A HANDBOOK

TO ACCOMPANY
A SET OF

ONE HUNDRED ASTRONOMICAL LANTERN SLIDES

PREPARED BY

C. A. CHANT, M.A., Ph.D.

PROFESSOR OF ASTROPHYSICS
UNIVERSITY OF TORONTO

Toronto, 1930

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(Name of school)

by

The Honourable G. H. Ferguson

Minister of Education

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A Handbook for One Hundred Astronomical Slides

EXPLANATION

This little book is designed to accompany a set of One Hundred Astronomical Slides which have been prepared by the author and which, he believes, will provide an easy and pleasant introduction to the study of the sky.

It has been written in the form of a lecture (which may be divided into any number of parts) and is intended to be read aloud while the slides are thrown on the screen, the time for showing each slide being indicated by numbers in the text.

In this way the author hopes that many of our young people may be led to form an acquaintance with the heavenly bodies.

The slides are divided into four parts, and while each part is almost complete in itself, they form a certain sequence and should be taken up in their natural order. It is very desirable that Part I should come first and as it demands connected reasoning it should be taken slowly—not too much at a time and with repetitions.

The subject is presented from the observational point of view, and an attempt has been made to develop it in a simple and logical manner, and to show how astronomers have been led to propound the views which are now generally accepted. It is shown how easily we can be deceived and how we must exercise our reasoning power in deciding what theories are to be accepted or rejected.

In preparing this introductory course in astronomy the author has endeavoured to give a clear and vivid picture of the structure of the universe,—indeed, to make his hearers actually *see* (in the mind's eye) the wonderful celestial bodies existing far out in the depths of space, and thus to excite the wonder and fire the imagination.

Those who know nothing of the world of nature about them or the heavens above them lose many of the intellectual and spiritual pleasures of life.

> Let knowledge grow from more to more,
> But more of reverence in us dwell.

PART I

(To be taken slowly)

THE CELESTIAL SPHERE AND IT MOTIONS

The Sphere Formed by the Sky

Let us go out into the open air and look around us. We seem to be standing upon a level plain, at the centre of a great hemisphere formed by the over-arching sky. (Slide No. 1). It is not easy to get a perfect view of this hemisphere if one is in the midst of a city, on account of the houses and the trees; but when we are out in the open fields or on a big body of water the full hemisphere of the sky is clearly seen.

The question naturally arises:—Does the sky form only a half-sphere, or is the other half below our level plain and thus hidden from us? As we go along in our study of the sky we shall be led to think that it really forms an entire sphere, one half being above our level plain, the other below. This is shown in our first picture. Here we see a person at the centre of a level horizontal plane, while over him the sky forms a hemisphere and under him, but unseen by him, it forms another hemisphere. This sphere formed by the sky is called the *Celestial Sphere.*

The Daily Motion of the Sun

Suppose the time is nine o'clock in the morning. (2) The sky is blue, perhaps with white clouds upon it, and in the south-east we see a very bright object which we call the *Sun.* It looks like a round disc up there among the clouds, on the inner surface of the sky. We know that it always rises in the east—though few of us ever see it come up from beneath our horizontal plane—that it moves upward and westward and reaches its highest position in the south at noon. We see it then continue to move to the west and, gradually getting lower in the sky, we see it sink in the evening below the western horizon. In the picture on the screen we see the sun, first as its upper edge just appears above the eastern horizon, then in its position at noon and then just as it is disappearing below the western horizon.

Here is another question:—Does the sun move *along* the sky or is it *fastened upon it* so that the sky and the sun must move together? Did you ever think about that?

The Daily Motion of the Moon

At night the scene is changed. The sky is dark blue, almost black, in colour; and on it are numerous bright dots which we call *stars*. Some are quite bright, while many are faint and can be seen only by looking sharply for them. These stars seem to form triangles, squares, dippers, and other figures. We shall examine some of them more closely a little later. Probably the moon also can be seen in one of its many shapes, or 'phases', as they are called. Suppose it is round like the sun, in which case it is said to be 'full', and we see it over near the eastern horizon. Let us watch its behaviour. We find that it continually moves over to the west and disappears below the western horizon just as the sun does. Indeed, whatever its shape may be, if we closely observe it, we shall see it move over and set in the west.

