STARTING ★ ASTRONOMY

E. O. TANCOCK

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PHILIP

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BY

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Preface

MY PREVIOUS BOOK " The Elements of Descriptive Astronomy "*after three reprintings of the revised edition, has been allowed to lapse. I wish to express my thanks to the Secretary to the Delegates of the Clarendon Press for giving me the copyright of all material in that book. Some of the material, dealing with that part of astronomy which does not become out of date, is here reproduced verbatim : most of the book has been entirely rewritten. The principal alteration in the lay-out is the inclusion of certain exercises on graph paper and the drawing of diagrams. These are intended to give the learner, whether as a lone student or as a member of a study circle, the opportunity to teach himself—to save him from the inactivity of protracted looking and listening. At what stage these exercises should be taken is largely a matter of individual preference. Some of the graphical exercises may be taken as soon as the ideas of Right Ascension and Declination have been mastered. For example, I have found that plotting the Orion region on page 111 makes a good introductory lesson after the subject-matter of Chapter 1 has been grasped. My hope is that the book will be found useful for anyone whose study of astronomy is likely to lead on to observation with the naked eye, field-glasses or a telescope. Most of the diagrams were drawn according to my instructions by the late Dugald Baird, whose death in 1948 deprived me of a generous helper. The sun-spot figures of area and solar latitude were kindly supplied by Mr. H. W. Newton of Greenwich Observatory. For permission to reproduce the drawings of Jupiter and Saturn I have to thank the Rev. J. E. T. Phillips. I also received much help from Mr. G. F. Kellaway, but for any errors or shortcomings which the book contains I alone am responsible.

* Clarendon Press, 1924

Anyone who is likely to take a lasting interest in astronomy is recommended to join the British Astronomical Association. This is a society of over 2,000 members which caters particularly for the amateur. Monthly meetings take place in London at the rooms of the Royal Astronomical Society at Burlington House, and the Journal is published ten times a year. Experts are very ready to give encouragement to all those who want help and advice.

E. O. T.

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Chapter 1

Introduction to the Solar System

ASTRONOMY is a peculiar subject, for a great deal of it may be described in either of two ways—as it appears to our deluded senses (and this is how the ancients apprehended it), or as man has found out that it really is. Some sections of it are better described in terms of what appears rather than what really is ; but as we study the subject we must try to bear in mind whether the description is in terms of the apparent or the real. Another matter that must not be forgotten is that some of the statements we make are only roughly true, true enough for the degree of knowledge which the student has so far reached ; but as he learns more he will see that they need modifying because they are not strictly true in detail.

Different people will have different aims in their study of the subject. Some will need it for the navigation of ships or aircraft. Others will read about it because they want to keep abreast of modern discoveries concerned with the host of stars that we can see and photograph ; and yet others because they like to become familiar with the constellations and want to make observations with a telescope. This book is intended to give a start to those who want to learn their way about the sky and make observations with quite small instruments or with no instruments at all. And let it be understood that there is a great deal to interest and occupy those who take up naked-eye astronomy. In these days of photography and giant telescopes it is a somewhat neglected branch of the subject.

The Sky seen without Instruments

First let us consider what the observer sees when he looks at the sky on a clear moonless night. He has no telescope or field-glasses. He sees perhaps 2,500 points of light which for the moment we will call stars. They vary somewhat in colour and a great deal in brightness. The arrangement of them in the sky is not obviously other than haphazard, but an observant person will soon see that some large areas of the sky contain few bright stars while other regions of the same size contain many. Some curious shapes and patterns will be seen—a large square perhaps, a big arc of a circle, an equilateral triangle; and with a little imagination we can see some resemblance to familiar objects or living creatures, a saucepan, a sickle, a flying bird or an animal with a tail. These patterns change in shape so slowly that the ancients regarded them as absolutely fixed: by naked-eye observation no man could detect any change in them in a lifetime. But it has been known from the remotest times that among these "stars" there are five bright star-like objects which do change their positions with respect to the others in most complicated ways; and during the course of months or years they will move from one star-group to another. These wanderers are *planets* (the word planet comes from a Greek word meaning a wanderer) and we have here a most important distinction: stars do not change their positions with respect to one another, but planets appear to wander about among the other bright points which are *stars*.

The astronomers of olden times found it very hard to explain these movements and peculiarities. All scientists seek for explanations of what they observe. The ancients believed what they saw—stars and planets moving round a fixed earth. The movement of the stars was, they believed, due to all the stars being fixed on to a single sphere, while the Sun, the Moon and each of the planets was fixed to a single transparent sphere of its own; and as the spheres spun round they made a heavenly harmony (the "Music of the Spheres") so divine that gross man was unable to hear it. This is referred to at the end of Plato's "Republic" and in Milton's "Arcades."

The Solar System

Now for the modern explanation of these differences—the explanation which we know to be the true one. It involves understanding what we mean by the *Solar System*, a term which is constantly used in all astronomical work. Stars are intensely hot and shine with their own light, as a white-hot poker does. Most of them are thousands of times bigger than the Earth. They differ very much in size, in temperature, and in distance from the Earth. The Sun is a fairly ordinary star, not remarkably large or small or hot or cold. It appears to us so splendid simply because astronomically

speaking it is very near to us, thousands of times nearer than any other star. Planets are bodies which move round our Sun, and they shine not with their own light but with reflected sunlight. The Earth is a small planet very near to the Sun. These are the chief members of the Solar System—the Sun and its attendant family of planets; and it is important to get clear on that point, that the Solar System contains one star and one only, our star, the Sun. This theory, that the Sun and not the Earth is the central body round which the planets move, had been put forward by Aristarchus of Samos in the 3rd century B.C. It was worked out much more fully by the Polish astronomer Copernicus in the 16th century. And yet we cannot quite leave it at that; the Solar System contains other bodies besides the Sun and the Moon and the Earth and the five bright planets which have been known and recognized as peculiar objects since before the building of the pyramids of Egypt.

The Movement of Heavenly Bodies

A body is said to *rotate* when it spins on its axis, to *revolve* when it moves round another body. The planets revolve round the Sun: they move not in circles but in ovals or *ellipses*, though none of these ellipses are very elongated in shape, not very different from circles—none of them, for example, anything like the long section of a rugby football. The paths (or *orbits* as they are called) of the principal planets are approximately but not exactly in the same plane. The Copernican theory given to the world in 1543 had established the fact that the Moon was a small body revolving round the Earth, and one of the first users of telescopes, in the early years of the 17th century, Galileo, at Padua in 1610 saw that the planet Jupiter also had small bright objects revolving round it, moons or *satellites* as they are better called; and from that time down to the present day more satellites have been discovered revolving round Jupiter and other planets, though some planets are without any satellites at all. Since the beginning of the 19th century about 2,000 small planets have been discovered, most of them between the orbits of Mars and Jupiter. These are known as the *Asteroids* or Minor Planets. The invention of the telescope has also revealed the existence of two other large planets besides the five major planets known to the ancients ; and in 1930 yet a third extremely faint and small planet was found revolving at a very remote distance from the Sun.

Other Objects in the Solar System

There are yet other objects which are members of the Solar System. Everyone has heard of comets, though the popular idea that they are objects which are seen to rush across the sky is quite wrong. They move in very elongated paths, but since they revolve round the Sun they also must be included in our list of members of the Solar System. Then there are what most people call shooting stars, though astronomers call them *meteors*—a better name, for they certainly are not stars. A few can be seen on almost any fine night—star-like objects which move rapidly, leave a streak of light and are gone. They are small bits of stone or metal rushing through our atmosphere. Lastly, there is probably a certain amount of uncollected dust in inter-planetary space, and this may account for a strange faint light, easy to observe under the right conditions and known as the Zodiacal Light. We describe this in greater detail on page 91.

That, then, is the Solar System : Sun, planets, satellites, comets, meteors and dust. A question naturally arises : Are there solar systems going round other stars ? The answer is that we have recently gathered some evidence for the existence of heavy planets revolving round one or two other stars ; but whether there are other systems of many planets revolving round a single star we simply do not know.

We are now in a position to understand our first distinction between stars and planets. The planets seem to move among the stars, but they are comparatively close to the Earth, and we see them moving across the background of the far more distant stars. Their movements are complex because, apart from *their* movement, *we* are constantly shifting our place of observation, by ourselves making a journey round the Sun ; and also because they move in ellipses which lack the simplicity of circles.

The following table gives the more important facts about the chief members of the Solar System :—

	Mean distance from Sun in millions of miles	*Mean diameter in miles*	*Time of Rotation*	*Time of Revolution round Sun*	*Number of Satellites*
*Mercury	36.0	3,000	88 days	88 days	None
*Venus	67.2	7,600	225 days ?	225 days	None
Earth	92.9	7,913	23h 56m 4s. 100	365¼ days	One
*Mars	141.5	4,200	24 37 22.654	687 days	Two
*Jupiter	483.3	85,700	9 53	11¾ years	Eleven
*Saturn	886.1	71,100	10 14	29½ years	Nine
Uranus	1,783	30,900	10. 8	84 years	Five
Neptune	2,793	33,000	15 40	165 years	Two
Pluto	3,666	Smaller than Earth	Unknown	248 years	None known
The Sun		864,000	About 25 days		
The Moon		2,160	Mean distance from Earth, 238,900 miles		

* These are the five bright planets which have been known from the earliest times.

Most of the Asteroids are between the orbits of Mars and Jupiter.

It will be seen that the remotest planet, Pluto, is at a mean distance of 3,666 million miles from the Sun. Light takes about five and a half hours to traverse this distance. We now know that the distance of the nearest star is about 25 million million miles : for this journey light takes about 4.3 years. Thus we say that the nearest star is 4.3 light-years away. The question of star distance will be discussed in more detail later. The subject is mentioned here merely to show what we mean when we say that the Solar System is isolated in space, or that it is very small compared with the distance separating it from even the nearest star.

Drawing an Ellipse

An ellipse may be drawn by tying together the ends of a piece of cotton and keeping it taut with a pencil which is moved round two drawing-pins (instead of round one pin, which would produce a circle). The eccentricity or degree of ovalness may be increased by a wider separation of the pins. Each pin position is called a focus of the ellipse, and the Sun is in one focus of each of the planetary orbits.

The following equation if plotted on graph paper will give an ellipse :—

$$\frac{x^2}{16} + \frac{y^2}{9} = 1$$

Kepler's Laws

It must not be supposed that when Copernicus' theory that the planets moved round the Sun was given to the world in 1543 the complex apparent movements of the planets were immediately made clear. Copernicus assumed that the planets revolved in circles with the Sun not at the centre. He was wrong. It was Kepler, a native of Württemberg, who showed, in the early years of the next century, that the paths of the planets were not circles, but ellipses. His three famous laws of planetary motion are :—

1. Every planet moves round the Sun in an ellipse with the Sun in one focus.
2. The Radius Vector (or straight line joining planet to Sun) moves over equal areas in equal times.
3. The squares of the times of revolution of the planets are proportional to the cubes of their mean distances from the Sun.

Newton's Law of Gravitation

These laws were discovered as the result of years of laborious work. Isaac Newton later deduced them from his own law of gravitation, given to the world in his "Principia," published in 1687. The Law of Gravitation states :—

Every particle of matter attracts every other particle of matter with a force proportional to the mass of each and to the inverse square of the distance between them.

It is this attraction or Gravitation which controls the planets in their movements round the Sun, and the satellites in their movements round the planets.

Chapter 2

The Sun

The Sun is probably the only astronomical body whose existence is really necessary for life on the Earth. It is a vast and extremely hot globe of which the outside is composed of gases at a temperature of about 6,000°C. What the inside is like at a temperature of some millions of degrees and at an enormous pressure it is not easy to imagine. The Sun is more than a million and a quarter times the volume of the Earth and has a density of nearly one and a half times that of water, so it cannot be composed throughout of gases in any such condition as we know on the Earth. Moreover, the surface regions are extremely rarefied, so the central parts must be very dense—probably denser than our heaviest metals. It certainly is not burning, in the sense in which the term is generally understood. Burning implies undergoing a chemical change, uniting with other things to form perhaps water and carbon dioxide and ashes. That the Sun certainly is not.

The Sun's Heat

There are some statements which scientists make which nearly always give rise to certain stock questions. If the Sun is not burning how does it remain hot ? This is an old problem which has caused a lot of trouble. Here is an answer which has been tried. If the Sun is a gas parting with heat, then it will get cooler. But when a gas cools, it contracts. But when a gas contracts it grows hotter. Therefore, the Sun is generating its own heat by contraction. However, this explanation has had to be abandoned : it has been proved that contraction could not possibly account for the great length of time for which we have evidence that the Sun has already been shining.

Another theory depended on the simple fact that when a moving body is brought to rest a certain amount of heat is generated. Millions of meteors must be drawn into the Sun every day, and every one of them must produce some heat by having its movement stopped.

Perhaps this could account for the Sun's vast stores of energy. But we know enough about the weight of meteoric matter which the Sun can accumulate in a given time to be able to say that this theory also must be given up.

There is no doubt now that the Sun's energy is sub-atomic. We know that the atoms of the elements are not the simple structureless units that they were at one time thought to be. Atoms of certain elements undergo changes and are converted into atoms of other elements. In the Sun the principal change seems to be the conversion of hydrogen into helium. These changes result in the release of enormous quantities of energy in the form of the light and heat which the Sun gives out. In this process of change a certain amount of matter ceases to exist as matter and is converted into radiation. The Sun is always getting lighter at the rate of 250 million tons a minute, day and night, year in, year out. Yet the Sun is so enormous that it can afford to lose its substance at this rate for millions of years before coming to an end.

The Sun is not an easy object to observe, nor generally a very exciting one when we do observe it. Of course we must never look directly at it through a telescope or field-glasses unless its brightness is reduced by fog or cloud. In clear weather we must take precautions by stopping down the aperture of the telescope and using a dark glass, or by using a special reflector which sends only a small part of the light and heat through the eye-piece. Or we may point a mounted telescope to the Sun, and then pull out the draw-tube a short distance and focus an image of the Sun on a piece of white paper held a few inches behind the telescope. And what do we see? Generally a plain circle, brighter in the centre than at the edge and with perhaps a few dark marks on it, and just possibly a few light marks in the darker edge, and that is all.

Sun-spots

But these dark marks—*sun-spots*—are interesting and mysterious and not without some influence on the Earth; how much influence it is hard to say. Rarely they are visible to the naked eye as black specks, but any naked-eye sunspots must be many times bigger than the Earth. Their existence has been known for centuries,

but systematic observation of them has not been carried out for more than about one hundred years. What does systematic observation mean? Keeping accurate records of their shape, size, number, position on the Sun, frequency, movements, and (in quite recent times) even of their temperatures. From detailed observations of them we now know that in general they increase in number for a few years, though irregularly: then for two or three years spots are relatively many and frequent. We speak of such a time as *sun-spot maximum*. Then they decline, and a few years after maximum the spots are few and infrequent: this is a time of *sun-spot minimum*. An increase sets in, and a few years after one maximum we have another. Using the figures on page 10 you can draw a graph to show these changes. On one-tenth inch graph paper, take one-tenth of an inch for each year on the horizontal scale (that is to say, on the vertical lines) and one-tenth for 40 units of area on the vertical scale. You will not get the degree of accuracy that is given in the figures, but can estimate near enough. Another curve can be drawn on the same side of the same piece of paper in another colour to show the mean latitude of the spots; that is, their distance from the Sun's equator. From these graphs, better than from the figures, you will get a general view of the Sun's peculiar behaviour over more than half a century; you can study the length of the sun-spot period (maximum to maximum), you will see whether the minima are half-way between the maxima, and you will see that an early indication of the approach of a new series of spots is connected with their latitude. You will have an opportunity of discovering things for yourself, which (within limits) is more interesting than being told the facts. Column 2 shows the Mean Daily Area corrected for fore-shortening and expressed in millionths of the Sun's hemisphere.

There is a relationship between the *aurora* and the frequency of sun-spots; in fact, a graph showing the frequency of the aurora follows nearly the same course as the sun-spot graph, the aurora being most frequent at the time of sun-spot maximum. The aurora is a brightening of the night sky occasionally seen in England, more often in Scotland, and much more often in polar latitudes. It is known to be a glowing of the rarefied upper atmosphere caused by outpourings of electrified particles from the Sun. A great display like that of January 25th, 1938, is extremely impressive. On this occasion the air was very clear over much of England, and there was no moon. Most of the sky was brilliantly lit up with red and green patches and streamers through which the bright stars shone clearly. It lasted with varying intensity throughout the night. But such a display is a very rare event, and many aurorae are so faint as to escape the notice of the unobservant. If an expert observer in

Year	*Mean of daily area*	*Mean distance from Equator*	*Year*	*Mean of daily area*	*Mean distance from Equator*
		o			o
1874	604	10.81	1911	64	6.49
5	248	11.22	2	37	8.06
6	126	11.17	3	7	23.23
7	108	9.57	4	152	21.79
8	22	7.58	5	697	18.77
9	38	21.96	6	724	15.81
80	440	19.64	7	1,537	14.63
1	681	18.30	8	1,118	12.75
2	1,000	17.81	9	1,052	10.76
3	1,154	13.06	20	618	10.43
4	1,079	11.26	1	420	7.90
5	807	10.38	2	252	8.02
6	381	10.33	3	55	15.26
7	179	8.44	4	276	22.73
8	89	7.39	5	830	20.20
9	78	11.61	6	1,262	18.66
90	99	21.99	7	1,058	15.05
1	569	20.31	8	1,390	13.50
2	1,214	18.39	9	1,242	10.51
3	1,464	14.49	30	516	9.87
4	1,282	14.18	1	275	8.31
5	974	13.54	2	163	8.32
6	543	14.33	3	88	10.56
7	514	7.96	4	119	23.75
8	375	10.49	5	624	23.30
9	111	9.54	6	1,141	20.35
1900	75	7.74	7	2,074	17.02
1	29	10.37	8	2,019	14.79
2	62	17.64	9	1,579	13·42
3	340	19.94	40	1,039	11·17
4	488	16.57	1	658	10·38
5	1,191	13.10	2	423	8.99
6	778	13.99	3	295	10.09
7	1,082	12.12	1944	126	21.53
8	697	10.38			
9	692	9.71			
1910	264	10.53			

England sees as many as fifteen aurorae in a year, even in the years of sun-spot maximum, he has made a very good score.

It is not possible to say that any connection has been established between British weather and the sun-spot period, but it does look as if the rainfall in some parts of the world is greatest at times of sun-spot maximum. Disturbances on the Sun also have a detrimental effect on long distance wireless transmission, particularly on the short wave-lengths.

All spots on the Sun appear to drift across the disc from left to right—that is, from east to west—in about a fortnight. This is due to the Sun's rotation on its axis. The same group of spots will sometimes remain visible during two or three rotations ; but the interval between two passages of a spot across the middle line of the disc will not give the true time of the rotation of the Sun because the Earth has in the meantime shifted its position. The equatorial regions rotate in about 25 days, but in higher latitudes the period is longer. The spots are gigantic and intense rotating storms in the gases forming the Sun's surface. The gases rise upwards, expand, and are thus cooled and so appear darker than the rest of the *photosphere* —as the visible surface of the Sun is called.

Eclipses

Eclipses of the Sun are caused by the Moon passing between the Sun and the Earth. If this happens when the Moon is comparatively near to the Earth in its slightly oval orbit the whole of the photosphere is covered and we get what is known as a *total eclipse* of the Sun. The detailed explanation of eclipses must be left to a later chapter, but as the total solar eclipse has given us a good deal of valuable information about the Sun something must be said about it where we are describing the Sun itself.

When the whole of the photosphere is covered by the Moon, or, as astronomers say, " during totality," we see other parts of the Sun which are ordinarily invisible. Flame-like objects called *prominences* are seen to extend far from the Sun's edge : these are composed mostly of glowing hydrogen. Beyond these is a whitish extension, which nearly all text-books describe as a pearly glow, called the *corona*. It may reach considerably more than a whole diameter away from the Sun. Until about the middle of the 19th century these appendages of the Sun had never been observed except during a total eclipse, and as total eclipses occur only about once in two years, and totality lasts on an average only about three minutes, almost nothing was known of their real nature. But with the invention of the spectroscope it became possible to observe the prominences on the uneclipsed Sun, so our knowledge of them has greatly increased. They are of two kinds, eruptive ones which sometimes undergo very violent changes in a few minutes, and quiescent ones which seem to remain sulky for days on end.

Of the corona we know less, as except for the parts very close to the photosphere it has been observed only during totality. The spectroscope tells us that it is composed of electrified particles and fine dust. Its structure varies with the sun-spot cycle, showing a more regular arrangement at maximum and wide extensions at minimum. What we really need is the development of some means by which we can observe the outer corona at all times ; but such an advance seems at present to be most unlikely.

Plate II shows a photograph of the total eclipse of the Sun of June 29th, 1927. It is the only total solar eclipse which has ever been photographed in Great Britain, because the next British total eclipse before that took place in 1724. This statement might give the impression that total eclipses are very rare events. They are not in themselves rare, as there is one generally about once in two years ; but in any one place on the Earth there are, on the average, about three in a thousand years. This eclipse was total along a belt about 30 miles wide, across the north of England. Totality lasted about 23 seconds, which is a very short time, but even in the most favourable conditions it cannot last longer than eight minutes.

The Sun will always be the object of much research, as among the thousands of millions of stars known to us it is the only one which we can examine in detail.

Chapter 3

The Moon

OF ALL the bodies which we see in the sky, with the exception of meteors,* the Moon is very much the nearest. You will remember that the Sun is about ninety-three million miles away, and even the Sun is one of our nearest neighbours. The Moon is less than a quarter of a million miles distant—less than ten times the distance round the Earth. It is also one of the smallest of the heavenly bodies with which we are acquainted, being in volume about one-fiftieth of the size of the Earth. The surface of the Earth is about thirteen times that of the Moon.

The fact that the Moon is so near to us makes it a most interesting body when seen through a telescope. It is as different as possible from the Sun. Whereas the Sun is a mass of fiery material, at an extremely high temperature, lashed by the fiercest storms, continually changing, the Moon is dead, rigid, unchanging.

It has been well said that the Sun is a laboratory, while the Moon is a museum—that is to say, the Sun is the scene of continual change, while the Moon is like stones under a glass case—always presenting the same appearance year after year.

The Face of the Moon

But if we examine the Moon with a small telescope, or even with a pair of field-glasses, we shall see that the marks on the surface are relics of a former time when she was the scene of great activity.

On the whole, the surface of the Moon is not at all smooth. There are, it is true, large areas which show comparatively little irregularity ; but, on the other hand, there are many regions dotted with what appear to be extinct volcanoes, and crossed by mountain ranges. Since there are no clouds on the Moon, the features stand out with remarkable clearness.

Perhaps the most conspicuous objects on the surface of the Moon

* See page 65.

are the almost circular mountains, of which there are such a vast number. These are generally spoken of as the *Craters*, and certainly they bear some resemblance to the craters of extinct volcanoes such as we know on the surface of the Earth. Those on the Moon vary much in size, from Tycho, which is more than two miles deep and more than fifty miles across, to comparatively small craters a mile or so in diameter. The "Walled Plains" are even larger than the craters ; Clavius, for example, is about 140 miles in diameter.

Many of the craters are probably volcanic, but there are others which lend a good deal of support to what may be called the "impact theory" of their origin. This is the view that the majority of the craters are not volcanic, but are caused by meteorites striking the surface of the Moon. Without going into the matter more fully, we may remark that there is a good deal to be said for both theories, and there are great difficulties in the way of either. A very small telescope is sufficient to show the great variation in size and shape and general appearance of the craters, as well as their remarkable distribution. In some parts they are crowded together ; in others they are almost absent. The beginner who studies the lunar surface with a small instrument will soon see that if he tries to account for the origin of the craters he is faced with a very difficult problem. Probably both meteors and volcanoes have had a share in producing the lunar features. The scenery of the Moon, could we explore it, would be found to be much more rugged than that of the Earth ; for whereas wind and rain and snow and ice are continually helping to wear down the roughness of our mountains, these agencies, if they ever did exist on the Moon, are now no longer there.

Life on the Moon ?

A visitor from the Earth would see at every turn sharp peaks and steep and jagged precipices such as most of us have never known on this earth. But it cannot be said positively that we should see no water and no signs of life. There is still a difference of opinion on this point, as the following extracts will serve to show.

1. From the *Memoirs of the British Astronomical Association*. The Moon. Dated September 23rd, 1916. From an article, "Lunar Changes," by W. H. Pickering, A.R.A.S.

"The view that the Moon is a dead unchanging world, . . . is so widespread and so firmly rooted in the minds not only of the general public but of the astronomical world as well, that the united and practically unanimous opinion of all the greatest selenographers of successive generations has hitherto been able to produce but little impression upon it.

". . . The writer knows of no astronomer who has devoted sufficient time to the study of the Moon to be worthy of the name of selenographer who has not become convinced by his own independent studies that changes both periodic and non-periodic are actually at the present time taking place upon its surface.

". . . The body most resembling the Moon with which we are acquainted is the planet Mars. There is now little doubt that the variable white spots which are found upon it are due to snow, and the variable dark spots to vegetation. The only plausible explanation of the similar changes occurring upon the Moon is that these changes are due to the same causes. If so, they involve the presence of both air and water.

". . . the evidence of the existence of ice upon the Moon is very strong.

". . . proof of the existence of vegetation, as indicated by the variable dark spots, is open to every possessor of a 3in. telescope."

2. From *An Introduction to Astronomy*, by Prof. F. R. Moulton. The preface is dated September 25th, 1916. On page 216 we find :

"W. H. Pickering has noticed changes in some small craters, depending upon the phase of the Moon, which he interprets as possibly being due to some kind of vegetation which flourishes in the valleys where he supposes heavier gases, such as carbon dioxide, might collect. Some of his observations have been verified by other astronomers, but his rather bold speculations as to their meaning have not been accepted."

It may be argued that this is rather old history ; but the problem seems to be in much the same state in the middle of the 20th century. In one of the Harvard Books on Astronomy, *Earth, Moon and Planets* printed in the U.S.A. in 1945, we are told that if any changes have occurred in the lunar landscape during the centuries of intensive telescopic observation, the changes are too small or uncertain for the observers to agree upon their reality. This probably refers to changes over a large area. On the other hand, an observer reported in the Journal of the British Astronomical Association that on October 19th, 1945, he saw a minute but brilliant flash inside the crater Plato. Another observer reported a bright flash equal to a third-magnitude star, seen on April 15th, 1948, near Grimaldi. In the *Monthly Notices* of the R.A.S., Vol. 109, No. 2, p. 177 (1949) a claim is made for "what is believed to be the first really definite physical change ever recorded on the Moon".

