and their radiant points is generally contained in most of the astronomical year books or almanacs.

Amateur astronomers devoting themselves particularly to meteoric astronomy are warmly recommended to undertake observations, apart from those of the already well-known times of appearance of such brilliant periodic meteor showers as the Lyrids, Perseids, and Leonids. It is chiefly the early months of the year which have been rather neglectfully treated in the past by observers, with the exception of course of such champions in the cause of meteoric astronomy as Denning and Herschel, and this may be best explained by the fact that disproportionately fewer radiant points are active at this period of the year. Certainly such observations, where the hourly observed number may fall to 3 or 4 per observer, are hardly entertaining and may often be tedious. But given a sufficient number of observers, so much material might in time be collected as would suffice for the investigation of meteoric phenomena and the cosmological deductions to be drawn therefrom.

It remains to be mentioned that in such systematically arranged observations of meteors, all that is necessary is to count the meteors, *i.e.*, to give the number of shooting stars that were seen within a certain time—for example, within one or two hours. In order to make the observations properly comparable, it is advisable whenever possible to always group the time of observation symmetrically round the rising of the apex; thus, for example, to observe from one hour before to one hour after the rising of the point towards which the earth's movement is directed.

More than likely the observer will turn his attention every year to those well-known, prolific periodical showers. In systematic observations of these more noticeable showers, the apparent tracks of the meteors should be drawn in on good star maps. Simple as this may appear at first sight, it can only be done correctly and well after some practice.

The rapidity and the transitory nature of these phenomena make considerable claims on the observer's presence of mind, and upon his ability to grasp the necessary detail.

In noting these tracks by drawing, the observer should proceed with the greatest accuracy, and only draw in that portion of the path which he has actually seen. Concerning the times of the observations of meteoric showers, these should be given as accurately as possible—that is to say the hour, minute, and also the second should be given, even though the observer's time-keeper is not particularly reliable. The subsequent correction of his time by means of a time signal, or by comparison with post-office or railway-station time, will give the time of his observation greatly improved value.

As the observer making observations of meteors in this manner will be very much occupied with writing, it may often happen that one or two meteors may slip past unnoticed, especially when observing the very active meteoric showers. In such observations the amateur might with advantage obtain the aid of an assistant, who should register the time when the observer calls, noting the exact second first of all, and who should also make all additional notes from the observer's dictation. The observer then confines himself to the indication of the meteor's path as his duty, and he can number the path according to the current number read out by his assistant.

We have already mentioned the star maps contained in Sir Robert Ball's "Popular Guide to the Heavens" as being useful for this purpose. For use in the open air it is advisable to mount these maps on stiff cardboard. If, however, the observer prefers not to spoil them by drawing meteor paths over them, copies may be made and mounted instead, or very transparent paper may be placed over the original maps. For the observer already practised in drawing, the *Rohrbach Star Maps*, on gnomonic projection, published for this very purpose, will render the very best service.

Of particular interest and the highest scientific value are those observations of shooting stars which have been made simultaneously at different places. These "*corresponding*" observations, which of course demand skill in drawing the meteoric paths, must above all be based on accurate time fixing, for, though not the only criterion, accuracy of time is nevertheless one of the most important points for the identification of a meteor observed at different places. From observational material of this type, determinations of the meteor's height may, among other things, be taken in hand, and the heights above the earth's surface at which the meteor in question appeared and then became extinguished may be calculated. The amateur who is also somewhat at home in the domain of mathematics, which gives such an added charm to astronomy, will be particularly stimulated by observations of this order, and may busy himself also with calculation.

Of all the groups of work in observational astronomy, this chapter is just the one upon which the amateur can confer his help in a way profitable to science, for the observations to be made demand no great expense in technical and optical instruments. In meteoric astronomy we can even do without the telescope. Good star maps, and a good chronometer, together with some diligence and perseverance, are all that the worker will find necessary.

Those kind readers who have followed as far as this, will know how wide a field for noble occupation and profitable work lies spread before the amateur astronomer. Those leisure hours we employ upon the starry heavens are not lost. Those who experience true joy in nature may, by looking at the heavens, free themselves from many of the cares of everyday life, and many a one has helped himself over sad and troubled hours by busying himself with nature, and especially with the stars. The study of the starry heavens always exercises a refining and ennobling influence, and permits us to elevate ourselves and to take a noble view of the world. To this bear witness the classical words of Adolf Diesterweg: "In order to be thoroughly at home with oneself, one must become a citizen of the world, and in order to thoroughly grasp earthly life, one must step forth into heavenly space and learn to comprehend that."

APPENDIX

LIST OF CELESTIAL OBJECTS FOR OBSERVATION, ARRANGED ACCORDING TO CONSTELLATIONS.

D = double or multiple star; C = cluster N = nebula; V = variable star.

CONSTELLATION	PAGES
Andromeda... ...	D., 90, 98; N., 122.
Aquarius	D., 93, 95,; N., 130
Aquila	V., 140
Argo	C., 119
Aries...	D., 90, 98
Auriga	C., 117
Boötes	D., 94, 95, 96, 99
Cameleopardalis ...	C., 121
Cancer	D., 92; C., 117; V., 140
Canes Venatici ...	C., 119; N., 124, 125
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FOR SEPARATE STARS AND OBJECTS FOR OBSERVATION, SEE APPENDIX.

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