The Daily Motion of the Stars

Also let us watch the stars. Perhaps there are three of them forming a triangle low down in the east, and several arranged in a straight line in the west. On looking to the north we see the Big Dipper, which everyone recognizes. There it is on an autumn evening, right-side up, as we might expect a heavenly dipper to be. An hour or two later let us look at these stars again. Those in the east are much higher, those in the west are much lower—or perhaps have disappeared altogether—while the Big Dipper has turned so as to rest partly upon its handle. The plain appearance is that the entire sky carrying the sun, the moon and all the stars, is in motion, turning steadily from east to west, and making a complete revolution in one day.

Now a neat way to study the motion of a bright object is by photography. (3) Here is a photograph of a familiar scene in Toronto taken on a winter afternoon. The camera was placed on the window-sill in an upper story of the Parliament Buildings and facing north-west. Through the leafless oak trees you see Hart House of the University of Toronto, and just to the right of it is one of the small domes of Trinity College. There are two automobiles coming southward on the West Crescent of Queen's Park while three persons are walking over the snow. As these motors seem to be standing still, the camera must have been exposed only a very short time—a small fraction of a second. (4) Next let us look at a photograph which was taken at night with the same camera in the same position, but the exposure was five minutes. You see the electric lights along the Crescent and also the lighted windows of Hart House. The road itself appears bright, but where are the automobiles? As a matter of fact there were many of them coming along the Crescent. The headlights of each car as it moved forward made two curved streaks of light upon the plate and there were so many of them that the whole road at last seemed to be lighted. If you look closely you will see the lights of a single car as it turned out to pass another car ahead of it. Also the trails from two or three cars can be seen as they turned to their left to go eastward along Old King's College Road. (5)

After this, with the camera in the same position, a picture was taken with an exposure of twenty minutes, and here it is. You can now see the trees and the buildings. The many cars which have come along have left trails of light which show the roads very clearly. Notice also the trails of several cars which turned out to pass others, and the trail of a car which came from the left and went straight eastward along Old King's College Road.

Now let us experiment with the stars. (6) If you face the north and raise your eyes about 45 degrees you see the Pole Star, with other stars about it. In this slide is a map of the stars as they are seen at about 9 o'clock p.m. on November 1. The Pole Star is at the centre. It is at the end of the handle of the Little Dipper which is clearly shown stretching from it to the left and downwards.

Next we shall try to photograph them. Choosing a place where the sky to the north is not very bright, we mount the camera on a window-sill or other solid base and tilt it upward so that it is directed towards the Pole Star. Having focussed the camera for a great distance, we open the shutter and expose for a long time —several hours if possible. (7) This is the kind of picture we get. It was taken in the city with an ordinary camera, the exposure being about two hours. You see a large number of trails, each one being produced by a star. You notice, too, that they are all arcs, or portions, of circles having a common centre. From our photograph we are led to think that the stars in the north are moving in circles around a common centre and we should expect the length of the trails they make to be proportional to the length of the exposure. The heavy trail near the centre was produced by the Pole Star. Notice that it is not exactly at the centre of the circles, though it is near to that point.

Of course somewhat finer pictures can be taken with a camera made specially for sky photographs. (8) Here is one made from a negative obtained at the Lick Observatory in California. As you see, the exposure was a long one. How long was it? At what season do you think the picture was taken?

Next, turn the camera to the south, tilt it up about 45 degrees and make another exposure. An hour is long enough this time. (9) This is what we get. The camera with which this picture was taken was a very ordinary one. Indeed any person can take such pictures. Try the experiment.