The Moon Through a Telescope

Plate I will give a better idea of the telescopic appearance of the

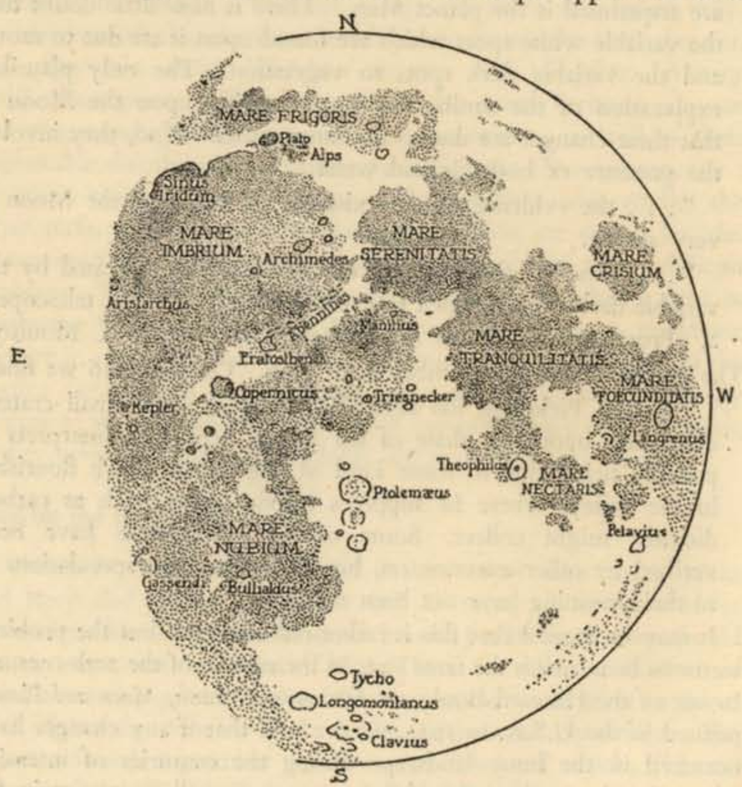


Fig. 1. Key to photograph of Moon.

Plate I

THE MOON, MARCH 12, 1938
THREE DAYS AFTER FIRST QUARTER

From a photograph taken with the 7" Refractor at Wellington College. Exposure ½ second. This is the unaided work of a schoolboy.

By kind permission of Dr. P. M. R. Hemphill

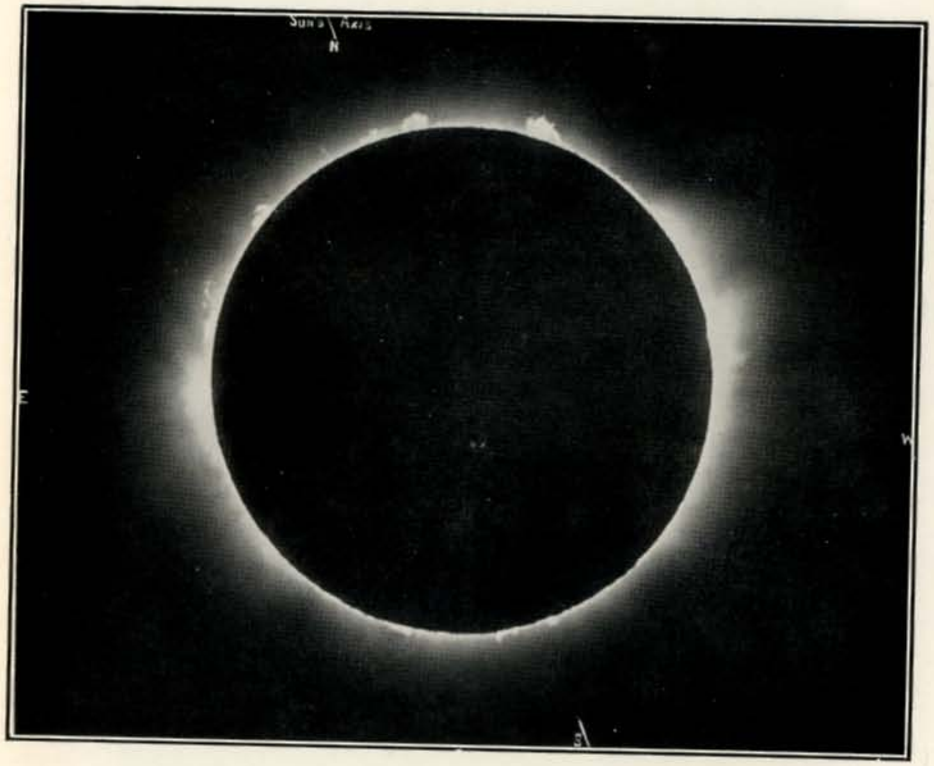


Plate II

TOTAL ECLIPSE OF THE SUN, JUNE 29th, 1927

6-inch refractor, focal length 45 feet, Exposure 19 secs. Taken at Giggleswick, Yorks.

Reproduced by kind permission of the Astronomer Royal

Moon than can be gained from many pages of description. It shows the Moon about three days after First Quarter, when she is waxing. Astronomical telescopes give an inverted image, but for the sake of the observer with a small instrument the photograph is not inverted. Note the large dark areas which are comparatively smooth, still known as " seas," and the immense number of craters, large and small.

The Moon is a lighter body than the Earth, and therefore objects on its surface would not be attracted with so great a force as on the surface of the Earth. A body on the Moon would have one-sixth of its weight on the Earth. This fact may partly account for the great size of the lunar craters, for in the case of a volcanic eruption on the Moon the ejected materials would be relatively light, and the explosive force of the eruption would hurl the stones and lava a greater distance than would happen with volcanoes on the Earth, in fact about six times as far.

The motions of the Moon should be studied carefully. She is like a great clock-hand moving across the face of the sky, and in this way has been, in the past, of immense service to navigators in the determination of time and thus of longitudes at sea, though this method has now fallen into disuse.

You have probably noticed that on some nights, although there are no clouds in the sky, the Moon is nowhere to be seen. At other times she is conspicuous throughout the night. When she is absent from the night-sky she is in the same part of the heavens as the Sun, rises with him, passes across the sky, as he does, in the day-time, and sets near him in the evening. But this will not be the case for many nights together, for the Moon changes her position rapidly, and sets later and later every day.

Let us try to make this clear in another way. Suppose that on a certain night the Moon is quite close to the Sun and they set near together and at about the same time. On the next night the Sun will set some time before the Moon. You may regard it as a race, and consider that the Moon has lost a certain amount of ground after the first lap.

The Moon was invisible on the first night, for she shines only with reflected sunlight, and on that night the half of her which was lit up by the Sun was the half which was turned away from the Earth.

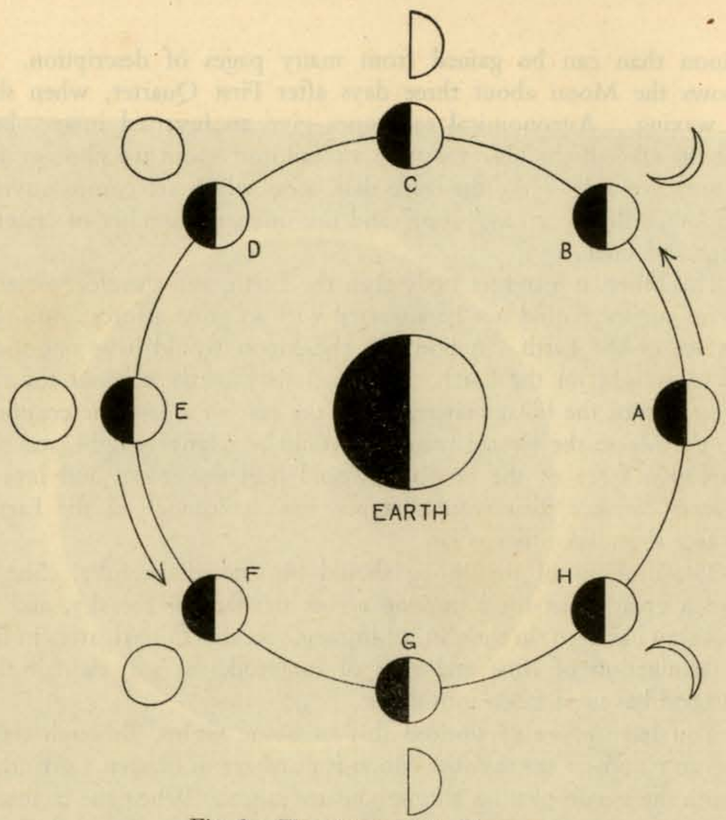


Fig. 2. The phases of the Moon.

On the next night the illuminated half was mostly turned away from the Earth, but not altogether ; and we could see a narrow piece of her edge—what we call a crescent—and that is what is popularly called the " New Moon." Still each night we notice the position and appearance of the Moon at about the time of sunset, and we shall see that she sets later and later, and as time goes on we shall find there is a Full Moon, and then we shall notice that the Moon is rising at about the time when the Sun is setting.

The Earth is then between the Sun and the Moon, and the illuminated half is turned towards the Earth. Still she rises later day after day ; the bright portion gets smaller and smaller ; she approaches closer and closer to the Sun until she once more becomes invisible for a few days, only to go through the same cycle of changes again.

Fig. 2 explains the *phases* of the Moon, or the way in which her appearance alters. In the diagram the light of the Sun is supposed to be coming from the right-hand side. The Moon is shown in eight different positions in her path round the Earth. When the Moon is at A she is invisible, being lost in the Sun's rays. This is *New Moon*. When the Moon is at B we see a small portion of the bright hemisphere, and this is represented by the crescent. C is *First Quarter*. D is known as the *gibbous* phase. At E the bright hemisphere is turned towards the Earth and we see *Full Moon*. Then the bright part which we see diminishes as the Moon moves round towards A again, passing through G, when we see *Last Quarter*.

The Moon performs a revolution round the Earth in about 27 days 8 hours, and will come back to almost the same position in the sky, relatively to the stars, in this time. But because the Sun also appears to be losing ground in the race (actually because the Earth is moving round the Sun) the Moon takes about 29 days 13 hours to return to the same position in the sky with respect to the Sun. In other words, the period from New Moon to New Moon is about 29 days 13 hours.

The question is sometimes asked—Does the Earth shine ? Considering that all the other planets are bright with reflected sunlight we should naturally expect the Earth to shine in the same way, and we may therefore suppose that to an observer on Mars or Venus the Earth would be a brilliant object in the sky. But we have a more definite proof. When we look at the crescent Moon we are often able to see the rest of the Moon very faintly illuminated. This is due to the light reflected from the Earth's surface, and is therefore correctly called *Earthshine*.

It is a noteworthy fact that we see only one side of the Moon. This is because the Moon revolves round the Earth in exactly the same time as she takes to rotate on her axis.

When the reader has drawn the Equator and the Ecliptic as suggested on page 40, he can learn a good deal from the diagram about the naked-eye appearance of the Moon. The apparent path of the Moon among the stars is never far from the Ecliptic, not more than about five degrees away from it at any time, though it does not follow the same course from one month to another. Consider the position in spring when the Sun is near the Spring Equinox. When the Moon is about three or four days old (that is, three or four days after calendar New Moon) she will be in about 3 hours of R.A.*, to the east of the Sun and therefore in fairly high north declination, easy to see in the western sky after sunset. At First Quarter she will be near the Sun's midsummer position, so will have a high meridian altitude. The Full Moon a week later will be in about 12 hours of R.A. from the Sun, so she will be near the Equator. At Last Quarter she will be near the Sun's midwinter position, so will be low in the sky and above the London horizon for only about eight hours. In the same way the student should see that a winter Full Moon has a high meridian altitude and is long above the horizon. A young Moon in autumn is in far south declination and will not be a conspicuous object in the evening sky.

It will also be seen that in late summer the Moon, when at about full, is increasing its northerly declination. Study the diagram, or Fig. 12, notice that for any given line of Right Ascension, a body will rise earlier the more northerly the declination. On the average, the Moon's motion among the stars causes its Right Ascension to increase by about 50 minutes a day, and from this cause alone it would rise later each day by that amount. But when this is combined with increasing north declination, the net result is that for four or five days it rises on the average only some 25 minutes later each day. This repeated appearance of a full or nearly full moon rising at about sunset for several successive evenings attracts attention and it is called the "Harvest Moon." Actually the "Harvest Moon" is the Full Moon nearest to the date of the Autumn Equinox, so it may be either a September or an October Moon.

The Moon at First Quarter is about 90° or 6 hours east of the Sun, at Full Moon 180° or 12 hours from the Sun, so an understanding of the phases of the Moon may sometimes help us to find our direction. In time of war people take an intelligent interest in the Moon and its movements, as direction-finding may be important, and the Moon's effectiveness in light-giving is associated with the likelihood of air raids.

If the Moon's apparent path exactly coincided with the Ecliptic, then at Full Moon the Sun, the Earth, and the Moon would be in one straight line. The Moon at Full would always pass into the Earth's shadow, undergoing an eclipse. Sometimes a whole year

* For explanation of R.A., see page 40.

passes without a lunar eclipse. If the whole of the Moon goes into the umbra of the Earth's shadow (see below) we have a total eclipse. If part of the Moon fails to get into the umbra it is a partial eclipse.

Shadows

Shadows come into several branches of astronomy, and we must look into the question in detail and understand the structure and varying appearance of a shadow.

In Fig. 3 let S be the Sun, which sends out light in all directions. Let D be a dark sphere giving no light of its own.

Draw four lines, each tangent to both S and D :—

One tangent to top and top,
One to bottom and bottom,
One to top and bottom,
One to bottom and top.

This produces in the diagram three areas :—

One marked black,
One lined,
One dotted.

They are flat areas in the diagram, but in space, since S and D are globes, these regions will be volumes—bits of cones.

From the black, no straight line can be drawn to S without hitting D. Thus S is entirely invisible. Black is complete shadow known as *Umbra*.

From the lined, straight lines can be drawn to some parts of S, but not to others. S is partly obscured by D. This region gets some light, but not full light. The lined region is partial shadow known as *Penumbra*. And the nearer to the centre line S D produced, the deeper the darkness of the penumbra.

From the dotted region, lines can be drawn to the edge of S on both sides. (Lay a straight edge along the diagram and you will see that this is true.) Thus D will be seen as a small circle against the larger circle S like a shilling on a half-crown. D will appear central on S only from the centre line. If the view is from just beyond the apex of the umbra cone, D will be nearly as big as S, like a florin centrally on a half-crown. As one moves into the dotted part further from the umbra, the nearer object D decreases in apparent size faster than the more distant S, and very far from the apex of the umbra D will be a very small dot seen against S.

Now let us see some applications of these principles in astronomy. In studying diagrams the reader must not be worried over the faulty representation of the relative sizes and distances of the objects.

In the diagram, J1 is part of Jupiter* with a shadow of a near satellite falling on it. It will be seen that the shadow is mostly umbra. It will be a dark shadow with not much partial shadow at the edge.

J2 is Jupiter with a shadow of a more distant satellite falling on it. This shadow is mostly penumbra. The general effect will be of a much less dark shadow than in the previous case. The reader will have to refer back to this diagram when he studies Jupiter in more detail later on in the book.

The Moon, revolving round the Earth in an ellipse, varies its distance from the Earth. Solar eclipses sometimes occur when the Moon is near the Earth, sometimes when it is far away (the variation is slight, but just enough to make all the difference).

E1 is the Earth at Solar Eclipse when the Moon is near the Earth. D now represents the Moon. The umbra just reaches the Earth, and there is a *total eclipse* within the umbra, but a partial eclipse of varying magnitude over a much wider area—that is to say, anywhere in the penumbra.

E2 shows an eclipse when the Moon is far from the Earth. The umbra fails to reach the Earth : there is no complete shadow on the Earth and no total eclipse. But part of the Earth just comes within the dotted region, where the whole Moon will be seen against the larger Sun—the florin on the half-crown. This is an *annular eclipse.*

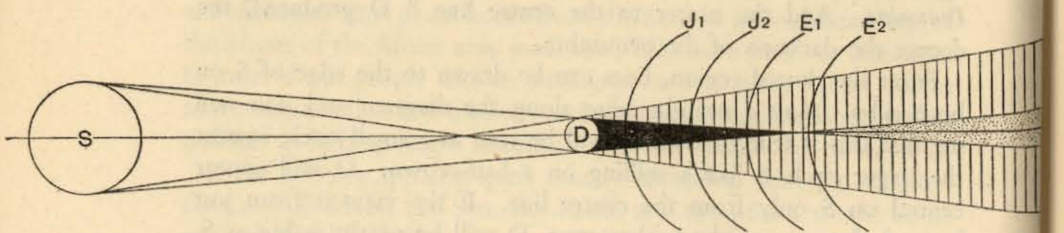


Fig. 3. Shadows and their causes.

* See page 55.

When only the lined penumbra hits the Earth, then the only kind of eclipse occurring will be a *partial eclipse.*

People sometimes ask " When Venus (or Mercury) comes between the Earth and the Sun, is the Sun eclipsed ? " No : the apex of the umbra is millions of miles short of the Earth. The view is as if from far outside the right-hand edge of the paper, and the planet appears as a small dot on the much larger Sun : in fact, Mercury in transit is invisible to the naked eye.

No shadow of any planet can reach anywhere near any other planet in the Solar System.

When a heavenly body disappears behind the disc of a nearer body it is said to be " occulted." The Moon in her apparent path among the stars often gets between us and a star or planet, thus producing an occultation. What from common usage has always been termed an " eclipse of the Sun " is, strictly speaking, an " occultation of the Sun." The expression " eclipse " is usually reserved for cases where a body shining by reflected light has its light-source cut off by entering the shadow cast by another body. The student will be able to investigate more fully the subject of eclipses and occultations when he reads the chapter on Jupiter and the phenomena of his satellites. We make no apology for repeating some of this work in other parts of the book. It is commonly not understood, and it will bear a little repetition.

Chapter 4

The Aspect of the Sky

By this expression " The Aspect of the Sky," we mean the appearance of the sky as regards position of star groups and their movement. But their position and their movement—even their visibility—will depend on three important factors : (1) the observer's latitude, (2) the time of year, and (3) the time of night. As all these factors play varying parts, it might be thought that the problem must be very complex. Certainly it is rather involved, but nothing worthy of the name of mathematics is needed for a general grasp of the subject to cover all parts of the Earth, all seasons, and all hours of the day or night.

The sky appears to us to be a globe, of which one half is above the horizon and the other half below. The observer appears to be at the centre of this blue globe. The Earth on which we live is also a globe, and we can employ similar systems of lines on these two globes for the exact location of places. First we must understand Latitude and Longitude on the Earth.

Angular Measurement

In discussing these terms and in much other astronomical work we shall have to be constantly speaking of angles and their measurement, and any reader who is not quite familiar with this elementary work must study what follows.

When one straight line meets another so as to make the adjacent angles equal, then each is a right angle. An angle which is 1/90 of a right angle is one degree, 1/60 of a degree is one minute, and 1/60 of a minute is one second. These are minutes and seconds of arc, not time. Thus :—

60″ (sixty seconds) = 1′ (one minute).
60′ (sixty minutes) = 1° (one degree).
90° (ninety degrees) = 1 right angle.

Another way in which astronomers are constantly speaking of angles is in the expression *apparent distance* or *apparent size*. This is the same as *the angle subtended* by something, the angle being at the observer's eye. A wall is 15 yards long. Then the *true* length of the wall is 15 yards. This is an unvarying length, but the *apparent* length of the wall varies. It is an angle at the observer's eye, and the size of it will depend on his distance from the wall. If he stands facing the middle of the wall at a distance of about 20 yards, and draws a line from his eye to each end of the wall, then those lines make an angle at his eye of about 41°. The *apparent* size of the wall at that distance is 41°, or, the wall subtends an angle of 41° at his eye. If he goes further away from the wall, say to 28 yards, then the angle becomes smaller and is found to be 29°. The student should familiarize himself with the ideas in the following statements :—

The apparent distance from the horizon to the zenith is 90°.
A halfpenny 3.3 miles away subtends an angle of 1″.
The diameter of the Moon is 2,160 miles.
The apparent diameter of the Moon varies between 29′ and 33′. (The Moon revolves in an ellipse, and thus its distance varies.)
The stars Castor and Pollux are about 4° apart.

Latitude and Longitude

The Earth rotates on its axis in 24 hours, and the ends of the axis are called the *Poles*—the North Pole and the South Pole. The circle drawn round the Earth exactly between the two poles is called the *Equator*. The equator is an example of what is called a *great circle* on a sphere. A great circle is one the plane of which passes through the centre of the sphere, and thus it cuts the sphere into two equal parts. A *small circle* cuts a sphere into two unequal parts.

For understanding latitude and longitude we will take a town on the earth for consideration. Let us take San Francisco (see Fig. 4). Suppose a straight line to be drawn from the centre of the Earth to San Francisco, and another straight line from the centre of the Earth to that point on the equator which is due south of San Francisco. These two lines will make an angle at the Earth's centre. The angle is about 38°. So San Francisco is 38° north of the equator ; or, in other words, we say the latitude of San Francisco is 38° N. The latitude of Cape Horn is 56° S., of the Poles 90° N. and 90° S., of Quito almost 0°, of London 51½° N.

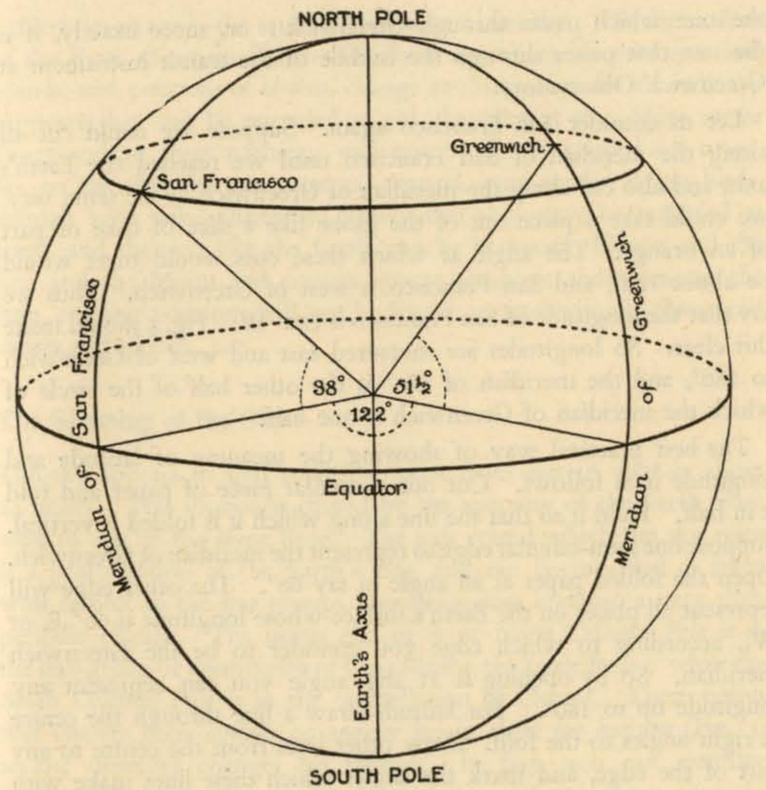


Fig. 4. Latitude and Longitude.

But Cape Spartivento in Italy is in latitude 38° N., and so is part of the Pamir plateau in Asia ; so latitude tells us only how far a place is north or south of the equator, but does not tell us on which side of the world the place is situated. The lines of latitude are drawn round the earth parallel to the equator, and are known as parallels of latitude.

Lines of longitude (or *Meridians* as they are called) are drawn from pole to pole due north and south. If we can say on which line of longitude a place is, as well as saying what its latitude is, we can state its position exactly. The meridian from which all longitudes are reckoned (just as latitudes are measured from the equator) is the one which passes through Greenwich ; or, more exactly, it is the one that passes through the middle of the transit instrument at Greenwich Observatory.

Let us consider San Francisco again. Suppose we could cut all along the meridian of San Francisco until we reached the Earth's axis, and also cut along the meridian of Greenwich in the same way, we could take a piece out of the globe like a slice of cake or part of an orange. The angle at which these cuts would meet would be about 122°, and San Francisco is west of Greenwich. Thus we say that the longitude of San Francisco is 122° W. Fig. 4 should make this clear. So longitudes are measured east and west of Greenwich to 180°, and the meridian of 180° is the other half of the circle of which the meridian of Greenwich is one half.

The best practical way of showing the meaning of latitude and longitude is as follows. Cut out a circular piece of paper and fold it in half. Hold it so that the line along which it is folded is vertical. Suppose one semi-circular edge to represent the meridian of Greenwich. Open the folded paper at an angle of say 60°. The other edge will represent all places on the Earth's surface whose longitude is 60° E. or W., according to which edge you consider to be the Greenwich meridian. So by opening it at any angle you can represent any longitude up to 180°. For latitude draw a line through the centre at right angles to the fold. Draw other lines from the centre to any part of the edge, and mark the angles which these lines make with the first line which you drew. For instance, if you draw a line on the upper side, making an angle of 38°, the point where it meets the edge will represent a place whose latitude is 38° N. Now open the paper at an angle of 122°. If the right-hand edge represents the meridian of Greenwich, the end of the 38° line will represent San Francisco in both latitude and longitude. Do the same for other towns on the Earth, and you will soon have a thorough understanding of these two terms.

It will be seen that the value in miles of a degree of longitude diminishes from the equator to the poles. At latitude 20° it is about 65 miles, at 40° it is 53 miles, at 60° it is 34 miles, and at 80° it is only 12 miles. A degree of latitude is equivalent to about 69 miles, or a second of latitude is 34 yards.

Now let us apply the same sort of ideas to the sky. On the surface of the Earth the main features are fixed : outlines of continents and islands, and positions of towns, change so slowly that for all ordinary purposes they can be regarded as not changing at all. Ships move about and so their positions will not be found printed on maps. So, on the sky, the star patterns—squares, semi-circles, flying birds, animals with tails—change so slowly that they may be regarded as fixed, and the sky, like the Earth, can be mapped. Planets and the Sun and the Moon and comets appear to move about among the stars, so their positions will not be found on astronomical charts and atlases and globes.

The Spinning of the Sky

The sky appears to spin round or *rotate* from east to west in about 24 hours. This illusion is caused by the spinning of the Earth from west to east in the same time. The axis round which the sky spins is a prolongation of the Earth's axis, and can be regarded as fixed with respect to the star groups, though it does undergo a very slow periodic change. The north end of it or *North Celestial Pole* is in the star-group or *constellation* of Ursa Minor, the Little Bear ; while the *South Celestial Pole* is in the constellation of Octans. These points will change their *altitude* or *angular height above the horizon* (Fig. 5) as the observer changes his latitude. In fact, you can examine Fig. 6 and as an exercise in elementary geometry prove that the

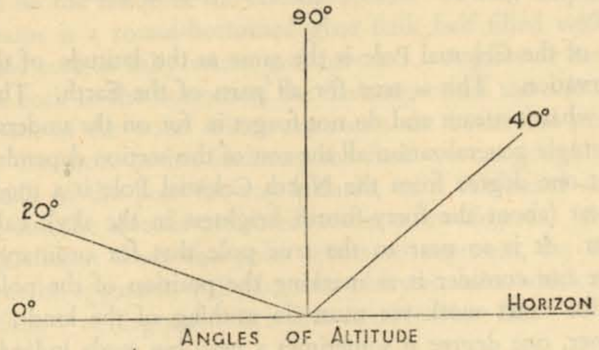


Fig. 5. Angular height above horizon.