All the Stars Describe Circles

Let us look into this picture. Near the middle are three parallel trails which seem to be quite straight. These were made by the three stars in the Belt of Orion (pronounced o-ry'-on), which is one of the glorious winter constellations. Above is a trail curving upward. It was made by the famous red star named Betelgeuse (bet'-el-juice). A short distance below the centre is a bright trail which was made by the star Rigel (ry'-jel), while near the bottom is the trail made by Sirius (pronounced like 'serious'), the Dog Star, which is the brightest star in the sky and hence makes a very bright trail. Note that the trails of Rigel and Sirius curve downwards. These trails, as well as that of Betelgeuse, are arcs of circles. As nearly as we can see, then, the stars in the Belt of Orion describe straight lines while all the others describe circles.

Now how can we explain all this? It is quite easy. The entire sphere formed by the sky, together with the stars, which seem to be fastened upon it, seems to turn about an axis, and every star describes a circle. (10) The axis passes through the common centre of the circles which we saw in the photographs of the Polar stars and through the common centre of circles described by the stars in the Southern Hemisphere. The point in the north is called the *North Pole of the Sky,* or the *North Celestial Pole;* that at the south is the *South Pole of the Sky,* or the *South Celestial Pole.* These are shown in the picture now on the screen. The Pole Star is near, but not exactly at, the North Celestial Pole. There is no star near the South Celestial Pole. Midway between these Poles of the sky is the *Equator of the Sky* or the *Celestial Equator.*

From our observation and experiments, then, it appears that the sun, the moon and the stars are attached on the inner surface of the Celestial Sphere which turns about an axis carrying all these bodies with it and making a complete rotation in one day.

This would explain why the sun, moon and stars rise in the east, cross the sky and set in the west.

Does the Sky Really Move?

But beware now! Stop and think! Is it really the fact that the sun, the moon and all the stars in the sky revolve about the earth once a day? They certainly appear to do so, and the people of ancient times believed that they actually did. Are we deceived? Is there any other way to account for what we saw? Yes, there is.

All this time we have been assuming that the earth on which we live is fixed in place and at rest; but how would the sun and the stars appear to behave if we were in motion while they were at rest?

Suppose you want to take a railway journey. You go down to the station and take your seat in the passenger car. There is another train on a nearby track and as you look out of your window you see it begin to move. For some time you may not be sure whether it is your train or the other one which is moving and you may perhaps have to look at the wheels on the other train to see if they are turning. You may be at rest and the other one moving, or you may be moving while the other one is standing still on the rails.

It is just the same with the earth and the stars. It looks to us as if the sky, carrying the stars, was moving from east to west, but things would look just the same if the stars were standing still and the earth was turning in the opposite direction, that is, from west to east. How are we going to tell whether it is the earth or the sky which moves? (11)

Experiment with a Camera and a Flash Lamp

In this picture is an apparatus with which we can make some interesting experiments. At the left-hand end of a board is a flash lamp mounted on a wooden arm which can be made to revolve by turning a crank. Thus, if the crank is turned the bright little light will describe a circle. On the other end of the board is mounted a camera which also can be rotated by turning the crank which you see.

The apparatus was taken into a darkened room and, first of all, while the camera was at rest, the left-hand crank was turned, making the flash-lamp describe a circle. You would expect the picture shown by the camera to be a bright circle. Next, the flash-lamp was kept fixed and the camera was rotated. What was the result? (12) The two results are shown in this slide—a circle in each case and you cannot distinguish one from the other!

So it is with the stars and the earth which carries the camera. You cannot say whether the stars actually describe circles or the camera rotates while they are at rest.

How can we find out which moves, then? There are several experiments which have been devised to test if the earth rotates. They are described in books on astronomy and are all difficult to perform.

The Gyro-Compass Shows that the Earth Rotates

One of the most useful things on an ocean ship is the compass. Without it the captain could not find his way to whatever port he wishes to make. Now in recent years the ordinary magnetic compass has to some extent been displaced by what is known as the gyro-compass. (13) Indeed in a submarine this is the only kind of compass which can be used since a magnetic compass is useless if it is completely surrounded by iron.

A photograph of the mechanism of a gyro-compass is shown in this slide. In it is a heavy wheel (enclosed in a case) which is very nicely balanced and can be made to rotate very fast by an electric motor. In the kind of compass shown here the wheel rotates 8,600 times a minute. This wheel as it spins about always tries to move until its axis is in the north-south direction, and from the graduated circle above, it is possible to learn exactly in what direction the ship is pointed at any time. Now if the earth did not rotate on an axis the gyro-compass would not act as it does.

and so we have good reason to believe it is the earth which turns —not the stars.

The axis about which the earth turns is the line about which the celestial sphere *seems* to turn. Suppose now you were standing at the North Pole of the earth, where would the North Celestial Pole be? Right overhead.

The Path of the Moon among the Stars

Let us now give some attention to the moon. As we have already observed, it rises and sets like the sun; but it will be interesting to find out if it stays in the same place in the sky while the sky is turning round each day or, if you wish, while the earth is rotating upon its axis. We can easily do this by watching where the moon is among the stars night after night.

You know you can see the moon and the stars at the same time and so we shall make a map of the stars and carefully mark the position of the moon on it. (14) Here is a chart of the sky which shows the posititon of the moon and its shape each evening for six days from February 20 to February 26, 1926. On the 20th it was near a bright star in the constellation Taurus (the Bull) and from the chart you can see how it moved through this constellation, then through Gemini (the Twins) and Cancer (the Crab). By continuing to chart the moon night after night we find that it continues to move eastward and that at the end of a month it has moved completely around the sky and come back to the place among the stars where it began.

Let us stop a minute to ask if we are not deceived again. Does the moon actually revolve about the earth? Yes, it does; and the time it requires to go completely round is called a *moon*-th, or, more properly, a *month*.

The Motion of the Sun in the Sky

Having settled the motion of the moon, let us investigate the sun. We wish to know if the sun stays at the same fixed place in the sky, as though it were nailed there. In this case we are 'up against' a difficulty since the sun is so bright that we cannot see the stars at the same time and therefore cannot draw a map to show where it is among the stars day after day. We might even wonder if there are stars in the sky around the sun at all.

However, the moon sometimes comes directly in front of the sun and shuts off its light. We say the sun is totally eclipsed. At such a time the stars about the sun can be seen and photographed. Also, if a telescope is pointed in exactly the right direction in the daytime one can see the stars. Thus we are sure that there are stars in all parts of the sky all the time, but, as has been remarked, the brightness of the sun prevents us from seeing just where it is among the stars.

Now we know that the sun moves north and south on the sky. In the winter it is much farther south than in the summer. (15) This is well illustrated in the picture on the screen. In the centre of it is the famous old monument which bears the name of Stonehenge. It is located in the south of England on Salisbury Plain, where many soldiers received their training during the Great War. Stonehenge was constructed about 3,600 years ago, probably for some sort of religious ceremonies. There are many stones, some of them of great size, arranged in concentric circles. If one stands on a large flat stone at the centre, called the 'Altar Stone', and looks out between two great upright stones and over the top of another upright stone some distance away, marked *A* in the picture, he will see that point on the horizon to the north-east where the sun rises on June 21, the longest day of the year. Another stone, *B,* to the north-west, shows the direction to look to see where the sun sets at that time.

Again, if one looks from the Altar Stone towards a stone *C,* in the south-east direction, he will face that point of the horizon where the sun rises on December 21, the shortest day in winter. It seems likely that these stones were placed in those positions in order to show the place of the sun's rising at these times. The picture certainly shows how much higher the sun is at noon in summer than in winter.

But does it also move eastward among the stars, as the moon does? Yes, it does. The astronomer has found a way to locate it among the stars from day to day and the path of the sun from May 15 to July 14 among the stars is shown in the next slide. (16) During these two months it moves through the constellations Taurus and Gemini, and, of course, we cannot see the stars in those constellations during these months.