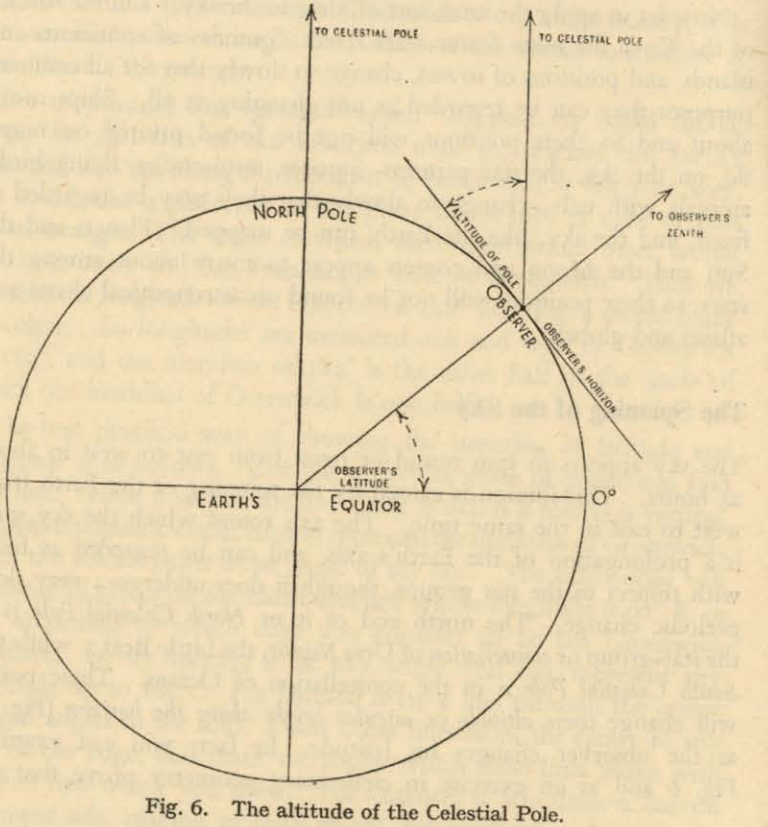


Fig. 6. The altitude of the Celestial Pole.

altitude of the Celestial Pole is the same as the latitude of the place of observation. This is true for all parts of the Earth. Think out exactly what it means and do not forget it, for on the understanding of this simple generalization all the rest of this section depends.

About one degree from the North Celestial Pole is a moderately bright star (about the forty-fourth brightest in the sky), called the Pole Star. It is so near to the true pole that for ordinary rough work we can consider it as marking the position of the pole itself, though for exact work we must do nothing of the kind : to the astronomer, one degree is sometimes a very big angle indeed. The poles then are to be regarded as fixed points in the sky, though they

will change their altitude with the observer's change of latitude : if the observer is at the North Pole of the Earth (latitude 90° N.) the altitude of the Celestial Pole is also 90°. The Pole Star is straight over his head, and the stars appear to move round him making paths parallel to the horizon. But at the Earth's Equator (latitude 0°) the Celestial Poles are on the north and south points of the horizon and the Celestial Equator passes from east to west through the *zenith* or point directly overhead. Thus the sky spins about a horizontal axis, and every star is above the horizon for 12 hours and below for 12 hours. All the stars in the sky can be seen, whereas at the poles half the stars remain for ever below the horizon.

The aspect of the sky in these special latitudes, the poles and the equator, is easy to imagine and understand ; but for intermediate latitudes where the sky axis is neither vertical nor horizontal but slanting, it is not so easy to follow. The student can look at the sky and find out for himself what happens, but this takes too long. He can look at diagrams, but the chief difficulty here is that no diagram can show the whole sky unless the sky is regarded as a sphere seen from the outside. Some people find this hard to picture with the help of a diagram on a flat piece of paper. But with practice and the exercise of a little pictorial imagination one soon becomes accustomed to the idea of the sky as a globe seen whole. For centuries, astronomers and navigators have been accustomed to the use of celestial globes, but the difficulty with them is that the horizon cannot be seen, and the constellations are seen from the outside and not as we see them on the inside of the celestial sphere. A very helpful piece of apparatus is a round-bottomed glass flask half filled with some blue liquid such as inky water, and inverted. A glass or metal rod from the cork to the bottom of the flask represents the celestial axis sticking out of the water which represents the horizontal surface of the sea. By more or less inclining the flask we can roughly adjust the altitude of the pole for any latitude, or a cardboard scale can be made and the altitude measured within a few degrees. A rubber band equidistant from the poles serves to represent the Equator. This piece of apparatus will illustrate many matters which it is not easy to follow in diagrams. It is illustrated in Plate III.

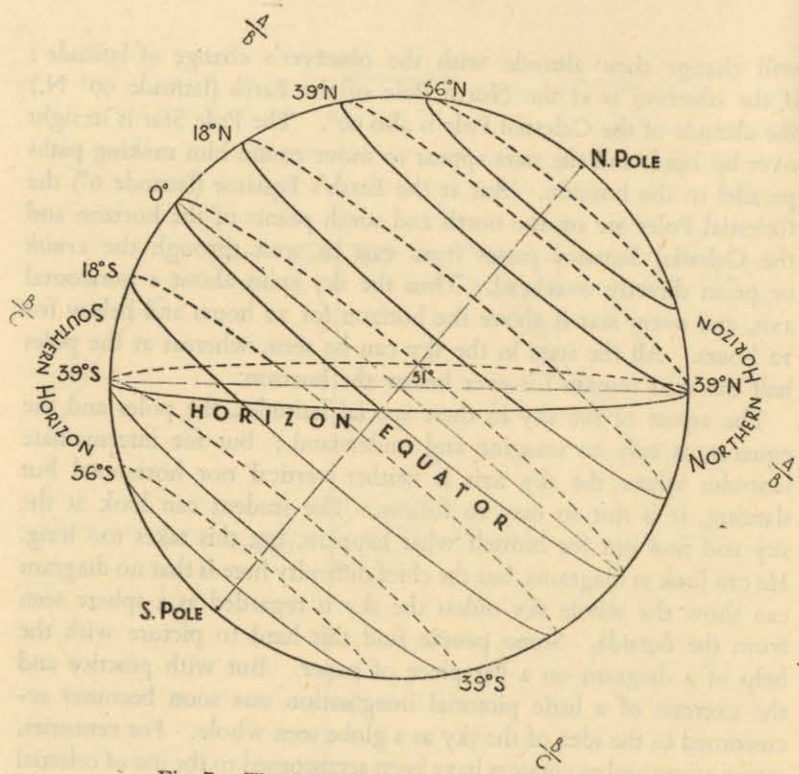


Fig. 7. The Celestial Sphere in Latitude 51° N.

Celestial Sphere in Latitude of London

The lines of latitude on the Earth are circles parallel to the Equator and, as the Earth spins, any point on its surface may be regarded as running along its own latitude line to complete a circuit in 24 hours. The corresponding lines on the sky are called circles of *Declination*, and in the same way these circles may be regarded as the daily paths of the stars. As we have already said, when the observer is at the North Pole the paths of the stars or declination circles are parallel to the horizon. Now suppose the observer goes to some intermediate latitude such as that of London, about 51° N., the pole of the sky comes down to 51° above his horizon or 39° from the zenith, and

all the declination circles towards the south are cocked up towards the zenith by the same number 39° as in Fig. 7. Thus the Equator, which at the Pole was on the horizon, is as though it were pivoted at the east and west points of the horizon, and due south of the observer it has risen to an altitude of 90° minus latitude of place (called the *Co-latitude*). All the declination circles or star paths in the northern hemisphere of the sky are more than half above the horizon, and all the star paths south of the Equator are more than half below the horizon ; or, in other words, all the stars north of the Equator spend more than half their 24 hours above the horizon, and all the stars south of the Equator spend more than half their 24 hours below the horizon. And the further they are from the Equator the more unequal are their two divisions of the 24 hours. We find that a star in 39° N. declination just touches the northern horizon without setting, while stars still further north are above the horizon even at their lowest. On the other hand, a star whose declination is 39° S. touches the horizon, but just fails to rise above it, and all stars further south than that are always below the observer's horizon.

Thus we can make a great generalization which is not peculiar to latitude 51° N. but can be applied in general terms to any latitude. The sky in any northern latitude can be divided into three parts :—

(*a*) Stars that are always above the horizon (called *circumpolar* stars).

(*b*) Stars that rise and set.

(*c*) Stars that are never seen (always below the horizon).

Stars in (*a*) are from North Pole to declination colatitude N.

Stars in (*b*) are from declination colatitude N. to colatitude S.

Stars in (*c*) are from declination colatitude S. to South Pole.

An observer in the southern hemisphere will have the South Celestial Pole above his horizon, and the student should not find it difficult to modify the generalization to suit southern latitudes.

The Meridian

The North-South line in the sky is seen to be a very significant line. It passes through the Pole and the zenith and is known as the *Meridian*. In Fig. 7 it is the circle which bounds the whole diagram. It is important because every star will be at its highest when on that line: a star will also be at its lowest on the meridian about 12 hours later, but this is generally of less importance, and in the case of many stars the lower *meridian passage* or *culmination* will take place below the observer's horizon. But altitude matters very much to the astronomer because greater altitude generally means clearer visibility. Again, in deciding what stars can be seen in any stated latitude or how favourably they can be seen we must consider the star in its extreme position—that is, its greatest or least altitude —on the meridian.

There follow some practical problems that might face any astronomer, and by reference to Fig. 8 it should not be difficult to arrive at the solutions.

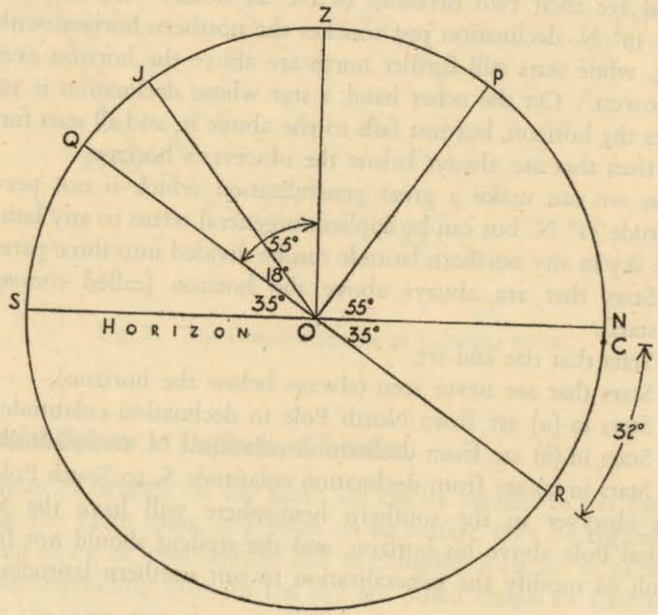


Fig. 8. Altitude and latitude on a meridian.

An observer is in Lat. 55° N.

(*a*) If Jupiter is in Declination 18° N., at what altitude will it cross the meridian at upper culmination?

(*b*) A star is seen near the horizon, almost straight below the Pole. Can it be Castor? A star list tells us that Castor is in Declination 32° N.

(*a*) Draw a circle for the meridian. Put O, the observer, in the centre and draw the geographical meridian line N. S. with N. on the right as is the usual custom. The latitude is 55° N., so put the North Pole, P, at that altitude on the north side of the diagram. Join O P. This is half the axis of the sky. A line from O to Q, the Equator, due south, will be at right angles to O P, so the Equator on the meridian will be (as always) at an altitude equal to the colatitude, in this case, 35°. But Jupiter, we are told, is 18° N. of the Equator, so the altitude of Jupiter (J) will be 35° + 18° = 53°.

(*b*) Find the point below the horizon due north where the equator is at its lowest: do this by joining Q O and producing the line to meet the meridian at R. R is 35° below the horizon. But Castor (C) is 32° north of R. Therefore, Castor when due north is 3° below the horizon. So the star we see below the pole could not possibly be Castor which we have now shown not to be a circumpolar star in that latitude.

Another important general statement can be extracted from Fig. 8, and that is that the declination of the zenith is the same as the latitude of the place. Please remember this as it will crop up again before long.

Apparent Movement of the Sun

We have said that the aspect of the sky involves not only the latitude of the observer but also the time of year and the time of night. These last two factors both depend on the position of the Sun, so we must now consider how the Sun appears to us to move. Look at Fig. 9 which shows the path of the Earth round the Sun. In position 1 the star we are considering will be well placed for observation, being opposite the Sun, or on the meridian at midnight. Position 2 is three months later, as the Earth has completed a quarter of its journey round the Sun. The star will now be on the meridian (as far as possible from the horizon) at about sunset and near the horizon at midnight. In position 3 we shall not see the star at all as when we look towards it we shall be looking straight into the rays of the Sun. It will culminate at noon.

Thus we see that the yearly revolution of the Earth round the Sun alters the positions of the stars with respect to the Sun's place in the sky by a small amount each day, which adds up to much as the months go by, and brings them back to their same positions again at the end of a year. We can put it in another way by saying that the whole sky spins daily from east to west, but the stars are going a little faster than the Sun, and the Sun has lost exactly one lap at the end of a year. It has thus traced out a path against the background of the much more distant stars. This apparent annual path of the Sun is called the *Ecliptic*. It is not the same as the Equator because the Earth's axis is tilted at an angle of 23½° from the perpendicular to the plane of the Earth's orbit. The Ecliptic thus becomes a great

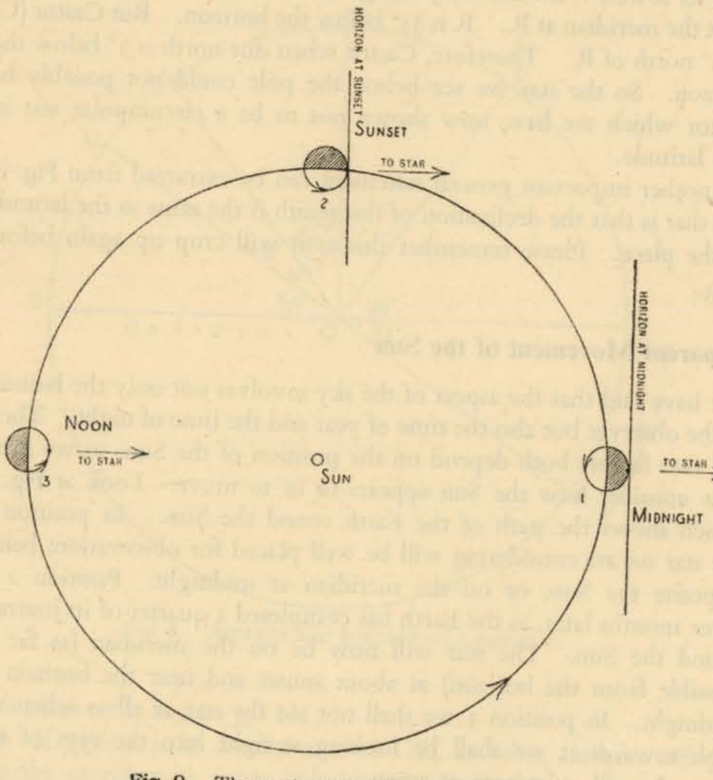


Fig. 9. The path of the Earth round the Sun.

circle or circumference of the sky cutting the Equator at two opposite points ; and at the two intermediate points it is 23½° from the Equator, to the north where the Sun is in the northern summer, and to the south where the Sun is in the northern winter. Fig. 10 should show how this happens though it does not show how it appears to us in the sky. The Sun is the small circle in the centre, and the

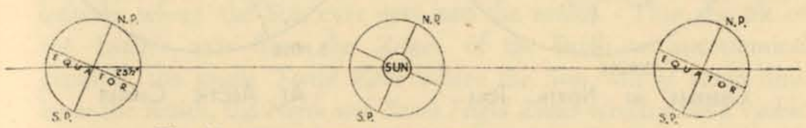


Fig. 10. The effect of the tilt of the Earth's axis.

Earth is shown in two positions six months apart on either side of it. For the moment please fail to observe the third position of the Earth in the centre of the diagram. The Earth's axis is drawn tilted at 23½° to the perpendicular to the line across the paper, which line represents the plane of the Earth's orbit. On the left side of the diagram the Earth's axis is inclined the full 23½° towards the Sun : this is northern midsummer day, June 21st. The Sun is in the zenith at latitude 23½° N. It will be remembered that we saw from diagram 6 that the declination of the zenith is the same as the latitude of the place, so the Sun's declination on that day is 23½° N. In the same way it will be seen that six months later the Sun's declination is 23½° S.

Zones of the Earth

Now for the intermediate position of the Earth. This is not really in the plane of the paper at all, but in front of it. In this position the Sun is neither north nor south of the Equator, but shining vertically on to it. It shows the position of the Sun on March 21st or September 23rd. In the course of the year then the Sun is causing stars that lie near the Ecliptic to go out of season for a time, and it is also altering its midday position from 23½° S. of the Equator to 23½° N. This 47° change in midday position will appear differently in different latitudes as Fig. 11 shows. S is the noon position of the Sun in midsummer, W the noon position in midwinter. The midnight position of the Sun on the same day can easily be discovered by imagining the Earth to rotate half a complete

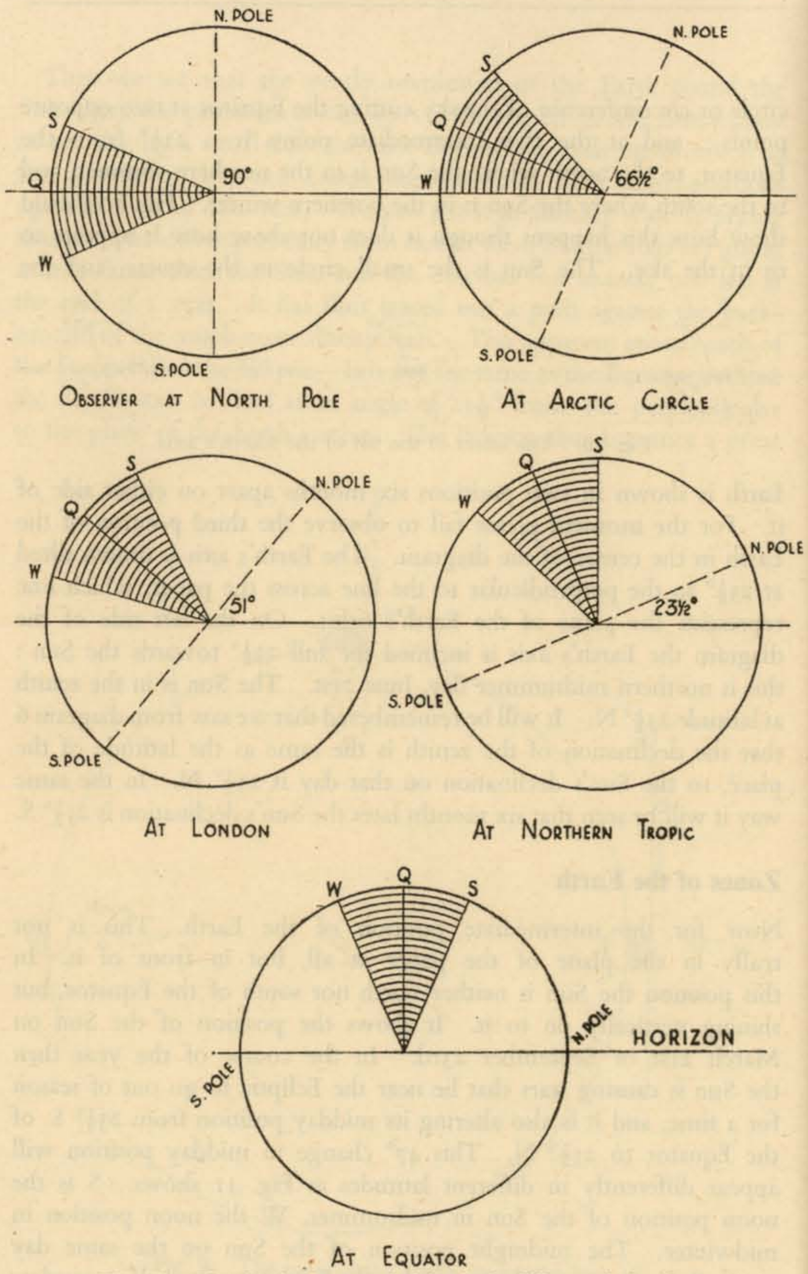


Fig. 11. The Sun's change of altitude in different latitudes.

spin about the axis ; that is, by dropping a perpendicular from the midday position through the axis. It will be seen that at the *Arctic Circle* the midwinter noon Sun touches the south point of the horizon, but does not rise : the midsummer midnight Sun touches the north point of the horizon, but does not set. That is how the Arctic Circle is located : it is the most southerly latitude where the midnight Sun can be seen. So, too, the northern *Tropic* is the most northerly latitude where the Sun ever gets into the zenith. Thus the tilt of the Earth's axis fixes the Zones of the Earth on astronomical grounds, the single *Torrid Zone* where the Sun will at some time be in the zenith, the *North* and *South Frigid Zones* which have a visible midnight Sun, and the two *Temperate Zones* which get no zenith Sun and no midnight Sun. It would be an instructive exercise to complete the series of diagrams for various latitudes from the Equator to the South Pole.

We sometimes speak of the length of the day as the interval from sunrise to sunset. Since the Sun takes three months to go from Q, the Equator, to S, its midsummer declination, and three months to return to Q, it is easy to see from the diagram that the poles of the Earth get six months' day and six months' night. (It is a common error to believe that this applies to all parts of the Earth within the Arctic and Antarctic circles.) At the Arctic Circle the longest day is 24 hours and the shortest day a possible glimpse of the Sun on the southern horizon. At the Equator all days will be 12 hours long.

Duration of Twilight

By imagining the Earth, and therefore the sky in each diagram, to spin about its axis, we see that in high latitudes the Sun approaches the horizon at a very slanting angle and so takes long to get far below the horizon : twilight lasts long. But near the Equator the Sun comes down at a much steeper angle and darkness comes on much more quickly.

If the reader will make the glass model suggested earlier in this chapter he can put rubber bands for Equator and Ecliptic or paint them as circles on the glass. The phenomena described in the last few pages are then easily followed in three dimensions.

Relation of Equator and Ecliptic

Another way of showing the seasonal behaviour of the Sun is to draw the Equator and the Ecliptic on graph paper. This is equivalent to making the framework for a map of the whole sky from the Equator to some such declination as 50° N. and 50° S., leaving out the polar regions. It produces the same kind of map as one of the world on Mercator's projection, with which anyone who has used an atlas must be familiar ; though with graph paper we must forgo the varying scale in declination which is more correct. The exercise teaches the beginner some astronomy, and it is a good method of learning about the stars in their relation to the seasonal position of the Sun in the heavens.

Take a piece of graph paper 9in. by 7in., divided in tenths of an inch, with length left to right. Mark a central horizontal broad line, 0°. This is the Celestial Equator. The horizontal lines will be declination lines, corresponding to latitude on the Earth. The vertical lines correspond to terrestrial longitude and are called lines of Right Ascension. The scale in declination is one-tenth of an inch (one small square) = 5°. Mark it in steps of 5° to 50° N. and 50° S. Right Ascension reads from right to left (in the sky this means from west to east) in hours from 0 hrs. to 24 hrs. 15° on a globe are equivalent to one hour, so one hour will be three-tenths of an inch. Mark a right-hand broad line 0 hrs., and the third line on the left of it 1 hr. and the sixth 2 hrs. and so on up to 24 hrs. Now if you are given the R.A. and Decl. of the Sun on any day you can put in a dot for its position, not very accurately as the scale is so small. For the present we will ignore dates. Here are some Sun co-ordinates with declinations sufficiently accurate for this work:—

R.A. h. m.	Decl. ° ′	R.A. h. m.	Decl. ° ′
0 0	0 0	14 0	12 30 S
2 0	12 30 N	16 0	20 30 S
4 0	20 30 N	18 0	23 30 S
6 0	23 30 N	20 0	20 30 S
8 0	20 30 N	22 0	12 30 S
10 0	12 30 N	24 0	0 0
12 0	0 0		

That gives 13 points, as R.A. 0 h., Decl. 0°, is the same point as R.A. 24 h., Decl. 0°.

Solstices and Equinoxes

Now mark the points and join them with a smooth curve which will be found to have a very flat S-shape. It may seem odd that the Ecliptic which you have been told is a circle should come out that shape, but if you are puzzled roll your paper into a cylinder with the curve outside and with the 0 h., 0° point coinciding with the 24 h. 0° point, and you will see that on a sphere the Ecliptic would be a circle cutting the Equator at 23½°. There you have the Sun's apparent path among the stars. Four of the dates have already been mentioned and might be written in along the R.A. scale. They are R.A. 0 h., March 21st ; 6 h., June 22nd ; 12 h., September 23rd ; 18 h., December 22nd ; and March 21st can be repeated on the 24 h. line. These four important dates are the Equinoxes and Solstices, the two days when the Sun is on the Equator, and the two when it is at the greatest declination it ever reaches.

March 21st ..	Spring Equinox.
June 22nd ..	Summer Solstice.
September 23rd ..	Autumn Equinox.
December 22nd ..	Winter Solstice.

In the northern half of the Earth, from Spring Equinox to Autumn Equinox, days are longer than nights : from Autumn Equinox to Spring Equinox, nights are longer than days.

Now estimate how much 9° is in declination and draw two other lines, each, throughout, 9° from the Ecliptic, one north and the other south of it. You now have a belt of the sky 18° wide with the Ecliptic running through the middle of it. This is the part of the sky in which (as has been known for thousands of years) the Sun, the Moon, and the bright planets are always to be found. In the early days of the science of the sky, many people studied Astrology rather than Astronomy—they believed in the influence of the stars and planets, Sun and Moon, on human character and destiny, and they attached undue importance to this belt. They divided it into twelve equal parts by lines at right angles to the Ecliptic (as you might do if you have drawn the map) and they called it the Zodiac—a kind of astronomical Zoo, for many of the star groups associated with it are named from animals. Nevertheless, it is still an important part of the sky for the astronomer. We know now that the planets

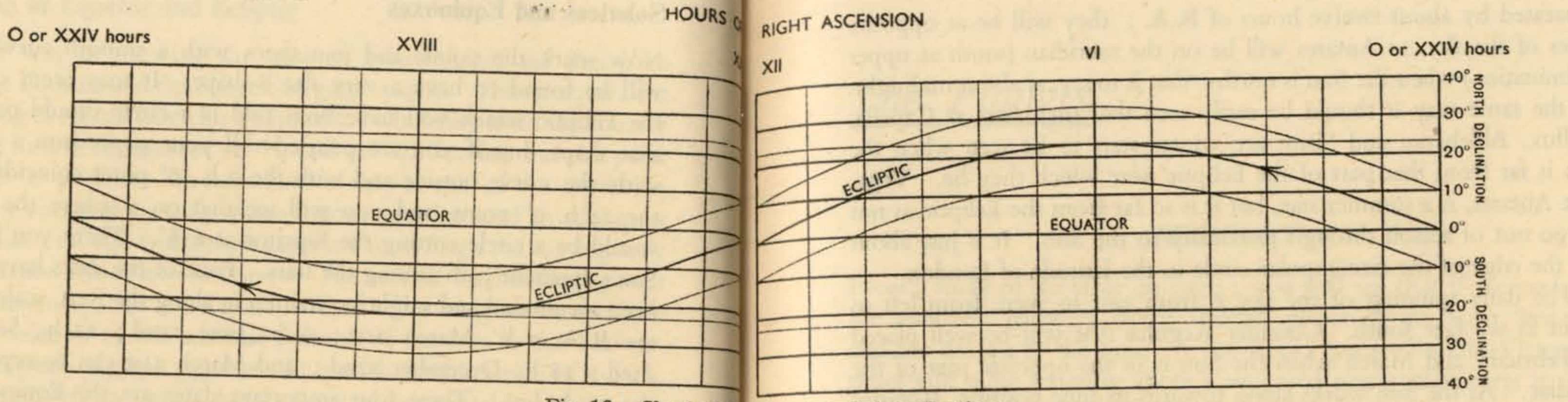


Fig. 12. Chart of the lower Celestial declinations.

are confined to that part of the sky because the Zodiac marks the extension of the orbit planes of the planets on to the Celestial Sphere. It is only another way of saying that the paths of the planets round the Sun are approximately in the same plane. If they were all in the same plane as the Earth's orbit, then the Zodiac would be narrowed down to the ecliptic itself, and the planets would all appear to run along that line.

The Zodiac

The diagram should come out something like Fig. 12, though that diagram has been taken only to declinations 40° N. and 40° S., and the Zodiac has not been divided into twelve parts. The twelve divisions are known as the Signs of the Zodiac, and the stars associated with them were the Constellations of the Zodiac. They are thus named reading from right or west towards left or east.