The Path of the Sun—The Ecliptic

Let us follow the course of the sun through the seasons. On the 21st of March it is on the celestial equator and the days and nights are equal. Then it moves north and east, daily getting higher at noon in the sky, until June 21, when it is farthest north of the celestial equator and the daylight is longest. Then it turns and moves south and, always continuing eastward, it reaches the celestial equator again on September 22. Then it goes on farther south and, of course, always east, until December 21, when the daylight is shortest. It now turns north and gets up to the celestial equator again on March 21. Thus half of its path is north of the equator and half is south.

The path which the sun follows in the sky is called the *ecliptic*, and it travels over exactly the same path year after year. The length of the year is the time it takes the sun to go completely around the ecliptic. This path of the sun, the ecliptic, is a circle in the sky. It is shown in the next slide. (17)

If only some kind fairy could fly up to the sky and mark on its surface the path followed by the sun (i.e. the ecliptic) and also the celestial equator, it would be a great convenience to people studying astronomy. But it cannot be done and so you must stir up your imagination and with the eye of the mind see the great sun up there in the sky ceaselessly moving forward day after day and year after year along its appointed path.

The ancient Greeks represented Phoebus, the god of the sun, as driving his chariot bearing the sun ever onward among the stars. His roadway was the ecliptic and with great skill he always drove his car exactly along it, never swerving to right or left. It is related that on one occasion his son Phaethon begged to be allowed to drive the car, and, though Phoebus hesitated, he at last consented. But the reckless youth drove carelessly, got off the road and nearly burned up the earth! Surely, then, you can picture to yourself the mighty sun moving along its path on the celestial sphere.

The Zodiac

Further, think of a long ribbon 16 degrees wide (that is, 32 times the width of the sun) tacked on the celestial sphere so that the ecliptic is along the middle of it. This is the *Zodiac.* Within that belt of the sky the moon and the planets are always to be found. With a little study one can learn the constellations along the ecliptic and thus be able to locate its position in the sky at any time that the stars are shining.

You must remember that this annual motion of the sun around the ecliptic has nothing to do with its apparent daily motion which causes it to rise in the east and set in the west, giving us day and night.

Deceived Again

But after all, does the sun really travel around the sky in the course of a year? No, it does not! We have been deceived again! It is the earth that actually moves about the sun though it seems to us that the sun is moving about the earth.

From the diagram (18) you will see how this happens. The earth actually travels in an oval, or rather elliptical, path about the sun, as shown by the small ellipse. When, on January 1, it is at *A* the sun appears to be at *a* in the ecliptic, among the stars in the constellation Scorpio (the Scorpion). Consequently the stars in Scorpio and in other constellations in the same part of the sky, such as Corona (the Crown) and Hercules, cannot be seen at that time; but when the earth has rotated on its axis until, at night, we look at the opposite part of the sky, we see Taurus, Orion, Perseus (per′-suce) and other winter constellations.

Three months later, on April 1, the earth is at *B* and the sun appears to be at *b*. Consequently we cannot see Cygnus (the Swan), Pegasus (peg′-a-sus, the Winged Horse), Aquila (ak′-wil-la, the Eagle), but we can see Leo (the Lion), Ursa Major (the Great Bear) and other nearby constellations. On July 1 the earth is at *C* and the sun appears to be at *c*; on October 1 the earth is at *D* and the sun appears to be at *d*; and then on January 1 the earth is back at *A* and the sun appears to be at *a* again. Thus while the earth actually moves in a little oval curve about the sun, the sun appears to describe a great circle in the sky which we call the ecliptic. From this diagram we see why we have different stars at different seasons.

A View of the Universe

So we have been deceived twice and we should learn the lesson that things are not always what they seem. But why were we deceived? It was because the earth moves so gently, without jolt or jar, as it rotates on its axis and at the same time moves in its path in space about the sun, that we do not feel that we are moving at all. If we could only travel far up in space, entirely away from the earth and the sun, then we should see things as they really are. We should have a bird's-eye, or air-plane, view of the universe. (19) The next picture illustrates what we should see. Here are two little celestial travellers who have been transported far up in space towards the Pole Star a very great distance—perhaps a thousand million miles—and allowed to see our wonderful universe from that place.

Far down below them in the direction from which they came they see the *Solar System*. There is the sun, still very bright, even though they are so far away from it. Then as they gaze steadily they see a number of round bodies moving about the sun. Those are the planets. The travellers notice that each of them looks like a bright half-circular disc and decide that the planets are spherical in shape, that they are really dark bodies and that only that hemisphere which is turned toward the sun is lighted up by the sun and so can be seen. The travellers watch the planets closely, trying to count how many there are and to observe how fast they move.

Nearest the sun is Mercury. It is the smallest of all and speeds along most rapidly. Next is Venus, much larger than Mercury, but moving more slowly. The next is the earth, of about the same size as Venus and travelling still more slowly. They observe also, that the earth has a round body revolving about it. That is the moon. The fourth planet is Mars. It has a diameter only about one-half that of the earth and it is accompanied by two tiny moons.

Then there is a wide gap, and the fifth planet is Jupiter, by far the largest of all. It has four large moons and several small ones which are difficult to see. The sixth member of the family is Saturn. It also is large, but much smaller than Jupiter. But it possesses a wonderful ring and a company of moons. After this comes the seventh member which is named Uranus (yew'-ra-nus) with four moons, and then follows the eighth and last, Neptune,* with one moon—travelling along its path like an old sheep with a single lone lamb! These planets which are far out from the sun move in their orbits more slowly than do the planets nearer the sun.

The travellers also see two comets which have come up to visit the sun. They approach it, pass around it, and then move off, probably never to return.

What could be more thrilling than to see this great family of planets moving majestically along in their orbits while their attendant moons continually revolve about them as if to protect them from any danger in the way!

Turning their eyes from the family of the sun, the travellers survey the other objects in the sky. In every direction they see

*The discovery of a planet beyond Neptune was announced in March, 1930, but its size and orbit are not yet ecrtainly determined.

the stars standing perfectly still like great lamps fixed out in the depths of space. Also, the travellers recognize the very same constellations which they saw when upon the earth. The stars must be at immense distances. Far over there is Orion and his wonderful Belt, and the Dog Star and the Bull, and the Milky Way and all the rest!

It is a wonderful universe!

PART II

THE PLANETARY SYSTEM, EARTH, SUN, MOON

A Look at the Planetary System

Let us now look more closely at some of the things we have seen and learn something about them.

First of all we shall compare the sizes of the orbits of the eight planets. (20) They are shown in this diagram. Notice that there are four quite close to the sun. These are the orbits of Mercury, Venus, Earth and Mars. Then there is a wide space and beyond this are the orbits of Jupiter, Saturn, Uranus and Neptune. Thus we can divide the planets into two groups—those near the sun and those far away.

Let us look at each group separately. (21) Here are the orbits of the four inner planets. Their distances from the sun are approximately 36, 67, 93, 142 millions of miles. Perhaps you can remember these numbers. The dots show the positions of the planets in their orbits every ten days; and the place of each planet on January 1, 1927, is shown. (22) Next we have the orbits of the four outer planets. In the case of the orbits of Jupiter and Saturn the dots show the positions of the planets at intervals of a year, while for Uranus and Neptune the dots show the positions every ten years. As you see, these outer planets require many years to make their circuits about the sun.

Each of the orbits in these diagrams looks circular in shape, but as a matter of fact every one is an ellipse. (23) You know how to draw an ellipse. You drive two pins in a board and over them put a loop of string. Put a pencil in the loop and run it about, keeping the string taut. The point where each pin is placed is called a focus of the ellipse, and if the two pins are near together the ellipse becomes nearly a circle. As a matter of fact all the orbits of the planets are nearly circular.