Aries, the Ram.	Libra, the Scales.
Taurus, the Bull.	Scorpio, the Scorpion.
Gemini, the Twins.	Sagittarius, the Archer.
Cancer, the Crab.	Capricornus, the Goat.
Leo, the Lion.	Aquarius, the Water-carrier.
Virgo, the Virgin.	Pisces, the Fishes.

Since the Zodiac was formed, a slow movement of the Earth's axis has carried the Right Ascension lines to the right or west by a distance approximately equal to one sign, so that the Signs of the Zodiac no longer coincide with the Constellations of the same name. For example, the Sign Cancer is now in the Constellation Gemini. It is difficult, and perhaps not of great importance for the beginner ; but the point is that if we are considering whether at a certain date one of the planets is in (say) Taurus, we must decide whether we are speaking of the Sign or the Constellation of that name. This slow effect is known as the *Precession of the Equinoxes*.

Now it will be instructive to put into this little sky map a few of the brightest of the stars. If the declination is given to the nearest degree, and the R.A. to the nearest ten minutes there should be no difficulty in getting them in accurately enough.

	R.A. h. m.	Decl. °		R.A. h. m.	Decl. °
Aldebaran	4 30	16 N	Regulus	10 10	12 N
Capella	5 10	46 N	Arcturus	14 10	19 N
Sirius	6 40	17 S	Antares	16 30	26 S
Pollux	7 40	28 N	Vega	18 40	39 N

Now consider such a star as Antares. In November and December the Sun is very close to that part of the sky where this star is situated, so we cannot expect to see it in those months. But in June, when the Sun is near the Summer Solstice, the Sun and Antares will be separated by about twelve hours of R.A. : they will be at opposite sides of the sky, so Antares will be on the meridian (south at upper culmination) when the Sun is north—that is to say, at about midnight. In the same way it should be easily seen that such stars as Capella, Pollux, Aldebaran and Sirius are winter stars to be seen when the sun is far from that part of the Ecliptic near which they lie. Vega, like Antares, is a summer star, but it is so far from the Ecliptic as not to go out of season through proximity to the Sun. It is just about on the edge of the circumpolar circle in the latitude of London.

The daily spinning of the sky is from east to west, from left to right as we face south. Consider Regulus : it will be well placed in February and March when the Sun is in the opposite part of the Zodiac. As the Sun works along towards its June position, Regulus will be a few hours to the left or east of it, seen for an hour or two in the western sky when the Sun has set. As the Sun draws near to Regulus, the star will go out of season, to reappear in October or November on the right or west of the Sun, and visible for an hour or two in the eastern sky before sunrise.

Chapter 5

The Planets

MERCURY

FROM a study of the table on page 5 you will see that if we exclude the asteroids, Mercury is the smallest planet in the Solar System, and the nearest to the Sun. A few books written in mid-Victorian times talk quite seriously about a supposed planet still nearer to the Sun than Mercury. This is because one or two strange observations had been claimed of dark objects moving across the Sun's disc, but the whole idea is now discredited.

Mercury's year is about three of our months in length. A planet's speed in its orbit is greater the nearer it is to the Sun, and as Mercury also has the shortest distance to go, its periodic time is much the shortest. From the exercise on the four innermost planets (see page 105) it will be seen that its maximum angular distance from the Sun or Greatest Elongation cannot be very big : it can never be more than 29°, though this figure will not be obtained in this exercise as we are using circles and not ellipses. But it should be clear that when we want to find Mercury we must look more or less in the direction of the Sun. At about the time of Eastern Elongation (when the planet is to the east or left of the Sun) we must look in the west just after sunset ; or at Western Elongation we must look in the east shortly before sunrise. If the sky is clear we should then have no difficulty in finding the planet. It is about as bright as the brightest star, but it will hardly be conspicuous in high latitudes because it will not be seen against a really dark sky. In equatorial and tropical regions, where darkness comes on much more rapidly, it is an easier object to find. If we want to find it in the evening we must choose a spring Eastern Elongation, as the Zodiac in the western sky will be at a steep angle to the horizon, so Mercury when some distance from the Sun will be relatively high up. In autumn evenings the Zodiac in the west lies near the horizon, so Mercury at the same angular distance from the Sun will be much lower in the sky. Fig. 13 should make this clear. The lined part of the diagram is the Zodiac.

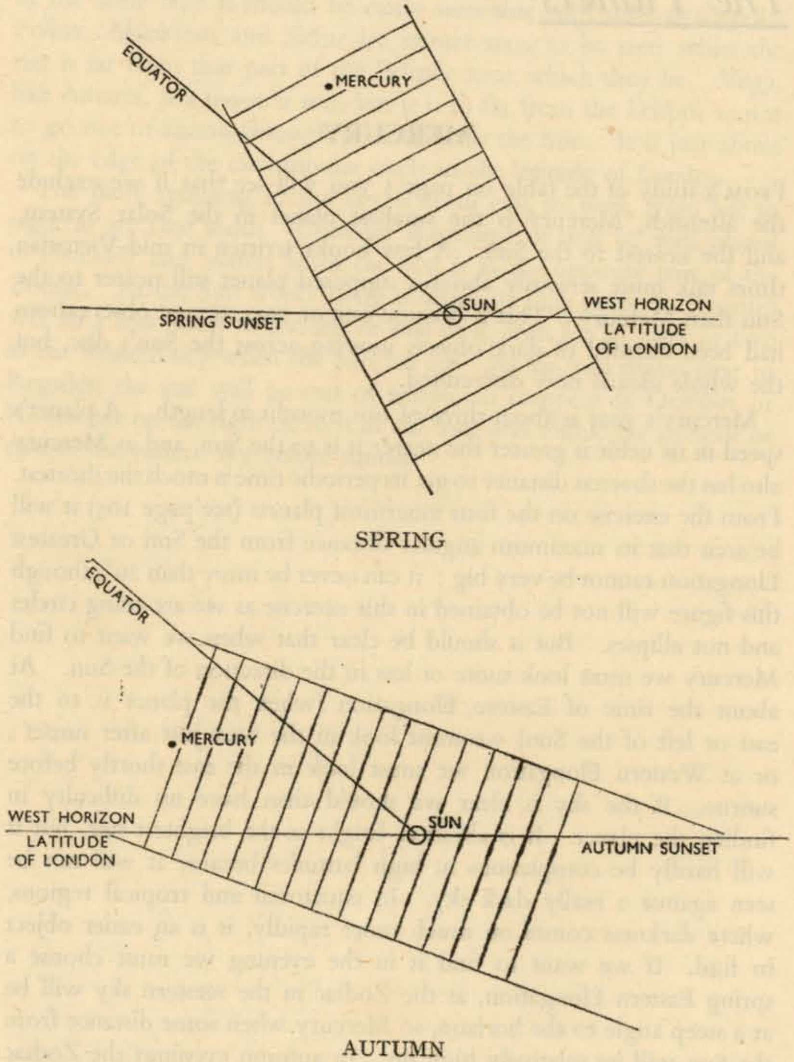


Fig. 13. The evening position of Mercury in spring and autumn.

It is sometimes said that stars twinkle, but planets do not. This is generally true, though to see Mercury twinkling is nothing unusual. Twinkling is an effect produced by our atmosphere, and it is generally greater when the object seen is at a low altitude.

Mercury Through the Telescope

Mercury is not a very interesting object in the telescope. Its phases are deduced and investigated in pages 105–107. The crescent may be seen after eastern or before western elongation, but the planet is small and distant compared with Venus, and it is very difficult to see any markings on its surface. Indeed it is only in recent years that it has been possible to establish the time of the planet's rotation, which is now taken to be 88 days, the same as its period of revolution round the Sun.

Mercury has no atmosphere, so almost certainly it cannot be the abode of life. The hemisphere which is always turned towards the Sun must be extremely hot, while the hemisphere of perpetual night must be far colder than any part of the Earth.

VENUS

The planet Venus is almost the same size as the Earth, actually about 300 miles smaller in diameter, but 300 miles in about 8,000 is not much. It is an interesting object chiefly on account of its great brilliancy. We should expect the brightness to vary a good deal : if the reader carries out the exercise suggested on page 105 it will be seen that some factors which decide brightness are by no means constant. The distance of the planet from the Earth can vary from 26 million to 160 million miles. The phase can vary from the thin crescent to the full circle. Actually the date of greatest brilliancy, which can be calculated from a formula, is 36 days before or after inferior conjunction*. When Venus at greatest brilliancy is visible in spring evenings the planet (being eastwards from the Sun which is near the spring equinox) attains a high altitude. (See Fig. 13 where the explanation is applied to Mercury.)

Venus Through the Telescope

For several weeks on either side of greatest brilliancy Venus is

* See page 105.

bright enough to be found in bright sunlight without the use of a telescope. No star can be seen with the naked eye in sunlight, and any other planet is very difficult. Venus at its brightest is about 100 times as bright as a standard first magnitude star such as Aldebaran. Near inferior conjunction its apparent diameter is about one minute of arc, so a telescope with a magnification of 30 will make it equal in size to the Moon with the naked eye. This sounds hopeful for the observer with limited apparatus : actually his hopes are likely to be dashed. He finds it impossible to believe that he has magnified the planet to the size of the Moon—unless the Moon is in the same part of the sky and he can compare the two. Probably the image will be unsteady, and the user of a small instrument is unlikely to see any marks on the planet's surface. But he *may* see conspicuous marks : there is always the possibility of a great discovery. However, the little crescent planet is a beautiful sight and the beginner must resolve to wait till he can use a more powerful telescope, and must employ his small glass on objects better suited to its low power.

From time to time marks have been seen on the planet's surface, but they are transient and ill-defined, otherwise we should not be still uncertain how long it takes to rotate on its axis. It has a dense atmosphere in which, by means of the spectroscope, we have been able to detect carbon dioxide, an important constituent of our own air. We know nothing as to whether Venus is the abode of life.

MARS

The next planet outside the orbit of the Earth is Mars. Its diameter is slightly more than half that of the Earth, and among the four little planets nearest to the Sun it is larger only than Mercury. But it is sometimes very close to the Earth : its mean opposition* distance is only 48 million miles, which in the scale of the Solar System is a very short distance indeed. On account of its greatly varying distance from the Earth it also varies much in brightness, being sometimes brighter even than Jupiter : at other times it is not even as bright as one of the fainter first magnitude stars such as Regulus. As is explained on page 107, November oppositions are probably the most favourable for observers in rather high northern latitudes. It is not an easy object for users of small instruments, and the beginner

* See page 105.

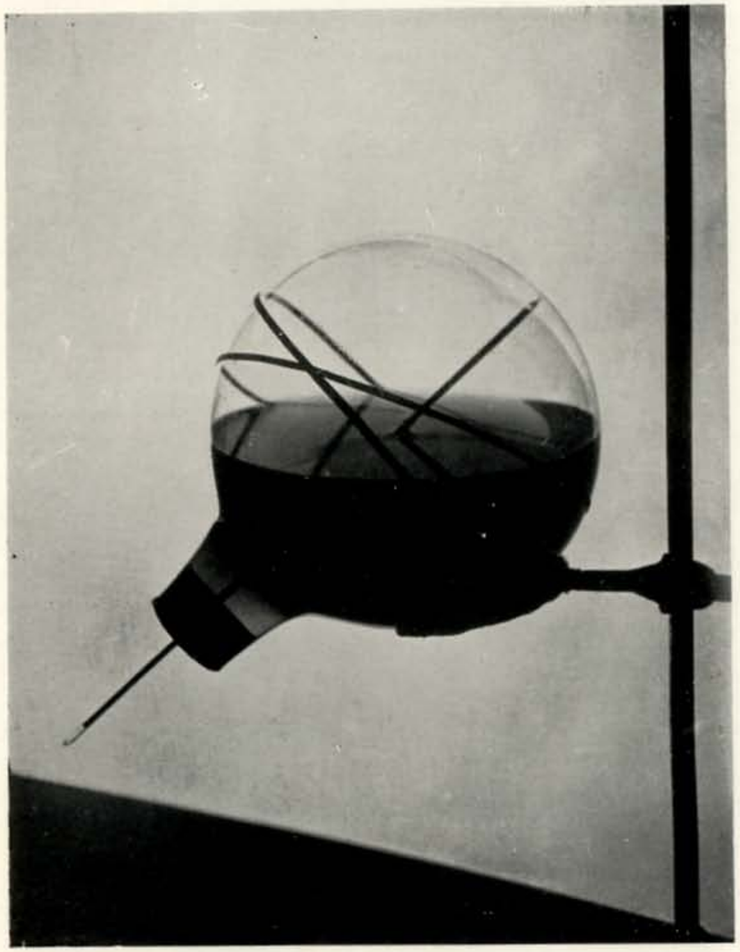
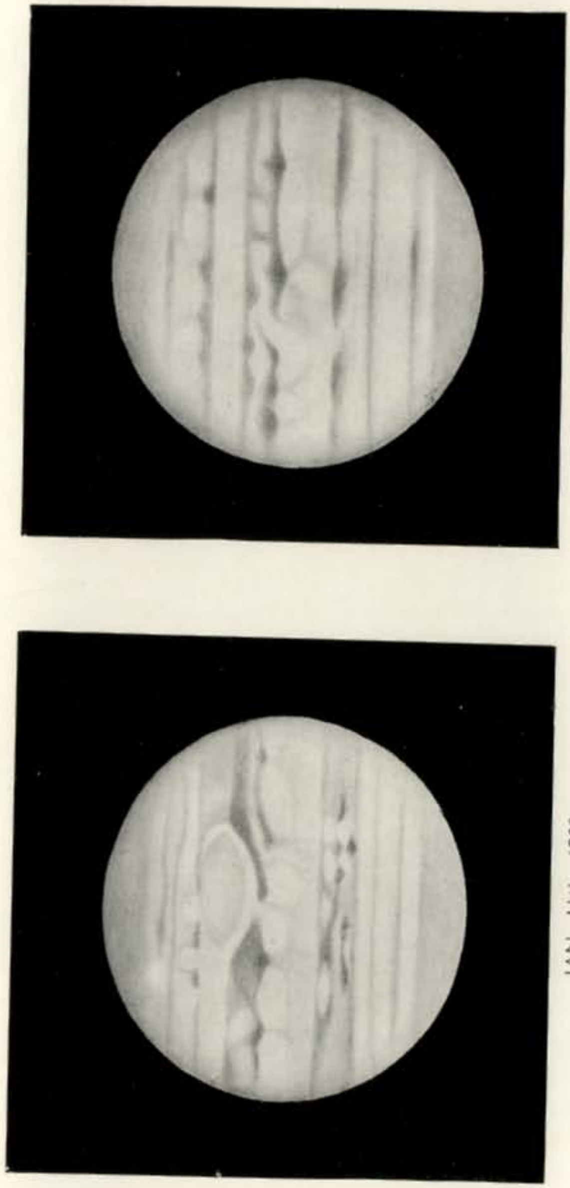


Plate III

HOME-MADE MODEL OF THE CELESTIAL SPHERE

Set for about Latitude 50° N.



FEB. 27th, 1908

JAN. 11th, 1908

Plate IV

DETAIL ON JUPITER SEEN THROUGH A LARGE TELESCOPE

From drawings by the late Rev. T. E. R. Phillips

with a small glass will do well if he can make out a lighter polar region (known as a polar cap), one or two dusky markings, and variations in colour on different parts of the disc, some greenish and others a kind of red-brown.

With bigger instruments a great deal of interesting detail has been observed. But even under good conditions the inexperienced observer must not expect just to go to the telescope and look in and see much. Seeing well in an astronomical telescope demands serious concentration, experience, training, and lastly, some natural gift or aptitude, which a good many mildly-interested people do not possess. It is interesting to notice the reactions of different people (when the vital need for careful focusing has been impressed on them) as they look for the first time at a good telescopic view of a planet. Some are not more than aware of the general effect. Others are quick to note shape, varying brightness on different parts of the disc, faint detail, differences of colour. Probably those who walk about the country-side and do not notice shapes of clouds, songs and movements of birds, and swelling buds, are the same people as miss the detail in the view of a planet. No doubt the power of observation can be to some extent aroused and developed, but the born observer is a startling and precious being.

Mars (unlike Mercury and the Moon) is known to possess an atmosphere containing water vapour, though it is a good deal less dense than that of the Earth. It develops mist and dust storms, and we see through it to the permanent markings on the solid crust of the planet.

Mars Through the Telescope

Everyone has heard of the question whether there is life on Mars. As the planet is not very different from the Earth in size, not much further from the Sun, has an atmosphere and a solid surface, the question is not entirely in the region of guess-work and wild speculation. In the last quarter of the 19th century the Italian astronomer Schiaparelli discovered long, straight, narrow lines which he called "Canali," a word which should probably have been translated "Channels." It is a great pity that the word "Canals" was ever used. It became generally adopted, and the unscientific public considered that if astronomers were talking about the canals of Mars then the planet must be the abode of intelligent life. The work of Lowell, the American, in the early part of the 20th century lent support to this view. The position at present seems to be that most observers admit the existence on the surface of Mars of peculiar straight markings which may be continuous lines or a succession of dots, but there is no reason to think that they are not natural. Few astronomers believe that we have any evidence for the existence of intelligent life on Mars. But the question whether there is any life at all on Mars is quite a different one. Some of the seasonal changes from green to brown are difficult to explain, and the simplest and easiest explanation (by no means necessarily the correct one) is that they are changes in vegetation not unlike the autumnal change in the leaves of many trees on the Earth. Most astronomers whose opinion is worth having seem to think that Mars probably has vegetation : we cannot say certainly. It is one of the many unsolved problems of astronomy.

The chief markings on Mars appear to be more or less permanent, but they are subject to variations that cannot always be explained away as seasonal. Sometimes a well-known but inconspicuous marking will develop in size and intensity until it becomes one of the most prominent objects on the planet. It may remain like this for two or three Martian seasons and then fade away again to a small patch only to be seen in the best telescopes under good conditions. We have not been able to observe Mars for a sufficient number of years as yet, to learn whether these apparently irregular changes recur or whether any periodicity can be assigned to them.

Mars has two very small satellites which no one can hope to see except in a large telescope. One of these satellites revolves in 7 hours 39 minutes, while Mars rotates in 24 hours 37 minutes. Thus if there are observers on Mars they will see this satellite rise in the west and set in the east three times a day.

Mars is decidedly the red planet, though we must not rely on colour for identification. Under certain atmospheric conditions any star or planet may appear red. Antares, Betelgeuse and Aldebaran are

reddish first magnitude stars, but even Venus and Vega and Rigel, which are normally white, may have a decidedly red tinge when they are near the horizon.

The Path of Mars

From the given figures, the apparent path of the planet Mars from August, 1943, to April, 1944, may be plotted on graph paper. On 9½ by 7½-in. paper, lined in tenths of an inch, a suitable R.A. scale is one small division for two minutes. Start at the right hand with

		R.A.		Decl.
		h.	m.	° N.
1943				
Aug.	16	3	34	17.5
„	26	3	57	18.9
Sept.	6	4	21	20.2
„	16	4	41	21.1
„	26	4	58	21.8
Oct.	6	5	12	22.4
„	16	5	22	22.9
„	26	5	26	23.4
„	31	5	26	23.6
Nov.	6	5	24	23.8
„	16	5	15	24.2
„	26	5	00	24.4
Dec.	6	4	44	24.4
„	16	4	28	24.2
„	26	4	16	24.0
1944				
Jan.	6	4	10	23.8
„	11	4	09	23.8
„	26	4	16	24.0
Feb.	6	4	27	24.3
„	16	4	41	24.7
„	26	4	57	25.0
Mar.	6	5	13	25.3
„	16	5	33	25.5
„	26	5	55	25.5
Apr.	6	6	19	25.3

3 hrs. 30 min., reading from right to left. The left side will then be about 6 hrs. 20 mins. The declination scale (to agree with the R.A. scale) should be one small division for 0°.5. Take 25° N. somewhere near the top. The path will be a narrow one in declination as it lies between about 16° and 25° N., not more than two inches wide.

To those who do not know the true and simple explanation, this apparent movement of Mars is very strange. It is not peculiar to Mars. As has been observed for thousands of years, all the outer planets seem to move among the stars from west to east. This is known as *direct* motion. Periodically they slow down and stop and then for some weeks their movement is from east to west. This is called *retrograde* motion. They then slow down again and get back into their ordinary stride from west to east.

Of course we know that this is an apparent movement—that no planet really stops in its orbit and gets into reverse. When the planets were believed to move round the Earth, each attached to a transparent sphere, this retrograding was very difficult to explain. On the Copernican plan the explanation is simple. While a planet is retrograding, the Earth is approximately between the planet and the Sun, and as the Earth is moving faster than any exterior planet, the planet gets left behind and appears to be travelling in the opposite direction, just as a train moving in the same direction as our train but more slowly appears to be going the other way. The middle of the retrograde path will mark the time of the opposition of the planet. After some weeks, when the Earth draws away from the planet and begins as it were to swing round the inner bend, the Earth's movement will be less parallel to that of the planet and more away from it, so the planet will appear to " pick up " and will resume its direct motion. Fig. 14 should make this clear. The positions of the Earth and Mars are shown at monthly intervals, as must be clear from the fact that the Earth's journey from a to g is half its annual revolution round the Sun. The capital letters A to G show the changing position of Mars as seen against the distant background of the stars.

The further a planet is away from the Sun the longer time it will spend in retrograding : on the other hand, the smaller will be the

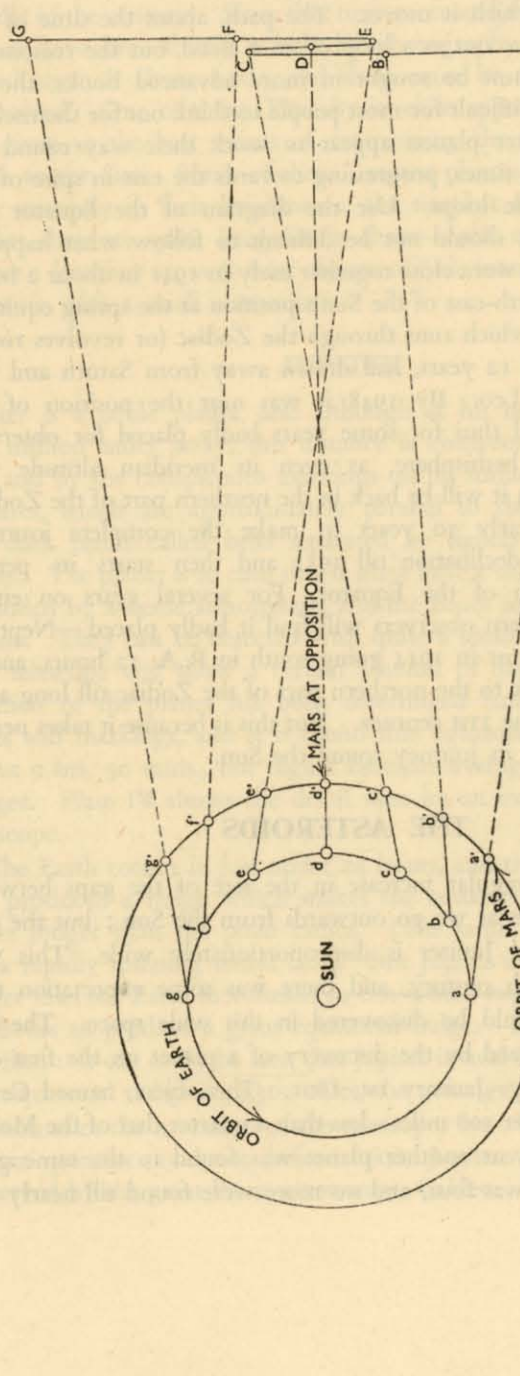


Fig. 14. Explanation of retrograde movement.

bit of sky over which it moves. The path, about the time of opposition, may come out as a loop or an S bend, but the reasons for these variations must be sought in more advanced books, though they are not too difficult for most people to think out for themselves.

And so the outer planets appear to work their way round the Zodiac in varying times, progressing towards the east in spite of the westerly retrograde loops. Use the diagram of the Equator and the Ecliptic and it should not be difficult to follow what happens. Jupiter and Saturn were close together early in 1941 in about 2 hours of R.A. to the north-east of the Sun's position at the spring equinox. By 1944 Jupiter, which runs through the Zodiac (or revolves round the Sun) in about 12 years, had drawn away from Saturn and was near Regulus in Leo. By 1948 it was near the position of the winter solstice and thus for some years badly placed for observers in the northern hemisphere, as even its meridian altitude was low. But by 1954 it will be back in the northern part of the Zodiac. Saturn, taking nearly 30 years to make the complete journey, remains in north declination till 1951 and then starts its period of 15 years south of the Equator. For several years on either side of 1957 northern observers will find it badly placed. Neptune was near the Equator in 1944 going south in R.A. 12 hours, and it will not come back to the northern part of the Zodiac till long after the beginning of the 21st century. But this is because it takes nearly 170 years to make its journey round the Sun.

THE ASTEROIDS

There is a fairly regular increase in the size of the gaps between the different planets as we go outwards from the Sun ; but the gap between Mars and Jupiter is disproportionately wide. This was noticed in the 18th century, and there was some expectation that another planet would be discovered in this wide space. The expectation was realized by the discovery of a planet on the first day of the 19th century—January 1st, 1801. This object, named Ceres, has a diameter under 500 miles—less than a quarter that of the Moon. In the following year another planet was found in the same gap. By 1807 the total was four, and no more were found till nearly the

middle of the century. Since that time more and more of these small planets have been found, mostly by photography, and the number now known is about 2,000, and there must be thousands yet undiscovered. One of them, Eros, by its close approach to the Earth, has given us the best means of determining the distance from the Earth to the Sun. Some of these " minor planets " or " asteroids " vary strangely in their brightness : the simplest explanation of this is that they are quite irregular in shape—rock masses rather than globes ; but they are very faint objects, of little interest to the practical observer with a small instrument.

JUPITER

Jupiter is a noble planet, and although at his nearest he is about 400 million miles away, this distance is compensated by his great size and by the conspicuous markings on his surface. These surface features, which are approximately parallel to the planet's equator, are dark bands called belts separated by lighter bands known as zones. The planet is so cold that it must have a solid surface, but this is hidden by a dense atmosphere, and the zones and belts are atmospheric. They can be detected with quite a small instrument, and a 3in. telescope will show a certain amount of detail. The time of rotation of the planet has been determined from observations of spots and markings, and it is found that equatorial regions average about 9 hrs. 50 mins., but higher latitudes average about 5 minutes longer. Plate IV shows the detail seen by an expert using a large telescope.

The Earth rotates in just under 24 hours, and this rate of spinning has produced a bulge which makes the equatorial radius about 13 miles longer than the polar radius. (The same effect can be seen on a rapidly spinning tennis ball.) But Jupiter is about 1,300 times larger than the Earth in volume, so one would expect a spin in under 10 hours to produce a great equatorial bulge. This is indeed what we find : it can easily be seen that Jupiter is oval in shape. Actually the equatorial radius is 44,300 miles, the polar 41,400.

Soon after the invention of the telescope, for which there seems to be no positive evidence before 1608, Jupiter was systematically observed by the great Pisan astronomer, Galileo. With the telescope which he himself constructed he made observations of the planet's four largest satellites ; and from that day to this every astronomer who has done any observing at all with however humble a telescope has made observations of some of the "satellite phenomena."

The four "Galilean satellites" revolve round Jupiter in nearly circular ellipses, almost in the plane of the planet's equator, like planets revolving round the Sun — a kind of Solar System in miniature. Here are some particulars of these famous bodies.