There is something else remarkable about these orbits. They are all very nearly in the same plane. (24) Further, the planets all travel in the same direction along their orbits. We cannot but wonder why this is so. (25)

In the next slide the relative sizes of the sun and the planets are given. As you see, the four inner planets, Mercury, Venus, Earth and Mars (shown at the bottom) are small, while the outer planets, Jupiter, Saturn, Uranus and Neptune (shown at the top) are large, and the sun is many times as large as all the planets put together. (26) In the following slide the relative masses, or weights, of these bodies are shown. The great iron weight above represents the sun, and the smaller ones below, the planets. As before, the masses of the inner planets are small, those of the outer ones much larger; but the sun is so large that if we could use up the material in it to make planets, 750 complete sets could be formed out of it.

Next, let us try to get a closer acquaintance with the different members of the family of the sun and we shall begin with that planet on which we live.

The Earth

The earth is a great ball about 7,918 miles in diameter. Five hundred years ago it was commonly believed to be flat, and occasionally we still come across some people who argue that it is so. But there are many observations which lead us to believe that it is spherical in shape. (27) As a ship on one of our great lakes, or on the ocean, is nearing port the first part which one on shore sees is the smoke and perhaps the tip of the mast; next the top of the smoke-stack comes into view and finally the body of the ship. This is exactly what we should expect if the earth is round, while if the earth were flat we should see the great body of the ship first.

Again, for $1,000 or more you can buy a ticket which will carry you completely around the earth, and such cruises are regularly advertised. (28) In this map is shown the route which is usually followed. Beginning at New York we can cross the Atlantic Ocean to Gibraltar, calling at the Azores Islands on the way.

Then we pass through the Mediterranean Sea, then through the Suez Canal, the Red Sea, the Indian Ocean, among the East Indies up to Japan, then across the Pacific Ocean to Honolulu and up to Victoria, B.C. After this we go down to San Francisco, then along the west coast of North America, through the Panama Canal and up the east coast to New York again. Such a pleasure trip usually requires four months. However, by using the railways and air-planes as well as the fast steamships the complete trip has been made in a little over 27½ days.

Perhaps some of you have taken a trip to the northern portion of Ontario, where some of the gold mines are located, or up to Winnipeg or Edmonton, or possibly to England, and while there have looked for the Pole Star. You were surprised to find it much higher in the sky than it appears in the southern part of Ontario. Also, some may have had the pleasure of going down to Florida in the winter-time. From there the Pole Star is lower in the sky than it is in southern Ontario. Indeed we find that for every 69 miles you travel northward, whether by ship on any ocean or by other means on the land, the Pole Star rises one degree in the sky, and if you could reach the North Pole of the earth it would be overhead.

Also for every 69 miles you travel southward the Pole Star sinks one degree, and when you get to the earth's equator it is right down at the horizon and you can hardly see it—if it is visible at all.

Now the earth must be practically a sphere or the Pole Star would not behave in this way. Indeed the astronomer has measured the earth so accurately that he is able to say that it is not a perfect sphere after all, but is slightly flattened at the poles, the diameter from pole to pole being 26 miles shorter than a diameter at the equator.

Surely, then, no one can doubt that the earth is spherical in form. We have already given reasons for believing that it is spinning on its axis and so need not dwell on that subject here.

The Sun; Its Distance and Size

Next let us consider for a short time our glorious sun. There is no other body in the sky which can compare with the sun in importance to us. We could live without the moon or the stars, but if we were deprived of the sun's light and heat we could not exist many days.

How far away is the sun and how large is it? With difficulty its distance has been measured, and we are told that it is about 93 million miles. It is hard to form any idea of this immense distance. If a celestial railway could be built from the earth to the sun and a train could travel the whole distance at the rate of a mile a minute without stopping, it would require 175 years to make the journey—two long lifetimes!

How large is the sun? As soon as we know the distance of the sun it is easy to find out its size. Perhaps you would like to know how it is done. (29) The picture shows a boy and a girl making an experiment to find out the diameter of the sun. The boy has in his hand a dinner plate, one foot in diameter, which he is holding between the girl's eye and the sun. First, when near the girl he holds the plate up. It covers up the sun and quite a bit of the sky as well. He then moves away and at last where he now is the plate just covers the sun. By means of a long cord the distance from the boy to the girl is measured and found to be 107 feet.