Satellite	*Diameter*	*Mean distance from Jupiter*	*Time of Revolution*	
	miles	miles	days	hrs.
I	2,109	261,000	1	18
II	1,865	415,000	3	13
III	3,273	664,000	7	4
IV	3,142	1,167,000	16	18

Jupiter emits no light of his own, so all the illumination of planet and satellites comes from the Sun. As the satellites go round the planet the following phenomena may be observed :—

Transit of satellite : The satellite is seen to cross Jupiter's disc.

Transit of shadow : The shadow of a satellite falls on Jupiter's disc.

Occultation : A satellite goes behind the disc of Jupiter.

Eclipse : A satellite disappears by entering Jupiter's shadow.

If we are observing Jupiter at the time of opposition the shadow of the planet will be directly behind Jupiter, so we shall not be able to observe an eclipse—Jupiter himself will hide his own shadow-region from us. But some weeks before or after opposition the shadow will still be directed away from us though somewhat to one side, and a satellite may be seen to disappear into Jupiter's shadow, or to come out of it, at some appreciable distance from the disc.

The four phenomena may be illustrated in a single diagram :—

Draw four concentric circles to represent the orbits of the satellites to scale : 100,000 miles to a quarter of an inch seems suitable. On that scale the Sun would be about 34 yards away, so we will mark sunlight by parallel lines coming from (say) the left (as good as any other direction). We will avoid putting the Earth at opposition,

so we will mark "line of sight from the Earth" slightly inclined to "direction of Sun's rays." But how wide can we make that angle of inclination ? (It is better not to represent the quite impossible.) Knowing the dimensions of the orbits of the Earth and Jupiter we can draw them on a separate diagram and measure the angle of greatest elongation of the Earth as seen from Jupiter (see exercise, page 107). It comes to about 10°. Put a circle for Jupiter in the middle of the orbits (not too grossly big) and draw his shadow extending beyond the orbit of satellite IV. Now we have four satellites numbered I, II, III and IV, in order of nearness to the planet, and we have four phenomena to illustrate. Put each satellite as a clear dot in one position on its orbit so as to illustrate one of the phenomena. Allot the phenomena as you like and put a key at the side to show which phenomenon belongs to which satellite. It may be mentioned that the shadow even of IV reaches all the way to the planet though the proportion of umbra to penumbra will be small (see Fig. 3 J2).

The different phenomena are not equally easy to observe. It may be easy to see an eclipse when it happens at some distance from the disc or a transit of the shadow of I which is mostly umbra. To see a satellite in transit on a bright zone away from the relatively dark edge of the disc may be impossible even in a big telescope. III and IV normally transit as much darker objects than I and II.

It was known in the 17th century that at about the time of the opposition of Jupiter the phenomena happened earlier than the predicted times ; but when Jupiter was nearer conjunction they were late. The explanation was given by Roemer in 1675. Near conjunction the light from Jupiter had to pass over nearly the additional distance of the diameter of the Earth's orbit. The size of the Earth's orbit was known reasonably accurately and thus it was possible to determine the velocity of light. More recent methods give the result now accepted, namely, 186,300 miles per second.

The phenomena are now predicted years beforehand and can be looked up in the *Nautical Almanac* or the *Handbook of the British Astronomical Association*. Every day there is something happening, though many of the phenomena will occur in daylight or when Jupiter is below our horizon. Here is a list for a single day, and from it the student can find out the kind of duration of some of the phenomena.

		h.	m.
I	Shadow commences	2	40
I	Transit commences	3	51
II	Eclipse commences	4	39.9
I	Shadow finishes	4	53
I	Transit finishes	6	05
IV	Transit commences	8	41
III	Eclipse commences	9	20.2
II	Occultation, emersion	9	53
IV	Transit finishes	11	49
III	Eclipse finishes	12	37.8
III	Occultation, immersion	14	14
III	Occultation, emersion	17	39
I	Eclipse commences	23	54.4

Admittedly an unusually busy day: it was March 23rd, 1937. For further information on this subject the reader must consult more advanced books.

SATURN

The next planet as we go outwards from the Sun is Saturn, as wonderful and beautiful an object as is to be seen in the whole heavens. The planet itself is large, second only to Jupiter, and it is accompanied by the extraordinary ring or system of rings illustrated in Plate V.

Saturn is about 760 times as big as the Earth in volume and it has a good many features in common with Jupiter. It is surrounded by a dense atmosphere through which we never see a solid crust: it has cloud belts and light and dark spots though these features are all much less pronounced than those of Jupiter. The flattening or ovalness of shape is greater than that of any other planet, and there are several satellites, some of which can be detected in small telescopes. Titan, the largest, is the biggest satellite in the solar system, and can be seen with a 1-inch glass.

Galileo saw the rings as something mysterious on each side of the planet—he did not know what; and it was not until telescopes had been improved towards the middle of the 17th century that the true nature and structure of the rings had been made out.

Suppose we are starting at Saturn's equator and making a journey in a straight line to the outer edge of the outer ring. We are 37,500 miles from the planet's centre. These are the regions we should have to traverse. It is 9,000 miles before we reach the edge of the innermost ring known as "C" or the crape ring. This extends for the next 9,800 miles. We are then at the edge of the bright ring "B," which touches the crape ring. We have a journey of 16,400 miles to the outer edge of ring "B" and then we come to a gap known as the Cassini division. This is 1,800 miles across: we are then at the inner edge of the outer ring "A." We have a further 10,100 miles to go and we are then at the end of our journey. Draw a section of a circle, enclosed between two radii, to show a piece of Saturn and the ring system to scale. That would represent a view as seen from a point on the axis of Saturn produced—a view which we on the Earth can never get. As Saturn makes its 29½-year journey round the Sun, the direction of the plane of the rings remains unchanged; but as this plane is inclined at an angle of about 28° to the plane of the Earth's orbit we get a varying view of the rings. In 1944 they were "open at their widest," that is the full 28°. You will get the effect by holding a coin horizontal and edge-on and then turning the near edge downwards through 28° of the full 90° which would show the coin as a true circle. Then from 1944 this angle diminishes: it is said that the rings are "beginning to close." In rather more than seven years (a quarter of Saturn's journey round the Sun), in September 1950, they were edge on; by 1958 they will be wide open again and about 1966 once more edge on, and by about 1973 again open at their widest.

Saturn Through the Telescope

These phases will, of course, much affect the appearance of the planet. To the naked eye it is decidedly brighter when the rings are open though it never falls below first magnitude. When the rings are open, a good 3-inch telescope should easily show the Cassini division (at the sides, where it is more easily seen than in front) and also the crape ring. But the crape ring needs practice and experience, and some people find it hard to see until they have once caught it and know just how to look and what to expect. It is remarkable that it was not discovered before 1850 : probably this is because it was so unexpected, but it may have become brighter since early telescopic observations were made. As the rings close, the crape ring and the Cassini division become more and more difficult. When the rings are edge-on they are seen as a narrow line estimated at perhaps 30 miles thick, and they are not always equally bright on the two sides of the planet. Then for some days the plane of the rings passes between the Sun and the Earth so that the unilluminated side of the rings is turned towards the Earth and it is impossible to see the rings even in a big telescope.

In a good telescopic view of the planet when the rings are not closed we may see the shadow of the ball on the ring (if the planet is not very near opposition), the shadow of the ring on the ball, the oval shape of the planet and possibly some markings on the surface. In the 1940's the planet was in north declination—favourable to observers in the northern hemisphere. For some few years on either side of 1960 it will be in the far south of the Zodiac, and though the rings will be well opened the low altitude will be a disadvantage for northern observers.

Saturn's Rings

The two questions most often asked about Saturn are : (1) Why has it any rings at all ? And (2) What are the rings made of ? The answers are :—

(1) The rings were probably once a single satellite. It came so close to Saturn that the varying gravitational effects of Saturn on different parts of the satellite put it to a strain it could not withstand and broke it up.

(2) All we know is that the rings are made of millions of small particles each moving in its own orbit. By theoretical calculation and by spectroscopic observation we know that the inner parts of the crape ring revolve in about 5 hours, while the outer parts of the outer ring

take 13.7 hours. The spectroscope has also told us that the atmospheres of Jupiter and Saturn contain much marsh gas and ammonia.

The planet often gives a remarkably steady image in the telescope. No keen astronomer should miss an opportunity of seeing this unique and marvellous object.

URANUS, NEPTUNE and PLUTO

As mentioned in Chapter 1, the five planets from Mercury to Saturn are brighter than the first magnitude and have been known from the remotest times : they cannot be said to have been "discovered." William Herschel, one of the very great observers of all time, made the first discovery of a planet in 1781. He was using a reflector* which he had made, and as it was the best telescope in existence, and as he was a genius he was destined to make a vast number of discoveries. He was carrying out a systematic examination of part of the sky and detected a star with a slight disc. Now stars do not show sharply defined discs : this object must be either a planet or a comet. (Many telescopic comets are merely small disc-like objects.) Its apparent movement among the stars soon showed it to be at least a member of the Solar System, and the nearly circular shape of its elliptic orbit, determined later when it had made a considerable movement, proved that it was a planet. Herschel's loyal attempt to name it Georgium Sidus was (mercifully) unsuccessful, and it is known as Uranus. It was found out later that on several previous occasions Uranus had been seen and plotted as a star, but those who saw it had failed to observe its minute planetary disc. It is just about on the verge of naked-eye visibility : to the amateur with a small instrument there is not much more interest in it than the satisfaction of identifying it and seeing its greenish colour.

Uranus has a periodic time (of revolution) of about 84 years, and by the early 1840's it had completed a considerable part of its orbit since discovery, and more than a whole revolution since it had first been marked down as a star. But sixty years after its discovery the observed position of Uranus did not coincide with its predicted position. This is a complicated matter : it must suffice to state here that in computing the position which a planet will occupy

* See page 94.

in the future, mathematicians must take into account the gravitational pulls (" perturbations " as they are called) of other planets ; and although no known influences had been omitted yet there was a discrepancy which could not be explained. The inference was that Uranus must be attracted by some planet as yet undiscovered. The problem was to deduce the position of the unknown planet—and then search the sky and find it. This problem was solved independently by two great mathematicians, Adams of England, and Leverrier of France. It resulted in the discovery of the new planet in 1846 by Galle of Berlin. This is one of the most famous discoveries in the whole history of science. The planet is called Neptune. As in the case of Uranus, it had been previously seen and recorded as a star. It is of the eighth magnitude and is thus quite invisible without a telescope.

But even the discovery of Neptune with its perturbations did not entirely clear up the irregular movements of Uranus, and in the 20th century some astronomers (notably Lowell and W. H. Pickering, working independently) sought for yet another planet by the same theoretical means. In 1930, by the comparison at the Lowell Observatory, Arizona, of photographs of the same part of the sky taken at different times, a small object was found in different positions on two plates. This proved to be a planet beyond the orbit of Neptune. It was named Pluto. Probably thousands of people, for their own satisfaction trying to find an appropriate name for the ruler of profounder depths than those of Neptune, hit on this name before it was officially announced. It is a strange planet, too small and remote to be seen in any but large telescopes. Its orbit at one part comes within that of Neptune, and the planet wanders far outside the Zodiac. Whether Pluto really could have caused the residual movements of Uranus—whether there was not an element of luck or fluke in the discovery—are matters of opinion. Perhaps there are other undiscovered planets beyond the orbit of Pluto.

Chapter 6

Comets and Meteors

NEARLY EVERYONE knows something of comets—that they are mysterious, apparently rare and perhaps unaccountable visitors ; that they have been associated in the past (and still are in some people's minds) with wars and pestilences and other national disasters. (The very word disaster suggests the malign influence of heavenly bodies.) And the apparent rarity (and perhaps the mystery) is enhanced by the fact that in 1946 none but the elderly had ever seen a bright comet.

Halley's Comet

The most famous of all comets is that which bears the name of Halley, a great astronomer and a friend of Isaac Newton. This comet is named after him because he observed it in 1682, rightly claimed that it was the same object as had appeared in 1607 and 1531, and correctly predicted its return in 1758. Thus he showed that this comet at least is a member of the Solar System, moving round the Sun in an elliptical orbit and controlled as the planets are by the Sun's force of gravity. And this we now know to be true of all comets. So Halley was the first person to show where comets fit into the scheme of astronomical objects ; and that alone would be enough to bring a man immortality.

Comets are not so rare as most people suppose. Most of them are never better than telescopic objects, but the number observed in a year probably averages about five. On the other hand, the number that become brilliant naked-eye objects is more like three in a century. If the question is asked, When is the next bright comet due to appear? the answer is that there is only one bright comet whose reappearance can be predicted, and that is Halley's, and it is due again in 1986. A bright comet may appear at any time, but there is no particular reason to expect one.

Halley's comet has a periodic time of about 76 years, the exact time varying on account of planetary perturbations. It goes out beyond the orbit of Neptune. All the other great comets have far longer periodic times, amounting to hundreds or thousands of years: we see them on one visit and cannot tell when they will return. Many of the small comets with periods of only a few years are seen at each return; but it is only when they are comparatively near the Sun that they will be seen. The Sun has a strange effect on comets, causing in many of them the development of a tail, and making the tail shine not only by the reflection of light from dust particles but also by an electrical effect on the rarefied gases, rather like the auroral light in the higher regions of the Earth's atmosphere. A comet's tail must not be regarded as something trailing out behind as it rushes through space, like the trail of smoke left behind by a fast moving railway locomotive. The tail, driven out by the pressure of the Sun's radiation, always points away from the Sun.

Halley's comet was somewhat disappointing at its 1910 apparition, certainly for an observer in Britain looking for it as an evening object. The tail lay near to the horizon. As a morning object it was far more impressive. In much lower latitudes it was a very fine sight. The wind had been taken out of its sails to some extent by the sudden appearance in the January evening skies of the same year of a wholly unexpected and brilliant comet with a tail about 30° long. This splendid object was conspicuous long before dark and was generally known as the Great Daylight Comet. Two bright comets have appeared in recent years. The first was seen from the Cape on December 8th, 1947. It was a conspicuous object with a tail ten to fifteen degrees long. Because it was travelling northwards, there were hopes that it might be seen from the south of England at the end of December. It did come just above the southern horizon; but by that time it had become too faint for detection. Some papers reported that it had been seen, but the culprit did not know his elementary astronomy, and there is no doubt that he mistook the bright planet Venus for the comet. The next bright comet was seen from Nairobi during the total solar eclipse of November 1st, 1948. It appeared on a photograph, exposed for 1/300 of a second, from an R.A.F. aircraft flying at 13,000 feet. The head was then 105′ from the Sun's centre. Later it became a very bright object, reaching a magnitude brighter than 1st, and having "a long tail."

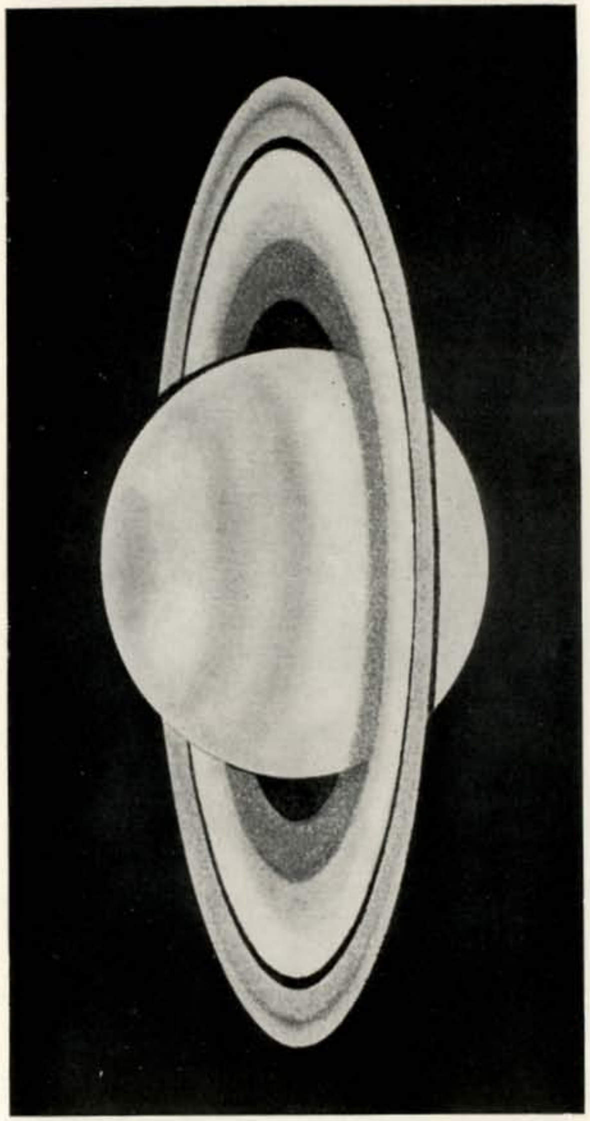


Plate V

SATURN, DEC. 5th, 1910

From a drawing by the late Rev. T. E. R. Phillips

Plate VI

COMET FINSLER (1937, f) AUGUST 7th, 1937

Exposure 55 mins.

By permission of G. F. Kellaway, Esq.

It was never visible to the naked eye in Great Britain. High northern latitudes have had bad luck since 1910, and it is time we had another good comet.

Telescopic comets—those which never become visible to the naked eye—are generally seen merely as small nebulous patches of faint light. Great comets generally have a bright roundish part called the head or coma, containing a smaller and still brighter part known as the nucleus. Streaming away from the coma is the tail, which may extend over a large part of the sky, perhaps even through several constellations. Plate VI shows a photograph of a comet. During the 55 minutes of exposure of the photograph the comet had moved appreciably against the background of the distant stars, so the star images come out as lines (" star trails ") instead of points.

Almost any comet which is once observed can be seen night after night, probably for a few weeks, apparently moving among the stars until it becomes fainter and fainter and is finally lost. There is great variety in the form and behaviour of comets. Their orbits are much more elongated than those of planets, and bear no relation to the general plane of the Solar System, so they will appear in any part of the sky and are as likely to be found near the celestial poles as in the Zodiac. As their paths cut across those of the planets, there is always the possibility of a collision, and so the question arises, What would happen if the Earth did hit a comet? The answer is that on more than one occasion the Earth has passed through the tail of a comet, and what happened was just what the astronomers expected—precisely nothing. A comet's tail, which is made of gas and dust, is so rarefied that it could not possibly produce an appreciable effect. But a collision with the coma of a great comet would probably be a very different matter; in fact, the Earth has before now encountered the head of a comet and the result was a shower of shooting stars. There is thus an intimate connection between shooting stars (better known as meteors) and comets.

Meteors

A meteor may be seen on almost any clear night as a faint (or sometimes brilliant) streak of light perhaps leaving a luminous trail for a second or two and then vanishing. A fair average rate of appearance on a moonless night is about six per hour. On some favoured nights such as about August 10th one might see them in the early morning at the rate of 25 or 30 per hour. These objects are known to be minute solid particles rushing through our atmosphere and visible at a distance of something like 80 miles. The brilliant large ones, which are rare, sometimes explode with great noise. Meteors are attracted by the force of the Earth's gravitation, and the speed of their movement through the air causes frictional rise of temperature which renders them incandescent. Some meteors are large enough to reach the Earth's surface before they are entirely worn away. These stony or metallic pieces are termed *meteorites*. Specimens are to be seen in many museums, and there is a fine collection at the British Museum of Natural History, Cromwell Road, S.W.7. The largest in that collection weighs 3½ tons, and the list at the end of the printed guide gives particulars of 680 specimens, many of them weighing only a few grammes. Millions of meteors enter the Earth's atmosphere every day, but only a very small proportion get through to the ground. The yellow metallic nodules found in the Chalk of the south-east of England are not meteoric.

Some meteors are stray wanderers: others move in swarms round the Sun in orbits similar to those of comets. In fact, the nucleus of a comet is probably a swarm of meteors; and collision with the head of a comet would produce a great shower of shooting stars such as has been observed and recorded on rare occasions from very remote times. The heads of some comets probably contain many big pieces of metal and stone, so a collision might produce quite awkward results, not merely a pleasant firework display.

Chapter 7

Stars and Nebulæ

THE VAST majority of the objects which we see in the sky on a clear night are stars—that is to say, they are large, incandescent, intensely hot masses, of which our Sun is a fair sample. We know that some stars are much bigger than the Sun, some much smaller; some are much hotter, others cooler. Nearly every star when looked at in a telescope appears as a clear point of light. We cannot magnify the stars to discs: we may say that they are too far away for that, or that our telescopes are not powerful enough.

If we look at the sky in order to find out how the stars are distributed, we shall see that there are signs of arrangement. They are not as haphazard as the first drops of rain on the pavement. The region of the constellation of Orion is rich in bright stars: on the other hand, the square of Pegasus, whose sides are about 15° in length, contains no bright stars. But the most conspicuous feature of star distribution is the Milky Way, a band of light of varying width which extends right round the sky. A telescope will show that it is composed of millions of stars invisible as separate objects to the naked eye.

Star Clusters

But there are other arrangements of stars which are not so obvious. Some small parts of the sky contain great numbers of stars, and these aggregations of stars are known as star clusters. Many of them are beautiful and interesting and easy to observe with small instruments. Star clusters are of two kinds, open and globular. The open clusters seem to have no particular structure, but appear as loose aggregations of stars: some naked-eye and telescopic examples are mentioned in Chapter 9 and a graphical exercise on one of them, the Pleiades, is suggested on page 109. Most of them are situated in the Milky Way. The globular clusters are much more condensed, and appear as spherical collections of thousands of stars. About a hundred of them are known, and one or two of them may with difficulty be found without a telescope, but an instrument with an object-glass at least four inches in diameter is necessary to resolve them into separate stars. Hardly any of them are in the Milky Way. This fact, that the open clusters appear in the Milky Way and the globular clusters outside it suggests that the Milky Way is the dominant feature among the stars that we see, and that the clusters are subordinate to it. It emphasises the insistent question as to the architectural structure of the great system of stars and clusters of which our Sun is a single insignificant member. This is a subject in which great advance has been made in recent years, and we must return to it later.

Other objects, some of which can be observed with small instruments, are known as nebulæ. The word nebula means a cloud or mist, and a good many misty-looking celestial objects have been known for centuries. Since they do not change their apparent positions among the stars it has long been known that they are not members of the Solar System, but belong to the realm of the stars themselves. With the increase of telescopic power some of the so-called nebulæ were seen to be after all only star clusters, and some people thought that that would eventually prove to be true of them all. But the spectroscope, as explained in Chapter 10, has shown that some bodies are truly gaseous, so the word nebula is one we are right to retain. The trouble is that we now know that very widely different types of bodies are called by this single word nebula. We must now try to explain their differences and see how they fit into the scheme of the Milky Way.

Planetary Nebulæ

First there are Planetary nebulæ. These appear in the telescope as small round objects resembling the disc of a remote planet such as Neptune. Each planetary nebula is shown by photography to be associated with a single very hot star. A planetary nebula must be millions of times bigger than the solar system, or we should not be able to see it as a disc ; yet, astronomically speaking, it must be a small object because it is associated with one star and not with millions of stars.

Irregular Nebulæ

The next kind of nebula we may call Irregular. The Irregular nebulæ are extremely varied in shape—in fact, perhaps it would be more correct to say that they have no particular shape at all. They form masses and streams and wisps of gaseous or dusty matter, shining partly with their own light and partly with light reflected from stars in their neighbourhood. Some of them are seen as dark objects against a background of stars or bright nebulosity. The nebula in Orion is the one which best repays observation with a small telescope. It is illustrated in Plate VII.

Spiral Nebulæ

The third kind we may for the moment call by their popular name of spiral nebulæ, though we shall see later that this also is not an entirely appropriate name. Many of them in photographs do show a decidedly spiral structure : some are rather flat and disc-like, others more nearly spherical, and only a small minority could be called shapeless. Millions of spiral nebulæ are now known, though the majority of them are very faint and are seen only on photographs taken with big instruments and exposed for hours.

Finding Star Distances : base-line Method

At the beginning of this century very little was known of the sizes of the nebulæ or of their true position in relation to the Milky Way ; and the reason was that great difficulty was experienced in determining stellar distances. Finding the distance of an inaccessible object is a problem which comes into many investigations outside astronomy, but sometimes the problem is fairly easily solved. The height of Mount Everest was known long before anyone got near the top of it. We can find the height of an aeroplane by observations from the ground. In warfare we can find the distance of a point behind the enemy's lines by observing from our own territory. The distances of the Sun and the Moon have been known with fair accuracy for hundreds of years. But fundamentally the problems are all solved in the same way : measure the length of a base-line, and from the ends of that base-line measure the angles of direction to the object whose distance is required. Then the size of the triangle made by the object and the two ends of the base-line can be discovered and thus the distance of the object is known. The line Greenwich to Cape Town has served for finding the distance to the Moon. But it must be obvious that a very short base-line will not serve for finding the distance of a very remote object : the angles at the ends of the base-line will appear to add up to 180°, and all we can say is that by using that base-line the object is found to be immeasurably remote. Now no base-line on the Earth is long enough for finding the distance to any star. But we have a longer base-line : we may observe the position of a star, and then observe it again six months later when the Earth is on the other side of the Sun. Thus we employ a base-line 186,000,000 miles long. When this method was first used it was still found that it gave no result for the distance of any star ; though with improved measuring instruments and by investigating a star which was believed to be relatively near, a result was obtained in the year 1838. This is a great year in the history of astronomy, and the first determination of a star distance was a great achievement. But it was soon seen that there are not many stars near enough for their distances to be determined by this method. By the beginning of the 20th century only about sixty star distances were known, and the vast majority of stars still remained "immeasurably remote." The problem of the size and structure of our Milky Way remained unsolved, and it seemed to be a baffling problem. Still, progress was being made : by 1915 about 200 star distances were known. Then, at about that time, indirect methods were evolved by which the distances of some stars could be determined without the use of a base-line.

Star distances: use of Spectroscope

The instrument that was employed in one of the first indirect methods of finding star distances was the spectroscope.* The spectra of individual stars are now photographed in thousands. Though stellar spectra are now classified in certain main groups, each star spectrum has its own individuality which depends on the position and nature of the dark or bright lines by which the spectrum is crossed. The brightness of a star as it appears to us is known as its

* See page 98

Magnitude, or better still *Apparent Magnitude*. The brightest stars are those of the first magnitude while those of the sixth magnitude are just visible to persons with good eye-sight. But, of course, the mere knowledge of the magnitude of a star tells us nothing of its true brightness. A star which appears to us very bright may in reality be a rather faint star which happens to be relatively near to us. The apparent brightness of a source of light depends upon its distance, and varies in accordance with a simple law which states that the intensity of the light varies inversely as the square of the distance. Thus, if a star could be brought three times as near as it is, it would appear nine times as bright. By the application of this simple principle, if we know how far away a star is and observe its apparent brightness, we can calculate its real brightness—what we might call its candle-power, but what we do call its *Absolute Magnitude*. Thus we know the absolute magnitudes of all those stars whose distances have been discovered by the base-line method. We also have photographs of the spectra of these stars. Now when a comparison was made of the spectra and absolute magnitudes of some of these stars it was found that there was a relation between the two—that stars with a certain type of spectrum had the same absolute magnitude. If we assume this relationship to hold good for other stars of the same type of spectrum, we may observe the spectra of those stars, and from the spectrum deduce the absolute magnitude. Knowing now the apparent magnitude and the absolute magnitude we can easily calculate the distance. In this way we may obtain the distances of stars previously regarded as "immeasurably remote." "A most dangerous form of argument," the reader may say : "Suppose the assumed relationship does not hold good in the case of the other stars, then your further deductions and calculations are all wrong." That is perfectly true and had been thought of before ; nevertheless, there are answers to that objection. The spectrum of a star is the most characteristic expression of its personality ; and there are strong reasons which cannot be gone into here for believing that the relationship does hold good. Moreover, this is only one of several independent methods of finding star distances which are in very fair general agreement, and it is not at all likely that the results obtained by these methods will in future require to be very much modified. They have at last enabled us to give a not unlikely answer to the problem of the structure of our star-system and the relationships between stars and star clusters and the different types of nebulæ.

In trying to state the result we must make use of figures which are so large that they seem almost meaningless. But if we use the value of the velocity of light the figures become less unwieldy. Light travels through space at about 186,000 miles a second : thus it takes just over eight minutes to come to the Earth from the Sun. From the nearest star it takes 4.3 years to travel to us. So we say that Proxima Centauri is 4.3 *light-years* away. One light-year is about six million million or six billion miles. The light-year is a manageable unit in which to state stellar distances.

The Galaxy

Our star system, The Galaxy, as astronomers now more usually call it, appears to be a flattened disc-like agglomeration of stars which different astronomers have likened in shape to a watch, a lens, and a bun. One more illustration perhaps will do no harm. It might be likened in shape to two large shallow dinner plates placed edge to edge, but with a piece of rather thick cardboard between the plates. Without further mystification we may say that it is probably a spiral nebula. The distance from one edge to the other right across the middle is probably of the order of 100,000 light-years. The Sun is about two-thirds of the distance from the centre to the edge. It contains the planetary and irregular nebulæ. The position of the globular clusters is less easy to describe : they are outside the plates, but would be contained within them if the plates were hemispherical bowls. What then do the cardboard and the plates represent ? The cardboard is the central stratum where the stars are most numerous ; but since our Sun comes just within it, the region can hardly be said to suffer from overcrowding. The plates are the boundaries of the region where star population is comparatively dense. Beyond the plates, in the region of the globular clusters, the density really does thin out. If it is realized that there is no sharp separation at the surfaces of the cardboard and at the plates, then perhaps it is not too bad a model.

What then of the nebulæ of the third class which on page 69 we called spirals ? They are the other systems of millions of stars, more

or less independent of our Galaxy, some of them probably resembling it in size and shape. Spiral is an inappropriate name, because a great many of them show no spiral structure at all. They are now called *extra-galactic* nebulæ—quite outside our Galaxy. We used the expression " more or less independent of our Galaxy." Why " more or less " ? Because just as there are clusters of stars, so there appear to be groups and clusters of Galaxies. In fact, our Galaxy seems to belong to a group of at least nine, which includes the nebula in Andromeda as well as the two Magellanic Clouds of which you are told more in Chapter 9. The Magellanic Clouds are certainly outside our Galaxy, though to what extent independent of it we do not know. Is there such a thing as complete independence in the whole Universe ?

The reader may now see the difference between the Milky Way and the Galaxy. Some people are confused by being told that all the stars we see with the naked eye are in the Galaxy : certainly very many of them are not in the Milky Way. The Galaxy is the spiral nebula we are in. The Milky Way is the middle dense stratum (the cardboard) of the Galaxy as we see it making a faint and irregular girdle round our sky—at least that is the way in which the terms ought to be used. This should show why stars seen not in the direction of the Milky Way are yet in the Galaxy. A beetle living in a field of grass might be puzzled at being told that the blades of grass which appear over its head in the direction of the sky are really in the plane of the field in which it lives. It is the same idea.

The Galaxy rotates about an axis which may be considered to be represented by the line joining the centres of the two plates, but the stars most distant from the centre take longest to get round. It is believed that the Sun's movement in this rotation is at the rate of about 170 miles per second and that it will take about 224,000,000 years to get round once. The Andromeda nebula illustrated in Plate VIII is probably a similar object to our Galaxy. It is one of the nearest to us of the spirals, being about 750,000 light-years distant. In it have been identified the same sort of objects as we find in our system—irregular nebulæ, variable stars, new stars, open and globular clusters. Similar systems or spiral nebulæ are found in millions, and with the 100-inch mirror at Mount Wilson it has been possible to photograph spirals which are believed to be 500,000,000 light-years away. The 200-inch telescope which has been recently constructed will penetrate twice as far.

A remarkable result of the application of the Doppler effect* is the discovery that the spirals are all moving away from one another at very high velocities. This "Expansion of the Universe" is a very difficult and intricate matter for the further study of which the reader must refer to more advanced books.

Double Stars

The telescope shows that many of the stars which appear to the naked eye to be single are in reality two stars very close together and these are known as *double stars*. They are of two kinds. It may happen that the two stars composing the double are almost exactly in the same direction from the Earth, and so appear to be very close together, but one of them may actually be many times as far away from us as the other. On the other hand, the two stars may really be close together, the two revolving round a common centre ; in this case the double is called a *Binary*. Thousands of double stars are known to exist. Some can be seen as doubles only with the aid of very large telescopes, but there are others which can be "split" with small instruments, and these are an endless source of pleasure to those who possess a telescope. In many cases the colours of the two stars forming the binary are quite different, and the pair then forms a very beautiful object in the telescopic field. The larger star is often of a reddish orange colour and the smaller one blue or green. On page 117 we mention some of the chief double stars and give directions for finding them.

It has long been known that there are certain stars which do not shine steadily with the same degree of brightness : these are known as *Variable Stars*. Within recent years hundreds of variables have been discovered, some having very regular periods, while others diminish and increase in brilliancy in a very irregular manner. Those like delta Cephei (Cepheid variables) show a relation between Absolute Magnitude and period of variation and they afford one of the most valuable indirect methods of finding the distances of globular clusters and of the less remote spirals. Of the regular variables the

* See p. 100.

best known is Algol in Perseus (see Fig. 17). It goes through a cycle of changes in about 69 hours. It is ordinarily rather fainter than second magnitude. It remains in this condition for 20 minutes, and then in rather more than 5½ hours it regains its ordinary brightness. Another star is revolving round it and partially eclipsing it. It is a pity that we do not call such stars occulting variables (see page 23). *Whitaker's Almanack* gives the times when Algol is at its minimum brightness.

New Stars

It happens occasionally that a new star or Nova makes its appearance. It is a comparatively rare event, only about twenty bright novæ having ever been recorded. A nova generally attains its maximum brightness in a few days and then fades, with irregular changes in its brilliancy, until after a few months it becomes invisible to the naked eye. No satisfactory explanation of these outbursts has yet been given. The most recent important nova was the one discovered in Hercules in December, 1934, by Mr. J. P. M. Prentice. Its spectrum underwent a remarkable series of changes. "New star" is really not a very happy name because we now know that Novæ are old stars which suddenly undergo a great increase in brightness.

Precession

On page 29 we hinted that some stars appear to have a slight movement of their own. They do slowly change their positions relatively to one another. This very gradual shifting of stellar positions is known as *proper motion*. When it is desired to state the star's position very exactly, it is necessary to allow for the proper motion that has taken place in the interval since the star's position was last measured. Another and much more important factor in the changing right ascension and declination of a star is the gradual movement of the First Point of Aries, which alters its position by about 50″ annually, but this is not a real movement of the star. This movement, known as Precession, has already been mentioned on page 43.

Other surprising discoveries in connection with the stars have been made in recent years. Though stars do not differ very much in weight, we know that they differ very much from one another in size. Some of the low-temperature red stars were long ago suspected of being of vast size. The first star diameter was measured in 1920 by means of an instrument known as an Interferometer. Betelgeuse is known to be larger than the Earth's orbit round the Sun ; while Antares has a diameter of about 400,000,000 miles—that is to say, the orbit of Mars would be easily contained within it. These stars are known as Giants. At the other extreme are the White Dwarfs, of which the companion to Sirius is an example. They are intensely hot and probably not much larger than the Earth, while the substance of which they are made is in the neighbourhood of 50,000 times as dense as water. Our Sun is intermediate between the giants and dwarfs and has a density rather less than 1.5 times that of water.

Chapter 8

The Chief Stars and Constellations

α Alpha	ι Iota	ρ Rho
β Beta	κ Kappa	σ Sigma
γ Gamma	λ Lambda	τ Tau
δ Delta	μ Mu	υ Upsilon
ε Epsilon	ν Nu	φ Phi
ζ Zeta	ξ Xi	χ Chi
η Eta	ο Omicron	ψ Psi
θ Theta	π Pi	ω Omega

WE HAVE already mentioned that as we view the stars there seems to be little or no orderly arrangement among them ; nevertheless, on looking at the face of the sky more closely we shall notice certain groups of bright stars. The whole sky has been mapped out and divided into areas containing particular star groups. These star groups are called *Constellations.*

Our purpose in this chapter is to give a list of the chief constellations, and to show how they and their brightest stars may be found and learned.

The division of the sky into constellations was attempted by the ancient civilized races—the Chaldeans, Babylonians, Egyptians, and Chinese ; but the divisions and their names which we now use are mainly the same as those employed by the ancient Greeks. Many of the names are those of animals, e.g., the bear, the lion, the dog, the ram, the swan, the serpent ; others represent characters from Greek mythology, e.g., Andromeda, Cassiopeia, Hercules, the Centaur ; while a few denote familiar occupations, e.g., the ploughman, the charioteer, the archer, and the water-bearer.

As you study the sky you may come across a bright star not shown on a star map. Of course it may be that this is a nova and that you have made a great discovery, but before you ring up Greenwich Observatory to report it, make sure that it is not one of the five bright planets. Their positions are given in *Whitaker's Almanack* as well as in the monthly notes of some of the scientific journals.

It is generally correct to say that the stars twinkle, but the planets do not ; but this is not always true. The planets sometimes twinkle when near the horizon, while the stars may shine steadily in the upper part of the sky.

The Pole Star Region

The obvious starting-point for an observer in the northern hemisphere is the Pole Star or Polaris. A stick may be pointed due north and elevated at an angle equal to the latitude of the place, and this will point to that star. It cannot be mistaken as there is no other bright star within about 15° of the Pole.

Having found the Pole Star we must next look for the Plough. This is the most conspicuous part of a very large constellation called the Great Bear, of which the Plough forms the body and the tail. The head is quite like that of an animal (more like an ant-eater than a bear, perhaps), but the stars are not very bright. The position of the Plough, as of all other stars, will depend on the hour of the night and the time of year.

In the evening hours of autumn it will be found below the Pole Star and not far above the northern horizon. Fig. 15 shows the shape and position of the Plough. The two end stars are known as the "*Pointers*," because they point almost exactly to the Pole Star. The Pole Star is the end star in the tail of the *Little Bear*, and of the other stars in this constellation the only conspicuous ones are the two at the end away from the Pole.

The stars in each constellation are named from the letters of the Greek alphabet, the brightest star in the constellation generally being α, the next brightest β, and so on, though the order is not always strictly in accordance with the brightness.

When you have found the Great Bear, look on the opposite side of the Pole at about the same distance, and you will see five stars forming a rather irregular W. This constellation is *Cassiopeia* ; it is situated in the Milky Way (Fig. 16).

Not far from the zenith but rather towards the west or north-west is a brilliant white star, which forms a nearly equilateral triangle with the Great Bear and Cassiopeia. This is *Vega*, the chief star in the constellation of *Lyra*. The other chief members of the con-

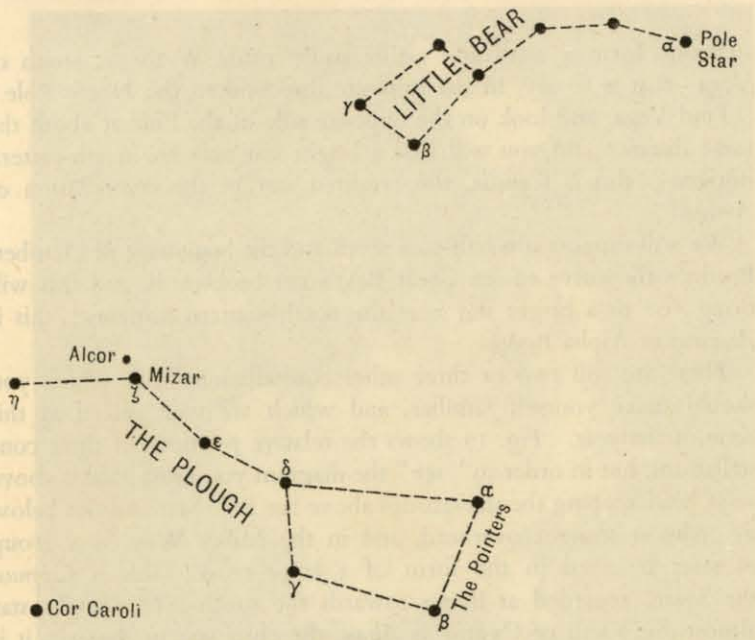


Fig. 15. The Plough and the Pole Star.

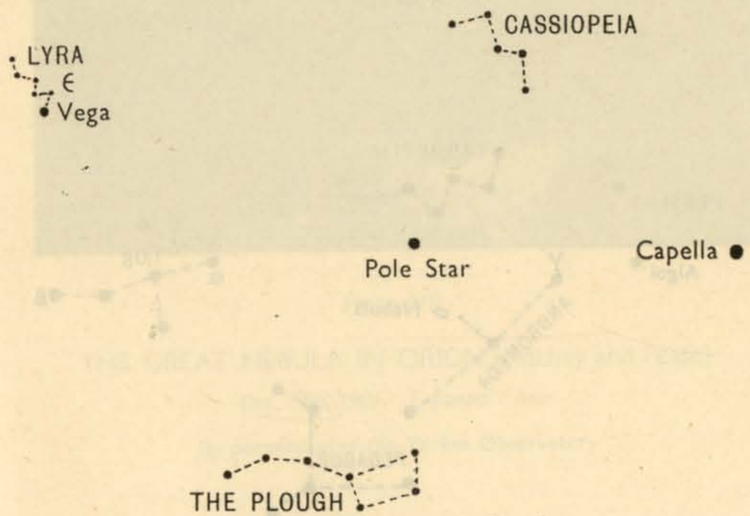


Fig. 16. The Plough and Cassiopeia.

stellation form a small and rather badly made W to the south of Vega—that is to say, in the opposite direction to the North Pole.

Find Vega, and look on the opposite side of the Pole at about the same distance and you will find a bright star near the north-eastern horizon ; this is *Capella*, the brightest star in the constellation of *Auriga*.

We will suppose it is half-past seven and the beginning of October. Produce the curve of the Great Bear's tail backwards, and this will bring you to a bright star near the north-western horizon ; this is *Arcturus* or Alpha Boötis.

There are still two or three other constellations with which you should make yourself familiar, and which are well placed at this time of the year. Fig. 17 shows the relative positions of these constellations, but in order to " set " the diagram you must hold it above your head keeping the star-groups above the Pole Star and not below it. Almost straight overhead, and in the Milky Way, is a group of stars arranged in the form of a large cross ; this is *Cygnus*, the Swan, regarded as flying towards the south. The bright star almost due south of Cygnus is *Altair*, the chief star in *Aquila* : it is the middle and brightest of three stars in a line.

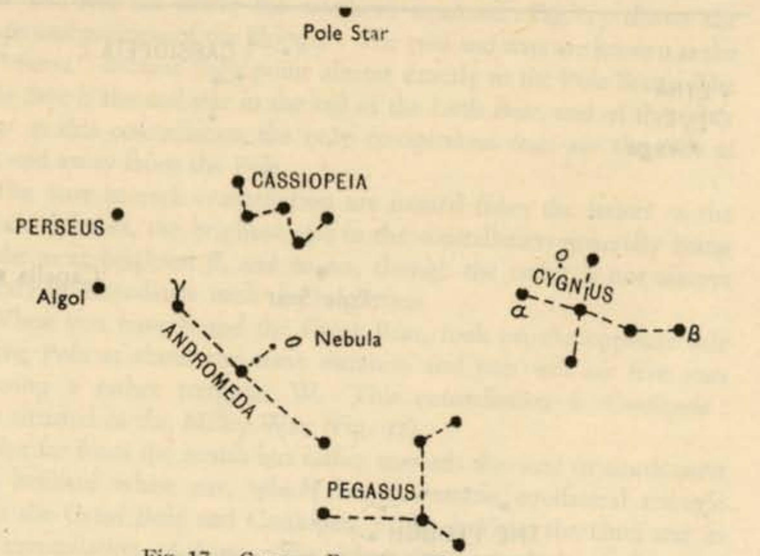


Fig. 17. Cygnus, Pegasus and Andromeda.

Plate VII

THE GREAT NEBULA IN ORION (Ritchey and Pease)

Oct. 19th, 1901. Exposure 1 hour

By permission of the Yerkes Observatory

Plate VIII

THE GREAT NEBULA IN ANDROMEDA (Ritchey and Pease)

Sept. 18th, 1901. Exposure 4½ hours.

By permission of the Yerkes Observatory

A straight line from the Pole Star through the most westerly star of Cassiopeia brings you to a couple of bright stars, separated by about twice the distance which separates the Pointers ; higher above the eastern horizon are two more, which with these two form a large square. This is the square of *Pegasus*, and the northern side of it forms part of a grand curved line of stars passing through *Andromeda* to *Perseus*. There are three bright stars in Andromeda, and to the north of the middle one there are two fainter stars. Close to the more northerly of these is the great Andromeda nebula, which is visible to the naked eye on very dark nights as a very faint hazy patch of light.

Take particular notice of this nebula. It is the most remote object the naked eye can see—an island universe like our own Milky Way. It is in the remote background of the sky, thousands of times as far away as the stars which seem to surround it. These stars are comparatively near neighbours, after which comes a vast distance of empty starless space before we arrive at the Andromeda nebula. We do not know what the nebula looks like to-day. What we see, in the 20th century, is this extra-galactic nebula as it was some time about 750,000 years ago, for the light takes about three-quarters of a million years to reach us.

The Orion Region

We will now consider how these stars have shifted their positions, and what new ones have come into view, at half-past seven in the middle of February.

We now find the Plough in the north-east. Pegasus is down near the western horizon and will soon set, followed by Andromeda and Perseus, though part of Perseus never sets in the latitude of the British Isles. Capella is nearly in the zenith, while Vega is almost on the northern horizon. Arcturus will rise in the east in about an hour.

The southern sky presents a grand spectacle, and we see an entirely different set of stars from those we saw in the autumn evenings. Most of the bright stars in this region are included in the graph-paper exercise on page 111. Almost due south is *Orion*, undoubtedly the finest constellation in the whole sky. The three stars forming his belt are very conspicuous. Above the belt are two bright stars

(Orion's arms), of which the more easterly (*Betelgeuse*) is of a reddish colour. The other arm is Bellatrix, not quite first magnitude. On the other side of the belt are the two stars which correspond to the legs. Of these the brighter is *Rigel.* Between the arms and slightly above them is a faint triangle which represents Orion's head. Beneath the middle star of the belt is a line formed of three stars, of which the most northerly is faint and the most southerly is the brightest. These three stars form Orion's dagger or sword. The middle one of the three appears indistinct, and marks the position of the great nebula in Orion. This splendid constellation deserves very careful study. Note that the upper star in the belt is almost exactly on the celestial equator.

Follow the line of Orion's belt downwards, and you come to *Sirius,* the chief star in the *Great Dog* or *Canis Major* and the brightest star in the sky. Follow the belt upwards about the same distance and you will find *Aldebaran,* the brightest star in *Taurus.* The little cluster of which he is the brightest member is known as the *Hyades.* Continue the line a little farther in the same direction, and you come to a much more conspicuous cluster, the *Pleiades.* (See page 109.)

There are some bright stars on the other side of Orion, and we must now give our attention to these. Make a line from Rigel through the eastern end of Orion's belt. Continue this line until you come to a bright star : this is *Procyon,* the chief star in *Canis Minor.* Almost due north of Procyon are the Twins, *Castor* and *Pollux,* of which Pollux is the southernmost and the brighter (see Fig. 18). The bright star not far above the eastern horizon is *Regulus* (Alpha Leonis) ; with the other stars close to it and to the north it makes a curve, forming the Sickle of Leo.

Other Constellations

There are three other first magnitude stars which must not be omitted. In the evenings of early summer the Plough is near the zenith. Make a line from the Great Bear's tail to Arcturus : continue about the same distance to the south and slightly to the west. The 1st magnitude star thus found is *Spica,* or α Virginis. A rather greater distance than this towards the east from Spica and still farther south is *Antares,* α Scorpionis, a giant red star. In autumn evenings

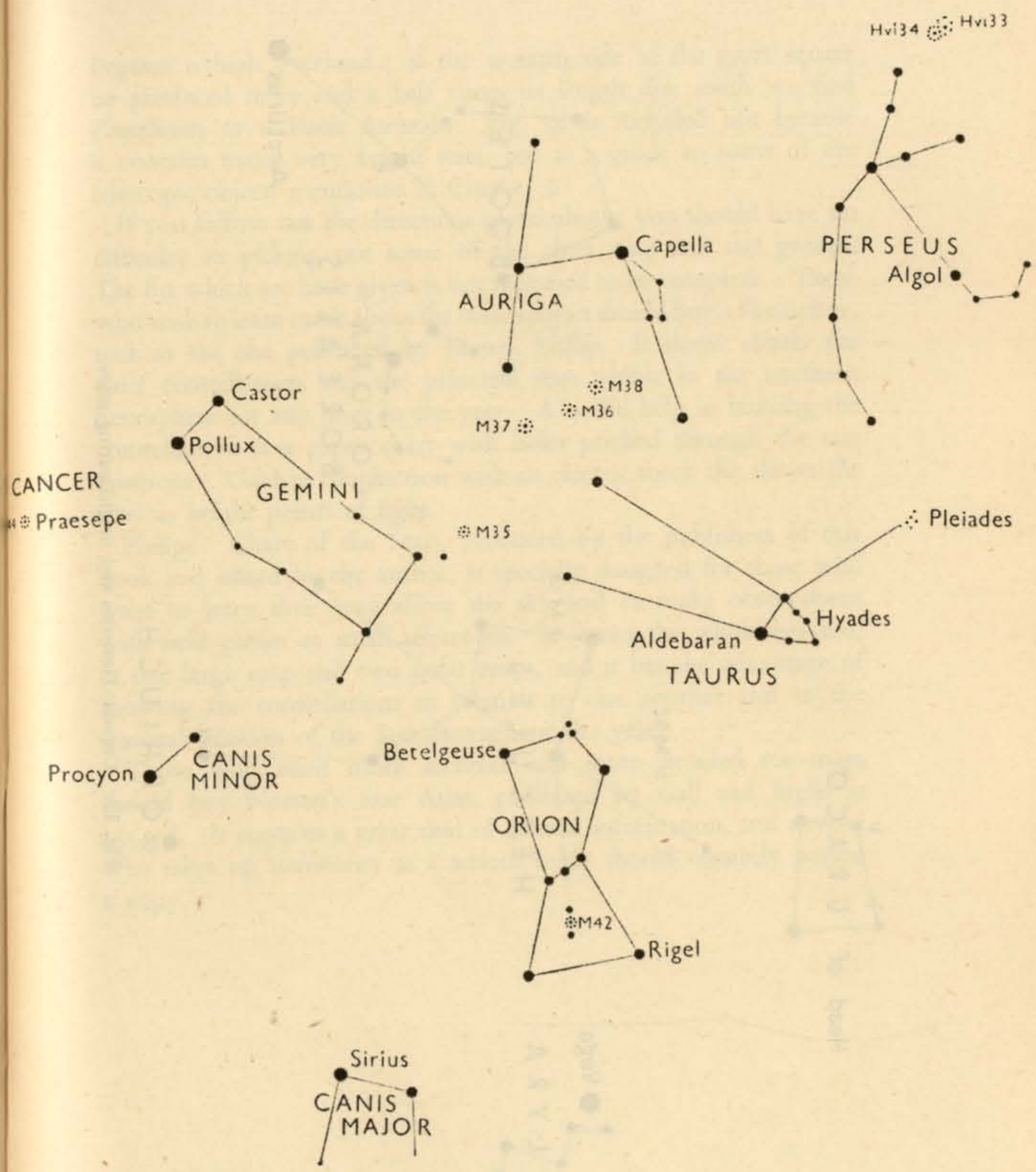


Fig. 18. Orion and neighbouring stars.

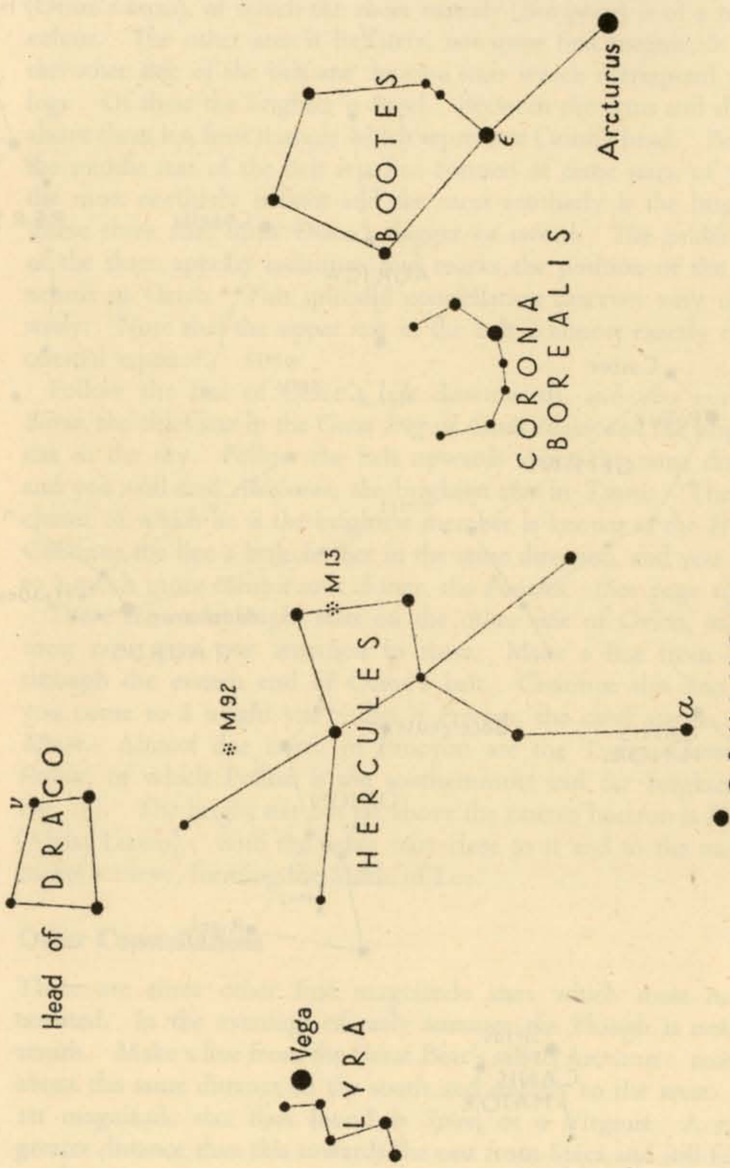


Fig. 19. Corona, Hercules and neighbouring stars.

Pegasus is high overhead : if the western side of the great square be produced three and a half times its length due south we find *Fomalhaut*, or α Piscis Australis. Fig. 19 is included not because it contains many very bright stars, but as a guide to some of the telescopic objects mentioned in Chapter 9.

If you follow out the directions given above, you should have no difficulty in picking out some of the chief stars and star groups. The list which we have given is not supposed to be complete. Those who wish to learn more about the same subject should buy a *Planisphere*, such as the one published by Messrs. Philip. It shows clearly the chief constellations and the principal stars visible in the northern hemisphere for any hour in the year. A useful help in learning the constellations is a paper chart with holes pricked through the star positions. Used in conjunction with an electric torch this shows the stars as bright points of light.

Philips' Chart of the Stars, produced by the publishers of this book and edited by the author, is specially designed for those who want to learn their way about the sky and to make observations with field-glasses or small telescopes. It shows the whole heavens, in one large map and two polar maps, and it has the advantage of showing the constellations in relation to one another and to the seasonal position of the Sun throughout the year.

Those who want more accurate and more detailed star-maps should buy Norton's Star Atlas, published by Gall and Inglis at 15s. 0d. It contains a great deal of general information, and anyone who takes up astronomy as a serious study should certainly possess a copy.

Chapter 9

Conspicuous Star Clusters and Nebulæ

Many people find star clusters most fascinating—and no wonder. They are very numerous : many are resolved (that is, separated into their component stars) in quite small instruments. Some of them show interesting and peculiar arrangements of stars ; and if the observer will forget that he is looking through a little hole in a telescope and cultivate the habit of seeing spaciously, the views he gets will sometimes bear comparison with the naked-eye constellations. Good doubles and multiples are sometimes to be found in the clusters, and a considerable variety of colour among the stars is not unusual.

The late W. H. Pickering, an eminent American astronomer, compiled a list of what he regarded as "The Sixty Finest Objects in the Sky." This appeared in "Popular Astronomy" in 1917. The list, with descriptions made at the telescope, was intended partly "to serve as an aid to those wishing to exhibit particular beautiful objects to students or visitors." Dr. Gingrich, Editor of "Popular Astronomy," has kindly allowed some quotation from this interesting article. For accounts of some of the more remarkable objects in far south declination, the author is much indebted to Dr. R. H. Stoy, of the Royal Observatory, Cape of Good Hope, for making some observations and notes in 1942.

The positions of these clusters and nebulæ are all shown in Philips' Chart of the Stars, or they can be located on other maps by means of the right ascension and declination co-ordinates.

47 Toucani. 0 h. 22 m. 72° 24′ S. A grand globular cluster. Pickering says "By far the finest." Dr. Stoy says "Visible to the naked eye : appears as a hazy patch in field-glasses and begins to be resolved in a 3-inch."

M.31. 0 h. 40 m. 41° N. The Great Nebula in Andromeda. Easily visible to the naked eye under good conditions. See Fig. 17. It is the only spiral nebula which can be seen without a telescope, and is thus the most distant naked-eye object. In a small instrument it is extensive, but little or no structure is seen. As it probably resembles our Milky Way system in size and structure, and its distance is of the order of 750,000 light-years, it deserves our attention and contemplation. See Plate VIII.

The Nubecula Minor. 0 h. 50 m. 73° 54′ S. The Lesser Magellanic Cloud. The smaller of those two patches which are said to look like bits of the Milky Way which have broken loose. It is not a spiral, but is regarded as one of a group of nebulæ of which our Galaxy is a larger member.

H. VI. 33, 34. 2 h. 18 m. 57° 0′ N. Always known as the Double Cluster in Perseus. Easily visible to the naked eye though not resolved, and is the best-known telescopic cluster in the northern hemisphere. It is really two clusters (h and Chi Persei) of which the "preceding" (or more westerly) is decidedly the finer. It contains a horse-shoe of bright stars. There is one intensely black region and this serves to set off those stars which are in the brighter portions. The " following " (more easterly) cluster is very fine and perhaps tends to get neglected as a show object.

The Pleiades. About 3 h. 45 m. 24° N. The best-known naked-eye cluster, which some beginners think is the Little Bear because there is some resemblance in shape to the Plough. As a telescopic object it needs a very low magnification.

The Hyades. A V-shaped cluster, actually the head of the Bull with Aldebaran for the eye. Like the Pleiades, easily resolved without field-glasses.

The Nubecula Major. Centre about 5 h. 25 m. 69° 20′ S. Much more extensive than the Minor. They both contain many clusters and nebulæ.

M. 42. The Great Orion Nebula. 5 h. 33 m. 5° 20′ S. A gaseous nebula in our Galaxy. It is located by the middle one of the three stars of the dagger. (See Fig. 18.) Pickering calls it " the finest and most detailed of all the nebulæ," and it is one of the few that really do bear close scrutiny in a small glass. There are many stars associated with it, among them four forming " the trapezium " which a 2-inch glass should show. There is a very black region contrasting well with the pale green which characterizes the gaseous nebulæ.

M. 37. 5 h. 49 m. 32° 33′ N. A first-class cluster of very faint stars ; but it does require something more than a very small glass.

M. 35. 6 h. 06 m. 24° 20′ N. Very close to the position of the Sun at the summer solstice. A large cluster just visible to the naked eye. There is a dark patch in the middle with two dark lanes leading to it, two curved lines of stars, and, as in so many clusters, one decidedly red star.

M. 41. 6 h. 45 m. 20° 42′ S. Open cluster. Visible to the naked eye. Quite good in a 3-inch with a low power. Here, again, there is a reddish star near the centre.

M. 46. 7 h. 39 m. 14° 42′ S. This is a fine cluster of faint stars including a planetary nebula, but it is no object for a small telescope. Slightly preceding and further north is a naked-eye cluster of a few bright stars.

Omicron Velorum. 8 h. 37 m. 52° 36′ S. An open cluster distinctly visible to the naked eye.

M. 44. 8 h. 37 m. 20° 10′ N. Præsepe in Cancer. A well-known object, not difficult to see on moonless nights. There are not many stars, but they are bright. A good field-glass object.

Eta Argus, or Eta Carinæ. 10 h. 43 m. 59° 25′ S. A variable star in a great diffuse nebula more than a degree across. Dr. Stoy says : " The 'Keyhole' nebula, the bright and dark gaseous nebula round Eta Carinæ, is visible in field-glasses, but, as with most objects, the bigger the telescope the finer it appears to be. It is not so bright as the Orion Nebula, but there is a far greater clustering of faint stars round it. . . . The dark part of the nebula has been called the 'Crooked Billet' and is quite easily made out with field-glasses."

N.G.C. 3532. 11 h. 04 m. 58° 24′ S. The Great Cluster in Carina. Pickering says : " The finest irregular cluster in the heavens, and possibly the finest object outside the solar system. There is no other irregular cluster in the same class with it. It is because it fills the whole field of view in the telescope that its beauty has not hitherto been more generally appreciated." Dr. Stoy says : " The component stars are fairly uniform in brightness and are evenly scattered over an area three to four times the size of the Moon. Unfortunately, the component stars are not brighter than the eighth magnitude, so that, although it can be seen with field-glasses, it requires a 3-inch with comet eye-piece to make it into a spectacle. That whole area of the sky is thick with stars and small clusters. They make the dark part of the Eta Carinæ nebula very much more conspicuous than the corresponding dark part of the Orion nebula."

M. 97. 11 h. 12 m. 55° 17′ N. The "Owl" nebula in Ursa Major. In a small instrument this is merely a little disc-like object, though it is one of the largest of the planetary nebulæ.

Kappa Crucis. 12 h. 51 m. 60° 10′ S. A loose cluster with no nebulosity, famous because the stars show a variety of colours. Dr. Stoy says: "Seen with field-glasses; resolved with a 2-inch, and is quite a pretty object in a 3-inch, though it needs a bigger telescope to do justice to all the various colours of the component stars."

Omega Centauri. 13 h. 24 m. 47° S. Generally called "the finest of all globular clusters," no doubt by many people who have never seen it, though photos of it are in many elementary books. Pickering called it "a somewhat over-rated object," and thought 47 Toucani finer. Tastes differ. It seems to lack the central condensation of some of the other globulars.

M. 3. 13 h. 40 m. 28° 38′ N. A very fine globular cluster if seen in a large enough telescope; but because the stars are of smaller magnitude it does not resolve like M. 13.

M. 5. 15 h. 16 m. 2° 16′ N. Another good globular. It is very bright and there is a good deal of line arrangement of stars.

M. 13. 16 h. 40 m. 36° 33′ N. Often called "The Great Cluster in Hercules." This is the most famous of globular clusters visible from Britain. Others perhaps have more central condensation or are more easily resolved, and each has its individual interest. A good 4-inch will resolve the edge, and it is centrally resolved in a 6-inch: it then looks bigger and more massive than M. 3 or M. 5. Under good conditions it is superb, and no other northern globular can really compete with it.

M. 92. 17 h. 16 m. 43° 12′ N. A globular not much inferior to M. 13, in fact it is actually brighter in the centre though less easily resolved.

M. 7. In Scorpio. 17 h. 51 m. 34° 48′ S. A very striking naked-eye cluster associated with nebulous matter. The B.A.A. Handbook described it as "a magnificent large loose cluster of bright stars." But it is too far south for satisfactory observation from England.

M. 8. In Sagittarius. 18 h. 1 m. 24° 23′ S. This is a rich cluster of stars superimposed on a nebula. It catches the eye as one looks at the rich part of the Milky Way in that constellation. The nebulosity is easily seen in field-glasses. There appears to be a broad line of dark nebula running through the middle. A most interesting and unusual object demanding close attention.

M. 22. In Sagittarius. 18 h. 33 m. 24° S. Professor Shapley says, "The first globular cluster to be recorded as such: discovered by Ihle in 1665." It is near the Sun's position at the winter solstice, a part of the sky packed with clusters, but cruelly low in altitude for British observers. This cluster is larger than M. 13. and regarded by some people as superior to it. It is certainly more readily resolved into brighter though fewer stars. A very grand object, but it appears (as far as one can judge from the south of England) not to have the central condensation nor the gradation from centre to edge that is found in M. 13. In a clear sky it is not difficult to find in field-glasses.

M. 11. 18 h. 48 m. 6° 20′ S. This has sometimes been wrongly described as globular. It is a condensed galactic cluster, requiring rather a large telescope as the stars are about magnitude 11. There is one much brighter star which the B.A.A. Handbook says is probably unconnected with the cluster.

M. 57. 18 h. 52 m. 33° N. The Ring Nebula in Lyra. The best of the annular nebulæ, but the user of a small glass must not expect to do much more than verify its existence. It is on the line between beta and gamma Lyræ. In a 7-inch it has the appearance of a thick ring, slightly oval and least bright at the ends of the long axis. Like other planetary nebulæ, it is really a shell or globe of gas round a very hot star. A delicate, interesting and mysterious-looking object.

M. 27. 19 h. 57 m. 22° 36′ N. The "Dumb-bell" nebula: a planetary. Not an exciting object in a small glass.

The Zodiacal Light

The Zodiacal Light is an astronomical phenomenon which anyone in Britain can observe, and if he is in a lower latitude he will see it better still. In England, select a night in February, March or April (mid-March for choice). There must be no cloud in the west, little or no haze, and no Moon. All trace of twilight must have gone, and the sooner after this has happened the better. It is to be preferred that there should be no bright planet in the western sky. A low western horizon is desirable, and there must be no artificial lights as from a town. The best conditions are probably found in the clear air just after the centre of a depression has passed. The observer's eyes must be quite accustomed to the darkness ; that is to say, all effect of artificial light from a room he may have been in must have worn off. Then without any instrument he surveys the sky from south to west and up to an altitude of about 50°. If he compares the brightness of the sky due west and south-west and south he will probably see that there is a faint lightness of the sky to the south-west. The sky to south and west is darker. The brighter patch is perhaps 40° or 50° broad near the horizon and rises to an apex about 45° high. This is the Zodiacal Light. It cannot be due to the Milky Way which in spring evenings is further round towards the north. The Light has no clearly defined outline and it varies somewhat in brightness. It is best seen in spring evenings because the Ecliptic, along which its centre lies, is then at a steep angle to the horizon. (See Fig. 13.) For the same reason, it can be seen before sunrise in autumn mornings. It is generally said to be due to sunlight reflected from dust and meteoric matter revolving round the Sun in and near the general plane of the planetary orbits—that is, the Zodiac—hence its name.

Chapter 10

Telescopes and the Spectroscope

In the last forty years very great advances have been made in our knowledge of the stars. A great deal has been found out about the composition of the stars, their temperatures, their sizes, their distances, and the direction and velocity of their movements. The two instruments which have made this possible are the photographic camera and the spectroscope, both used in conjunction with the telescope.

There are several reasons why photography is such a valuable aid in the study of astronomy. In the first place, the pictures obtained by its use are in many cases more accurate and reliable than those which are drawn by hand.

In the second place, objects which are too faint to be seen will after hours of exposure imprint themselves on the sensitized film. If we cannot see an object after looking for it patiently for some minutes we are not likely to see it by staring for hours. This is not so with the photographic plate, for an exposure of some hours will reveal the presence of stars which do not appear on a plate exposed for only one hour. Lastly, there are certain rays which do not affect our eyes, but yet leave their impression on a plate. They are not visible rays, but chemical or actinic rays. In this way photography has been the means of discovering vast numbers of stars and nebulæ which it is almost certain must always remain invisible.

The camera has also enabled us to find out whether what appear as minute objects are distant stars or members of the Solar System such as comets, asteroids or satellites. A part of the sky is photographed on two separate occasions a few days apart, and the two pictures are compared. If the second photograph shows an object in a different position from that which it occupied on the first occasion, we can be certain that the object is a member of the Solar System. Six of Jupiter's satellites were discovered by photography, and hundreds of the asteroids have been discovered in the same way, and as already mentioned on page 62 this was the method employed in the discovery of Pluto.

Telescopes

Every telescope must have some means of forming an image of a distant object. If this is done by means of a lens (called the object-glass), the telescope is a *refractor* (the lens refracts or bends the light). The first telescopes ever made were of this kind. But if the image is formed by a curved mirror the telescope is called a *reflector*. The ordinary look-out telescopes with which everyone is familiar are refractors. Astronomers use either kind. Reflectors are cheaper, but, on the whole, they need rather more care and technical knowledge. Most quite small astronomical telescopes are refractors. The size of a telescope is generally given as the diameter of the object-glass (o.g.) or mirror (often called the *speculum*). Thus we speak of a 3-inch refractor or a 6-inch mirror. The biggest refractor in the world is the 40-inch at the Yerkes Observatory of the University of Chicago. It is at Williams Bay, Wisconsin. The biggest reflectors are the 100-inch aluminized glass mirror at Mount Wilson, California and the 200-inch at Mount Palomar.

The image formed by object-glass or mirror is very small and must be magnified by a lens (known as the *eye-piece*) at the eye-end of the telescope. The simplest kind of refractor consists of object-glass and eye-piece mounted in a tube. The image thus produced is inverted, but this does not matter to the astronomer. For terrestrial work, of course, the image must be erect ; but to produce an erect image in a telescope (not necessarily in opera-glasses) we must use a more complicated eye-piece containing an extra lens. This involves increased expense, and results in a less bright image, so the astronomer prefers the inverted image. Most astronomical photographs and drawings are set as seen in an inverting telescope.

The object-glass is a convex lens and it brings parallel rays of light (from a distant object) to a point known as the *principal focus* (or simply *focus*) of the lens. The distance from the centre of the lens to the focus is known as the *focal length* of the lens.

By the *magnification* of a telescope we mean the number of times it increases the length of a line. Thus if a telescope makes a line appear 25 times as long as it appears to the naked eye, we say the telescope has a magnification of 25. The magnification of an astronomical telescope is the focal length of the object-glass divided by the focal length of the eye-piece. Thus with an object-glass of focal length 40 inches and an eye-piece of focal length half an inch we get a magnification of 80. It is commonly thought that astronomers are always trying to bring the utmost magnification to everything they observe ; and often the first question asked of an astronomer is, "How much does your telescope magnify ?" The answer to this last question is, "It depends on which eye-piece I am using." Astronomical telescopes are supplied with several eye-pieces of different focal lengths. Some objects are better seen with a low power, though it is perfectly true that an astronomer does want sometimes to use the highest power he can. There are reasons why he cannot always use the highest power he possesses. The chief reason is that though the night may be clear, the atmosphere may contain air-currents of different density which make the image unsteady. High magnification will then result in a very blurred and "boiling" image. It is not worth it : he will use a lower power for the sake of a steadier image or perhaps decide that after all it is too bad a night for observation.

The higher powers may be used for planets under good conditions, or they will sometimes be wanted for "splitting" very close double stars—that is to say, distinctly showing two separate stars. The question then arises, "How close an angle of separation can one manage with a telescope of any given size ?" The theoretical answer is sometimes stated in seconds of arc as 4.56 divided by the aperture in inches. Thus a 4-inch glass would split a double star where the angle of separation is $\frac{4.56}{4} = 1''.14$, but this implies a telescope of first-rate optical quality, and very good observing conditions. In normal circumstances perhaps one should take double the amount and say that with a 4-inch we should expect to split a double star of 2″ separation.

There is a simple way of finding, approximately, the magnification of a small telescope. Look at a brick wall through the telescope, but keep both eyes open. With a little practice it is possible to see one brick in the telescope superimposed on a number of bricks seen with the other eye. Count the number of brick-edges unmagnified equivalent to one brick magnified, and that gives the magnification.

Another method for any telescope is to stand a foot or two back from it when it is set up pointing to the sky, and look at the eye-piece. In the centre of it will be seen a round white spot of light smaller than the surface of the lens. The magnification is the diameter of the object-glass divided by the diameter of the white spot; but it is difficult to measure the diameter of the spot accurately without an instrument.

Eye-pieces are sometimes marked with the magnification thus: x 45. It is possible that this value does not apply to the particular object-glass that you are using; and in any case some makers tend to overstate magnification. It is as well to discover the powers of your eye-pieces by your own measurements.

The simplest kind of stand allows a telescope to move vertically so as to change the altitude, and horizontally so as to change what is called the *azimuth**: we therefore call it an alt-azimuth stand.

Plate IX, Fig. (a) shows a 3-inch refractor with a sighting telescope or finder, on an alt-azimuth stand. The disadvantage of this kind of stand is that in following a star we have to give the telescope two movements as the star is moving from east to west (very likely) and changing its altitude. Fig. (b) shows a gunnery instrument known as a Director, also on an alt-azimuth stand. The telescope is fitted with divided circles reading altitude and azimuth in degrees and reading to 5′ on a divided screw head. In Fig. (c) the same instrument is mounted on a home-made adaptor. The main axis, formerly vertical, is now pointing to the Pole of the Heavens. It happens to have been made for latitude 51°N., so is elevated at that angle. (See page 30.)

The rising and setting of the stars and their apparent daily motion across the sky are due, of course, to the Earth's rotation about its

* Azimuth: angular distance from south point of horizon, measured westward to 360°.

(a)

(b)

(c)

Plate IX

(a) 3″ Refractor with finder on alt-azimuth stand

(b) No. 5 Director, Mk I, on alt-azimuth stand

(c) No. 5 Director mounted as an equatorial for Lat. 51°

Photographs of the director by permission of the War Office

Plate X

THE 74" REFLECTOR FOR THE DAVID DUNLAP OBSERVATORY, TORONTO. VIEW IN THE SHOPS FROM THE NORTH WEST
By permission of Sir Howard Grubb Parsons and Co.

axis ; but this motion is just too slow to appear as actual movement to the naked eye. The first time that an observer uses a telescope on any celestial object one of the most striking things is the way in which this slow motion has been magnified into quite a perceptible drift. With powers of 200 and over it is magnified to such an extent that an object sails across the field of view of the eye-piece and disappears beyond the edge almost before the eye has had time to focus and adjust itself to the telescope. By tilting the vertical axis to the Pole of the Heavens as in Fig. (c)—that is, making this axis parallel to the Earth's axis of rotation—a single rotary movement of the telescope around this one axis alone will be sufficient to counteract the movement of the stars, and the effort of keeping it continuously pointing at a particular object will be reduced to a minimum. This is called an *equatorial* mounting. An added refinement is to apply the counteracting motion to the telescope by means of governed clockwork or electric motor. The star then appears to stay quite stationary in the field and the observer has both hands free. Nearly all large astronomical telescopes are equatorials. In this case it should not be difficult to see that the altitude scale has now become a declination scale, and the azimuth scale a right ascension scale, on which the degrees are easily converted into hours, minutes and seconds. The divided-circle equatorial can quickly be directed to any given point in R.A. and declination and thus we turn it to objects such as star clusters and nebulæ which are invisible to the naked eye. For this it is necessary to know where some particular R.A. is at the moment. We can work this out from tables in the Nautical Almanac, or, if we can afford luxuries, we keep a sidereal clock. This tells us the Sidereal Time, i.e. the right ascension crossing the meridian (see page 104). Knowing that, and using the R.A. scale, we can easily move the telescope to any other R.A. For astronomical work, this director is a mere toy : it is introduced here to show the principle of an equatorial. Note the equatorial mounting in Plate X, with the polar axis for Toronto (Latitude 44°N.), the great mirror on the far side, and the counterpoise weight on the near side.

Care of Instruments

Optical instruments must be treated with care if they are to be kept serviceable. Lenses should not be touched with the fingers, but if they require cleaning they should have dust removed from their surfaces with a soft camel-hair brush, and should then be wiped with a piece of well-washed linen in preference to chamois leather. Grease may be removed with a little pure alcohol. Draw-tubes should be cleaned, polished, and used dry. Steel parts should be occasionally oiled and then wiped almost dry. A dew-cap in the form of a tube of stout paper or cardboard should be used on damp evenings to prevent moisture from being deposited on the object-glass. Moisture on outside surfaces should be allowed to evaporate before caps are replaced. To separate the lenses forming the object-glass is most risky, as it is more than likely that a skilled optician will be required to put them together again correctly.

The Spectroscope

The problems solved by the spectroscope are even more remarkable than those which have been solved by the camera. If we allow a narrow beam of light to pass from a white-hot solid, such as a piece of lime, through a triangular piece of glass (known as a prism) the light is refracted—that is to say, its direction is changed. But this is not all : it is also dispersed or split up into a band of colours. The same phenomenon takes place when sunlight falls upon drops of rain (but in this case it is reflected as well) and the rainbow is produced. So with our lime-light we get the "colours of the rainbow," with red at one end of the band of colour, passing through yellow and green and blue to violet at the other end.

If sunlight is treated by a prism in the same way, it is also split up into a band of similar colours ; but if the beam of light is a very narrow one and a suitable apparatus (termed a *spectroscope*) is used, it is found that the band of solar light (now called a *spectrum*) is crossed by numbers of narrow dark lines which run at right angles to the length of the spectrum. These are known as the Fraunhofer lines, being named after the German physicist who was the first to carry out a systematic examination of them, in 1814, though they had been discovered by Wollaston, an Englishman, in 1802. These lines are normally definite in position, and the number of them is very great, though only a few were observed when they were first discovered. We will fix our attention on two of these dark lines which are close together in the yellow part of the solar spectrum, in which they are always present.

Now if we take a spirit lamp or a bunsen burner, and put into it some common salt or, in fact, any other substance containing the metal sodium, the flame is coloured a brilliant yellow. If we look at this flame through the spectroscope we shall find that the light is seen only as two lines of yellow occupying exactly the same positions as those two dark lines in the solar spectrum. The fact that the position of the bright lines in the one case is precisely the same as that of the dark lines in the other is enough to suggest that there is some connection between the two. We could hardly be expected to regard it as a mere coincidence. These facts were known before an explanation was forthcoming, and it was seen that a solution of the problem—the connection between the dark lines and the bright ones—would probably have very far-reaching results.

We must now go back to the lime-light spectrum. The light from the white-hot lime gives rise to a continuous spectrum, a band of light from red to violet with no dark lines ; but if this light, before reaching the spectroscope, is made to pass through the spirit flame with the sodium in it, a continuous spectrum is no longer seen, but we get a spectrum from red to violet, but with two dark lines in exactly the same position as the two yellow lines caused by the glowing vapour of sodium. The two dark lines are thus produced by the light which reaches the spectroscope having passed, on its way, through the cooler vapour of sodium. The sodium vapour absorbs the light of the same kind as it itself sends out. We thus conclude that the two dark lines in the yellow part of the solar spectrum are caused by the presence of sodium vapour in the Sun's atmosphere. A spectrum with bright lines is called an *emission spectrum* ; one with dark lines is known as an *absorption spectrum*. The cause of the spectral lines belongs to the realm of advanced physics and is quite beyond the scope of this book. We have considered only two of the thousands of lines which our finest modern instruments show to be present in the spectrum of the Sun. But the principle is the same throughout. Each element has its own particular series of lines. In some cases hundreds of lines belong to the same element. It is true to say that Kirchhoff, who solved the riddle of the dark lines in 1859, has given us the key to the cypher in which the chemical constitution of the Sun and the stars is written.

Thus by the examination of the spectra of the Sun and the stars and the nebulæ, we are enabled to name the elements which compose them, and also to decide whether the bodies themselves are partly solid or composed entirely of glowing vapour. Sodium, potassium, iron, carbon, calcium, magnesium, copper, silver, hydrogen and oxygen have been found to be present in the Sun, together with many other of the common elements we find on the Earth ; and one element, helium, was actually discovered in the Sun many years before it was found to exist on the Earth.

When a source of sound is approaching us, we observe a rise in the pitch of the note : when it is receding from us the pitch drops. This is easily detected when we meet a car on the road. The moment the car has passed us and is going away we observe a fall in the pitch of the general hum that the car gives out. In the same way, when the body which emits the light is moving towards the spectroscope, the lines are displaced slightly towards the violet end of the spectrum ; when it is moving away the lines are shifted towards the red end, and the amount of the shift of the lines depends on the speed of the object towards or away from the observer—generally called *velocity in the line of sight*. This is known as the *Doppler effect*, and by means of it we learn about the movement of the body whose light is being examined. So, when the lines in a stellar spectrum are displaced regularly, first towards the red and then towards the violet, we know that the body is moving alternately away from the Earth and towards it, and is therefore revolving round another body, possibly a dark star. Such a system of two stars is known as a *spectroscopic binary*, and in this way the spectroscope tells us of the existence of bodies which emit no light at all, or certainly none that we can detect.

The subject of spectroscopy has in recent years become immensely complicated. In an elementary book it can only be touched upon, and for a more detailed understanding of its remarkable methods and results the reader must be referred to more advanced works. But to leave it out altogether is impossible, for that would take astronomy no further than the middle of the 19th century ; and the main advance in the science since that time has been due to those who have employed the spectroscope in their work.

APPENDIX I

THE TIDES

THE TWO chief reasons for including an explanation of the Tides in a beginner's astronomy book are that they are caused by the Moon and the Sun, and that they are very little understood even by many people who sail upon the sea. The whole matter is extremely complex, and any short explanation must be put in terms of a simplicity which actually does not exist. Some of the facts must be stated here without explanation.

The Moon is the chief influence in causing tides on the Earth. By its power of gravitation it produces a high tide on the side of the Earth nearest the Moon, and another high tide on the far side of the Earth. The intermediate parts with the water drawn away will have a low tide. The Sun does the same thing, but to a lesser extent than the Moon. Thus at Full Moon and New Moon (when Earth, Sun and Moon are approximately in a straight line) the Sun's tides will be added to those produced by the Moon ; so that at these phases high tide will be very high and low tide very low. But at First Quarter and at Last Quarter the Sun and the Moon are not working together, but against one another ; so the Moon's high tide will be diminished because it coincides with the Sun's low tide, and the Moon's low tide will have added to it the Sun's high tide. Thus at these two phases high tide will not be very high nor low tide very low. The very high and very low tides at New and Full are called Spring Tides (occurring every fortnight and nothing to do with the season Spring). The not-very-high high tides and the not-very-low low tides at First and Last Quarter are called Neap Tides.

For simplicity we will regard the Earth as rotating inside a completely covering tidal ocean. Omitting the Sun for the moment (the less important tide-producer), if the Moon were at rest and not revolving round the Earth, then as the Earth rotates in (nearly) 24 hours, to-day's morning high tide would be followed by another high tide 12 hours later, and to-morrow morning's high tide would be at the same time as to-day's. But actually by to-morrow the Moon has moved round a bit in its orbit, and taken the high tide with it, and the Earth must rotate through that extra bit to bring us to the new high tide position. This extra bit takes 51 minutes, so to-morrow morning's high tide will be 51 minutes later than this morning's, or, by the 12-hour clock, this evening's high tide will be 25½ minutes later than this morning's.

This is offered as the simplest possible explanation of the main facts. In actual practice there are all kinds of complications. Most people will swallow the explanation that the Moon draws up the water on the near side of the Earth; that the water on the far side forms a high tide because it is "left behind," is a stumbling-block. Of course the whole question is really a highly mathematical one. In one's seaside experience of tides there are local peculiarities to do with currents, varying depth of the sea, winds, and configuration of the coast-line. There are astronomical factors such as the Moon's declination and whether Moon or Sun is near to the Earth or far away, for it must be remembered that the orbits of the Earth and the Moon are not circles but ellipses, and the nearer a body is to the Earth the greater is its tide-raising effect. For further light on all these matters the reader must consult more advanced books. There is a good chapter on the subject in Dr. Waterfield's "The Revolving Heavens."

APPENDIX II

TIME

We should like to keep time by the Sun. Unfortunately, we can't, because solar days (intervals between two successive passages of the Sun's centre across the meridian) are not of equal length. The reason is this. The length of a solar day is a rotation of the Earth *plus a little more* (about four minutes) because the Earth has in the meantime moved a little further on in its journey round the Sun. Now because the Earth's orbit is an ellipse and not a circle its velocity varies, so the *plus a little* mentioned above will not always be the same amount: that will make solar days vary in length. But even if the *plus a little* was always the same—now refer to Fig. 12 and you will see that the Sun's daily eastward shift is at the solstices entirely eastward, whereas at the equinoxes it is slanting, and that makes the purely eastward shift (or plus a little time) less. So for these two reasons solar days will vary in a complicated way. We cannot have any truck with a Sun that behaves so irregularly. Astronomers have therefore scrapped the Sun as a time measurer and have invented a Mean Sun, which doesn't really exist, but is regarded as moving regularly along the *Equator* doing the mean or average of all the irregular things which the real Sun does in the course of a year. This gives us Mean Time which before the war of 1914–18 was clock time throughout the British Isles. Sometimes the mean Sun is ahead of the true Sun, sometimes behind it. The difference between the two is known as the Equation of Time, and it can amount to as much as 17 minutes. Its value for each day is given in *Whitaker's Almanack*.

But as the Sun (whether true or mean) in its daily journey across the sky seems to move from east to west, it will arrive at the meridian of Greenwich before it reaches the meridian of, say, Birmingham; and if mean noon is the instant when the centre of the mean Sun reaches the meridian, then Greenwich and Birmingham will have different mean times. And all other places will have different mean times according to the terrestrial meridian (or line of longitude) they are on. Only places on the same meridian as one another will have the same time. But it would be grossly inconvenient to have different times for London, Reading, Birmingham and Exeter, so we pretend that all places in the British Isles have the same time and we all use Greenwich Mean Time (G.M.T). In the years of Hitler's war we did not use G.M.T., but G.S.T. (Greenwich Summer Time) or even, for a part of the year, Double Summer Time. This is merely G.M.T. called by the wrong hour ; 7 o'clock G.M.T. is called 8 or even 9 as the simplest way of stopping people from staying up very late at night and using much electricity. It is an ingenious way of thwarting mankind who like to lie in bed and waste the morning sunlight and then stay up late and waste the fuel which must be used to generate electricity.

Reverting to G.M.T., if it is asked how far westwards we can continue this pretension that G.M.T. is our time when we know quite well that it isn't, the answer is that when the difference amounts to about an hour it is agreed that it is about time to stop the farce. So time all round the world is arranged in slabs of 15° or one hour each, and as one moves out of one of these sections and into another one's watch must be put back an hour in travelling westwards or forward in travelling eastwards.

The astronomical clock is part of the equipment of every well-appointed observatory. It tells Sidereal Time which at any moment is the Right Ascension then crossing the south meridian. It facilitates the laying of the equatorial telescope on any particular point in R.A. (and, of course, in declination, though that does not depend on time). The starting point for R.A. is the First Point of Aries, where the Sun is at the spring equinox. Thus, when the First Point of Aries is due south the clock will read 0 hr. 0 min. 0 secs., and it will tell the hours, minutes and seconds of R.A. as they come to the meridian. As the sidereal clock keeps time by the stars it will gain four minutes a day on ordinary clock time.

APPENDIX III

Exercises and Practical Work

1.—AN EXERCISE ON THE FOUR INNERMOST PLANETS

36 67 93 141

THESE REPRESENT the mean distances of Mercury, Venus, the Earth and Mars from the Sun in millions of miles. Draw three concentric circles with radii in the proportion of the first three, and also one to the same scale for Mars, but in drawing the orbit of Mars put the fixed leg of the compasses just outside the centre. This will represent the fact that the orbits of the Earth and Mars approach most closely in one place, and are at their widest distance apart on the far side of the Sun. At what part of the diagram this happens does not matter. We all know that the orbits are really ellipses and not circles, and the orbit of Mercury is the least circular, but to draw them as circles will not mislead in this exercise.

Choose a position for the Earth, say on the extreme right of its orbit ; not that there could be anything peculiar in that position, but so that if diagrams are compared they will all have the same orientation.

When an interior planet (one whose orbit is inside that of the Earth) is on the near side of the Sun it is said to be at *Inferior Conjunction* with the Sun : on the far side it is at *Superior Conjunction*. When an exterior planet is on the far side of the Sun it is at *Conjunction* : when the Earth is between the Sun and a planet, the planet is at *Opposition* to the Sun. So we can mark as small dots —

M′ and V′—Mercury and Venus at Inf. Conj.
M″ and V″—Mercury and Venus at Sup. Conj.
Ms′—Mars at Conj.
Ms″—Mars at Oppn.

Suppose that on a certain day Mars was at Opposition, Venus at Superior Conjunction, and Mercury at Inferior Conjunction (an unlikely but not impossible arrangement). In a year's time the Earth will be back in the same place, but the other planets will be in quite different parts of their orbits because none of them takes a year to make one revolution.

Copernicus, who died in 1543 (about 66 years before the invention of the telescope) realized that if Mercury and Venus are spheres (which we now know they are) they would show *phases* (that is to say, changes in apparent shape), more or less (but not exactly), like the phases of the Moon. This was not a very difficult prediction to make. What do the phases of the Moon or of a planet depend on ? On the amount of the illuminated hemisphere (illuminated by the Sun) which is turned towards the Earth.* Consider the case of Venus. You should see that by representing it as a small circle with the half that is turned towards the Sun always illuminated, you can put it in different parts of its orbit and see that it will have different phases. There should be no difficulty in putting Venus in where it will have a half-circle phase—that is, where an observer on the Earth will look along the line separating the light and dark hemispheres. If you are inclined to put this half way between Superior and Inferior Conjunctions (as you put a half moon between New and Full) you are making a common but rather elementary mistake. There are, of course, two positions where the phase is a half circle.

Venus will generally be invisible at its two conjunctions, as it will be lost in the brightness of the Sun's rays. At Inferior Conjunction it might be seen against the disc of the Sun (Transit of Venus), but generally not, because the orbits are not quite in the same plane. If the Earth's orbit is in the plane of the paper then that of Venus should be slightly tilted to it, but that is too much of a complication for us to introduce. Near Superior Conjunction Venus may be visible, and you should be able to see what sort of a phase it will show. Is much or little of the illuminated half turned towards the Earth ? What will be the phase near Inferior Conjunction ?

The great difference between the phases of Venus (or Mercury) and those of the Moon depends on the fact that the Moon does not much alter its distance from the Earth, and therefore does not vary much in apparent diameter† ; but Venus may be many times further from us in one position than in another, and will thus vary much in apparent diameter. If the apparent diameter of Venus is inversely

* See Phases of the Moon, page 18, and Fig. 2.

† For an explanation of apparent size, see page 25.

proportional to its distance (which is practically true of any planet) then by measuring distances on the diagram you will find out how to represent the phases both as shapes and as relative sizes. Near Inferior Conjunction the apparent diameter of Venus is more than a minute of arc, and the phase can be seen in field-glasses magnifying six times.

When we observe Mercury it will always be somewhere near its widest angular distance from the Sun—*Greatest Elongation* as it is called—and from the diagram you can measure the size of this angle approximately—not accurately, because you are working with circles, whereas the true orbits are ellipses. Venus is a much easier planet to find, partly because its angle of Greatest Elongation is so much larger than Mercury's. Measure the size of this angle on the diagram.

You will be able to think of other factors which decide the apparent brightness of a planet. In fact, you might arrange a competition between Mercury and Venus, giving either planet a score of one mark under each of your headings, and see which wins and by what score. One factor which you might not know is reflecting power or *Albedo*. Venus has more reflecting power per square mile of surface than any other planet in the Solar System. Suppose one of these planets wins by, say, three points to one in your competition, do you think it must, therefore, appear to be the brighter planet ?

You can find a place in your diagram where Mars at opposition (the Earth is no longer to be fixed in one place) is as near as it can be to the Earth. At the diametrically opposite point you will find the greatest opposition distance. These are known as *favourable* and *unfavourable* oppositions. The most favourable oppositions of Mars are those that take place towards the end of August : the most unfavourable are in February. But the August oppositions are not really the best for observers in the northern hemisphere of the Earth, as Mars then does not rise high in the sky. At November oppositions Mars is not so very much further away, and its altitude* is much greater, and this gives clearer definition in the telescope. Observers in the southern hemisphere have the advantage both ways at the August oppositions—the planet near to the Earth and high in the sky. Oppositions of Mars recur at intervals of about two years and two months.

* Altitude : Angular height above horizon. See page 29 and Fig. 5.

While you are investigating phases, see if it is possible to put Mars in a position where more than half the illuminated hemisphere is turned away from the Earth. In other words, tackle this problem :— Can Mars ever show a crescent phase ?

These two following exercises can be taken at any stage where the scales of R.A. and Declination can be understood ; in fact, the Orion exercise makes a very good introduction to astronomy after the significance of the Solar System has been grasped.

2.—AN EXERCISE ON THE PLEIADES

(To be mapped on graph paper)

The most conspicuous naked-eye cluster in the whole sky is the Pleiades in the constellation of Taurus. Several of the individual stars can be seen, and the cluster must have attracted attention from the earliest times, as it is mentioned in the Iliad and the Odyssey of Homer as well as in the Book of Job and the Book of the Prophet Amos. Many star-gazers like to test their eyesight by mapping the group with either naked eye or field-glasses.

Take a piece of graph paper 9 by 7 inches ruled to one-tenth of an inch with each fifth line broad, and use it with the length horizontal. Mark a vertical broad line near the right (west) side 40 mins. This is 3 hrs. 40 mins. of Right Ascension. Go three broad lines eastwards (i.e., to the left) and mark it 41 mins. and so on to 45 mins. near the left-hand edge of the paper. Each small division is 4 secs. of R.A. That settles the R.A. scale. Mark the third broad line from the top 20′ : this is 24° 20′ of North Declination. The next broad line down is 24° 15′. Continue down the side, and 23° 30′ N. will be near the bottom of the paper. Each small division of declination is 1′ of arc. Plot the stars whose names are given in the following list. The column headed " Magnitude " shows the apparent brightness of the stars, the higher figure denoting the fainter star. A star of any magnitude is about 2.5 times brighter than one of the next fainter magnitude. There are about 20 stars in the sky which rank as first magnitude, while those of the sixth magnitude are just about at the limit of naked-eye visibility. The brighter the star, the larger the dot to represent it.

It is not claimed that the positions are dead accurate, and the shape will not be perfect because the group is an appreciable distance from the Equator, but when the chart is made it will serve quite well for learning the chief stars in the group, and others can be put in which may be visible to fine eyesight or with the slight magnification of field-glasses or a small telescope. An added interest is given to the Pleiades by the fact that they are sometimes occulted by the Moon. (See page 23.)

The stars in the given list are probably in the order of decreasing visual brightness, but the student should form his own opinion from observation with field-glasses or a small telescope.

		R.A. h.	m.	s.	Decl. N. °	′	Mag.
Alcyone	..	3	43	00	23	53	3.2
Atlas	..	3	44	42	23	50	4.0
Electra	..	3	40	25	23	53	4.2
Maia	..	3	41	20	24	08	4.4
Merope	..	3	41	50	23	43	4.4
Taygeta	..	3	40	40	24	14	4.7
Pleione	..	3	44	45	23	55	5.2
Celaeno	..	3	40	20	24	03	5.6
Asterope	..	3	41	25	24	20	6.2

3.—AN EXERCISE ON THE ORION REGION

(To be mapped on graph paper)

Here is another graph paper exercise, to give a map of the stars of the Orion region, which contains more bright stars than any other equal area of the whole heavens.

Again take a 9 by 7-inch piece of graph paper with the length horizontal. Mark a broad line near the west (right) side as 3 hrs. of R.A. Each small division is 4 mins., so the next broad line is 20 mins. (actually 3 hrs. 20 mins.), the next 40 mins., and the next 4 hrs. Continue the scale, and 8 hrs. will be near the east margin. Mark a broad declination line not far from the top as 35° N. Each small division is 1° of declination, so the broad lines can be numbered 35°, 30°, 25°, etc. The Equator (0°) will be below the centre line, and 20° S. will be near the bottom of the paper. Positions in R.A. will be given to the nearest minute, and in declination to the nearest fifteen minutes of arc : that will involve estimating to one quarter of a small square.

Note that this is a large part of the sky, and thus it is on a much smaller scale than the map of the Pleiades given in the last exercise. In fact, the whole of the Pleiades would occupy about one small square of this chart. This part of the sky can be well observed in the evenings from December to March. What is the maximum altitude that Orion's belt will reach in the latitude of London? See Fig. 8.

Do not be content with just plotting these stars on paper. Make a point of going outside one winter evening and comparing your chart with the stars you actually see.

Star	R.A. h. m.	Decl. ° ′	Mag.
1	3 44	24 0 N.	0
2	4 17	15 30 N.	4
3	4 24	19 0 N.	4
4	4 33	16 30 N.	1
5	5 32	10 0 N.	4
6	5 53	7 30 N.	1
7	5 23	6 15 N.	2
8	5 30	0 15 S.	2
9	5 33	1 15 S.	2
10	5 38	2 0 S.	2
11	5 30	6 0 S.	4
12	5 12	8 15 S.	1
13	5 45	9 45 S.	2
14	6 43	16 30 S.	—1
15	7 36	5 15 N.	1
16	7 42	28 15 N.	1
17	7 31	32 0 N.	2

Notes

1. The Pleiades.
4. Aldebaran—the Bull's eye. Join 2 to 3 and 4 and you get the V of the Hyades, a scattered cluster in Taurus.
5. Part of the triangle forming Orion's head.
6. Betelgeuse, a red star, slightly variable. 6 and 7 are Orion's arms.

8, 9, 10. Orion's belt.

11. The mid-most of three stars. It marks the position of the Great Nebula.

12, 13. Orion's legs. 12 is Rigel.

14. Sirius, the Dog Star, in Canis Major : the brightest of all stars: brighter than Mag. 0, hence the — sign.
15. Procyon in Canis Minor.
16. Pollux.
17. Castor, a good telescopic double.

APPENDIX IV.

Practical Work for the Beginner

A GOOD MANY people suppose that practical astronomy is only worth while for those who possess large telescopes. This is far from being true. Many interesting observations can be made with no instruments at all, and much more can be done with a pair of field-glasses or quite a small telescope. Certainly the larger the instrument the more use it is to the astronomer, but any instrument, however small, is of some use, and will show us objects which, with the naked eye, will be seen less clearly or not at all.

NAKED-EYE OBSERVATIONS

Without instrumental aid we can learn the chief constellations and the names of the brightest stars. It is well to draw charts from eye-observation and to number the stars according to their brightness, and compare with the order given in a star atlas. The brightest stars will be found to differ considerably in colour. A comparison of the colour of Arcturus, Vega, Betelgeuse, Aldebaran, β Librae, Antares, and Sirius will be found instructive. It will be useful to note and remember the times of year when different constellations may be best observed.

The Sun should be observed with a dark glass. Sun-spots can sometimes be seen, particularly in the years near sun-spot maximum.

The details on the surface of the Moon should be drawn. The chief " Seas " may be identified with the aid of a map of the Moon. The earliest possible observation of the crescent after New Moon should be recorded.

Any naked-eye observation of Mercury is worth recording. Venus is often visible when the Sun is hardly below the horizon, and for many weeks before and after " greatest brilliancy " the planet is visible in bright sunlight. The relative colour and brightness of the bright planets should be noted, the magnitudes being compared with those of first magnitude stars. The magnitude of Mars at opposition will be found to vary according to whether the opposition is favourable or unfavourable (see page 107), and that of Saturn will depend on whether the rings are "open" or "closed." The movement of the planets among the stars can easily be observed, and it is a matter of interest to mark the position of any planet week by week on a star chart.

OBSERVATIONS WITH A SMALL INSTRUMENT

A telescope, of course, will show us much more than can be seen with the naked eye, but here a warning is necessary. Do not imagine that even a moderately large telescope will show you the objects as you see them depicted in books. Almost everybody is disappointed on first looking through an astronomical telescope. We are accustomed to pictures which are drawn by practised observers who use really large instruments ; or we see photographs taken with the aid of giant telescopes, and we expect to see something of the same kind through a glass which cost only a few pounds. However, if we do not expect too much, we can find plenty of objects in the sky which are well worth examining with even a hand telescope. It should be mounted so that it is perfectly steady.

If you take a keen interest in astronomy and have the use of a telescope, you should keep a note-book and make careful drawings of everything you see. You should mark every drawing with the date and the time of observation, and also the power of the eye-piece used. Map the constellations from the sky, and compare with printed diagrams.

The Sun. Never look through a telescope at the Sun without using either a dark glass or a diagonal reflector. You should use a pale glass even with the reflector : a blue-black, obtained from an optician, is best, as it cuts out much of the heat. Better still, project the image of the Sun on to a piece of white cardboard (see page 8). You may see some dark marks and wonder whether they are sun-spots or dirt in the telescope. Touch the telescope so that it shakes, and if the dark marks also shake they are sun-spots. Focus them on the card, and see if you can observe the dark central part or *umbra* and the lighter edge or *penumbra*. You may also be able to see the grey and white structure of the Sun's surface—rather like rough

drawing-paper—but it is not conspicuous. It is best to avoid the great heat of midday in observing the Sun.

The edge of the Sun is less bright than the centre, because the light from the edge has to pass through a greater thickness of the gases surrounding the Sun.

Do not expect always to find sun-spots.

The Moon. At Full Moon the light from the Sun is coming almost in the same direction as that in which you are looking. Thus there is little contrast of light and shadow. Full Moon is therefore not a good time for examining the details on the Moon ; nevertheless, the long bright "rays" are best seen at Full.

Notice the craters with walls. Some have a peak in the middle ; others are without this feature. Observe the great variation in the size of the craters. The features are clear and sharp because there is no atmosphere on the Moon. Look at the ragged edge of the Moon, and try to find a bright peak surrounded by darkness. A little consideration should tell you whether it is sunrise or sunset on this peak. With the aid of a map of the Moon, many of the chief seas and craters can be identified by means of a pair of field-glasses magnifying six times ; among others the *Maria* Criseum, Fecunditatis, Nectaris, Tranquilitatis, Serenitatis, Imbrium, Procellarum, and Nubium ; and the *Craters* Langrenus, Copernicus, Kepler, Aristarchus, Tycho, Plato and the Sinus Iridum. The writer has himself identified all the principal objects in Plate I by means of a 1-inch telescope.

For the possessor of a small telescope the Moon is the least disappointing of all celestial objects.

Mercury and Venus. Find out from *Whitaker's Almanack* or the *B.A.A. Journal* when to look for Mercury. You should be able to see the crescent form of Venus without difficulty. The planet is best observed in daylight or twilight. A power of 30 shows the phases well, and near inferior conjunction magnifies it to about the same apparent diameter as the moon with the naked eye. This is hard to believe when we make the observation, but it is none the less true. Mercury requires a power of about 100 to see clearly the disc and phases. You are unlikely to see any surface markings on either planet. A 3-inch glass may show some variation in brightness on different parts of the disc of Venus.

Mars. A disappointing object. The image of it is seldom clear and distinct. No marking is likely to be seen with less than a 3-inch telescope. Note the colour and compare with that of other planets.

Jupiter. Observe the oval shape and the belts. The satellites may be seen looking like tiny stars. Four of them are within the range of a good pair of field-glasses. None but the greatest telescopes will show any of the other satellites of Jupiter. A 3-inch glass should show some details of the belts. If reference be made to *Whitaker's Almanack* and the planet be observed at the correct times, it should be possible to see an eclipse, or a transit of a shadow across the planet's disc (see description of Jupiter, page 56). These phenomena are interesting, but difficult to observe in a small telescope.

Saturn. Generally a clear and distinct image is seen. Notice the ring, and the belts on the planet, less distinct than on Jupiter. Look for the gap between the ring and the planet. It may be possible to see the shadow of the planet on the ring, except near the time of opposition. A 2-inch telescope should show the ring and Titan, the largest satellite ; a 3-inch may show two other satellites, Iapetus and Rhea ; a good 4-inch may show Cassini's division in the ring and five satellites.

Meteors. Note the time at which a meteor is seen, its magnitude and colour, and mark its path on a star chart. The path can be determined approximately with the aid of a stick held at arm's length. Drawings should be made of any comets visible to the naked eye.

Nebulæ. Refer to the description and the diagram of Orion (Fig. 18) and there will be no difficulty in finding the nebula. It is sometimes called the Fish-mouth Nebula on account of the dark gap on one side. Four stars close together in the middle are known as *the Trapezium.*

The nebula in Andromeda may be located from the diagram of that constellation (Fig. 17). There is another round nebulous patch close to the main nebula. The extent of the nebulæ will be better seen if the telescope is gently tapped while they are being observed. These two nebulæ are both visible to the naked eye. The one in Orion is a wonderful object, and a good deal of structure may be seen on a clear dark night even with a small telescope. Nebulæ

on the whole are disappointing objects, mostly appearing as structureless blobs in any but large instruments. But they are mysterious objects, and it gives some satisfaction even to identify them. Wonderful detail and variety of structure have been brought out by photography. (See Plate VII.)

Star Clusters. Several clusters are visible to the naked eye. The Pleiades are unmistakable ; the Hyades are less obvious. Others are *Præsepe* or the Beehive in Cancer, the double cluster *H. VI.* 33, 34 in Perseus, and the region just south of α Persei. All of these are well worth studying in field-glasses. Many parts of the Milky Way will be found to be very rich in stars. There are other clusters which can just be discerned with the naked eye, among which are some of the true globular clusters. These are among the most wonderful objects in the sky, worth looking at with any telescope, though they can hardly be resolved with less than a 4-inch. Fuller details are given on pages 87-91.

DOUBLE STARS

A few stars can just be seen to be double without optical aid. Mizar and Alcor in the tail of the Great Bear form almost too wide a pair to be called a double. Less obvious naked-eye doubles are *α Capricorni*, *ο Cygni*, *ω Scorpionis*, *θ Tauri* and *σ Tauri* very close to Aldebaran, and *ε Lyræ*. These all repay examination with field-glasses, as also do *ν Draconis* and the three stars of Orion's dagger. ε Lyræ is a remarkable star, each of the components being double, as may be seen with a good 3-inch telescope.

β Cygni. Refer to the diagram of Cygnus, Fig. 17, and find the star β of that constellation. It is the star at the extreme end of the cross away from Cassiopeia. It is a wide double and can be " split " with a small telescope. Note the colour of each of the component stars.

γ Andromedæ. The bright star at the end of Andromeda next to Perseus, Fig. 17. Another excellent double but only about one-third as wide as β Cygni. Again note colours.

ζ Ursæ Majoris. This star is Mizar (see diagram of the Plough, Fig. 15). Alcor is easily seen close to it. Mizar itself is a wide double. Several stars are visible in a 3-inch telescope.

Castor (see Fig. 18). A fine double.

The Pole Star. A double of which one star is very much fainter than the other.

θ Orionis. The central star of the sword of Orion. Surrounded by the Great Nebula (see Fig. 18, M42). The four stars forming the trapezium are visible in a 2-inch glass.

σ Orionis. Just below the southern-most of the three stars of Orion's belt. Several stars can be seen with a 3-inch telescope.

TABLE I.—LIST OF DOUBLE STARS OF INTEREST TO BEGINNERS

(Most of them are shown in the star charts)

Star	*R.A.*		*Decl.*			*Magnitudes of Components*	*Distance apart*		*Remarks*
	h.	m.		°	′		′	″	
α Ursæ Minoris ..	1	49	N.	89	02	2, 9		18	The Pole Star.
γ Andromedæ ..	2	1	N.	42	6	3, 5		10	Fine double : colour contrast.
θ Tauri	4	24	N.	15	48	4.7, 5	5	37	Naked-eye double in Hyades.
σ Tauri	4	35	N.	15	45	5.2, 5.7	7	9	Naked-eye double in Hyades.
σ Orionis	5	36	S.	2	36				Multiple star.
α Geminorum ..	7	31	N.	32	0	2.0, 2.8		4	Castor : less bright than β.
α Canum Venaticorum	12	54	N.	38	35	3.2, 5.7		20	Known as Cor Caroli. Fig. 15.
ζ Ursæ Majoris ..	13	22	N.	55	11	2.1, 4.2		14.5	Mizar. Alcor, fifth mag. is 11′ distant.
ε Boötis	14	43	N.	27	25	3, 6.3		2.9	Not easy with less than 3-inch.
α Herculis	17	12	N.	14	27	3, 6		4.4	Colour contrast.
ν Draconis	17	31	N.	55	13	4.6, 4.6	1	2	Split with field-glasses.
ε Lyræ	18	43	N.	39	37		3	27	Each a double, 3″ and 2″.6. Other stars in 4-inch field.
β Cygni	19	29	N.	27	51	3, 5.3		35	Very easy. Fine colour contrast.
ο Cygni	20	11	N.	46	30	3.7, 5	5	37	A third star in telescopic field.
α Capricorni	20	15	S.	12	40	3.2, 4.2	6	16	Naked-eye double.

TABLE II.—LIST OF FIRST MAGNITUDE STARS.
(Different observers are not in exact agreement as to the order)

Star	Constellation	Mag.	R.A.		Decl.	
			h.	m.	°	′
Sirius	Canis Major α	—1.6	6	43	S. 16	38
Canopus	Carina α	—0.9	6	23	S. 52	40
α Centauri	Centaurus	0.1	14	36	S. 60	38
Vega	Lyra α	0.1	18	35	N. 38	44
Capella	Auriga α	0.2	5	13	N. 45	58
Arcturus	Boötes α	0.2	14	13	N. 19	28
Rigel	Orion β	0.3	5	12	S. 8	15
Procyon	Canis Minor α	0.5	7	37	N. 5	22
Achernar	Eridanus α	0.6	1	36	S. 57	30
β Centauri	Centaurus	0.9	14	00	S. 60	7
Betelgeuse	Orion α	Var	5	52	N. 7	24
Altair	Aquila α	0.9	19	48	N. 8	43
α Crucis	Crux	1.1	12	24	S. 62	50
Aldebaran	Taurus α	1.1	4	33	N. 16	25
Pollux	Gemini β	1.2	7	42	N. 28	9
Spica	Virgo α	1.2	13	22	S. 10	54
Antares	Scorpio α	1.2	16	26	S. 26	20
Fomalhaut	Piscis Australis α	1.3	22	55	S. 29	53
Deneb	Cygnus α	1.3	20	40	N. 45	06
Regulus	Leo α	1.3	10	6	N. 12	13

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