Now let us look at the diagram down at the bottom. *A* represents where the girl's eye is and *XY,* at the far side, represents the sun, while *BC* is the plate, 107 feet away from *A,* which just hides the sun. It is clear that if the sun was at *DE,* which is twice 107 feet from *A,* and was just hidden by the plate, then the diameter of the sun would be twice that of the plate, or just two feet. If it was three times 107 feet off, namely at *FG,* and was just covered, its diameter would be 3 feet. So you will see that the number of times the sun's diameter is greater than that of the plate is just the number of times the sun's distance is greater than 107. Let us divide 107 feet into 93 million miles. It is contained 4,589 million times and so the sun's diameter is 4,589 million feet, which is the same as 869,000 miles. More careful measurements make it 866,000 miles. The diameter of the earth is 7,918 miles and so by long division we find that the sun's diameter is nearly 110 times as great. It is tremendous. If the sun were represented by a football the earth would be a very small pea!

The width of most country roads and of many city streets is 66 feet. Suppose we represent the sun by a great sphere 66 feet in diameter just filling the space at cross-roads in the country. The earth would be represented by a ball 7 inches in diameter (the size of an ordinary stove-pipe), 1 1/3 miles away—beyond the next cross-roads. If the great sphere were on King St., near Yonge St., Toronto, it would just fit between the buildings on the opposite sides of the street and the 7-inch ball representing the earth would be beyond Bathurst St.

Sun Spots and Faculae

To the naked eye (looking at it through a dark glass for protection) the sun looks like a great bright disc, but with even a small telescope one sees interesting features on it. (30) Here is a phtoograph of the sun. On its disc there are some irregular-shaped dark markings, which are known as sun spots. Note that the central part of the spot is darker than the outer portion. Notice also that some of the spots are clustered together to form groups while others are apart by themselves. Sometimes these spots are so large that several earths could be dropped into them and not fill them up.

Just what causes these spots we do not know. You have often heard of volcanoes belching forth fire and smoke and ashes. The earth's crust cracks and the hot molten material within bursts forth. Perhaps there is somethng like this on the sun. The surface layer becomes weakened at some place, cracks and allows the fiercely hot matter within to explode and shoot up far above the sun's surface.

In the picture you will notice that near the outer edge the disc is darker. This shows that there is an atmosphere of some sort on the sun. Light from the edge of the sun as we see it passes through more of this atmosphere than does the light from the centre of the disc and so more of it is lost by absorption.

Note also the bright blotches around the group of spots near the edge. These are called *faculae* (which is a Latin word meaning 'little torches'). They are mountains of flame which thrust their summits above the absorbing atmosphere, just as some mountain peaks on the earth sometimes pierce through the clouds. (31)

The Rotation of the Sun

In the next picture are nine photographs of the sun, taken on successive days. Look at the large group of sun-spots in the first photograph (August 6). We have learned that the diameter of the sun is 866,000 miles, and if you compare the length of this group with the sun's diameter you will find that it is about one-tenth as great, so that the group is at least 86,000 miles long. It is so large that it could be seen with the naked eye, and some groups are much larger. In the second photograph this group of spots is farther to the right, and if you look for it on the succeeding photographs you see that it steadily moves to the right. On August 12 a trace of it can still be seen, but on the next day it has disappeared completely. Other spots behave in just the same way. Now how do you explain this? You say at once, the sun rotates on an axis, and by observing the spots we can learn how long it takes to turn completely round. It takes about 25 days.

The Mass of the Sun; Frequency of Spots

Suppose we were able to take the material comprising the sun to form earths with it. How many do you think we could make? 332,000! We say that the mass of the sun is 332,000 times the mass of the earth. But it is well to know that one cubic foot of the sun would not weigh as much as a cubic foot of earth. Indeed, one cubic foot of water weighs 62½ lbs.; one cubic foot of sun 1.4 times as much, or 87½ lbs.; while one average cubic foot of earth weighs 5.5 times as much, or 341 lbs.

Other remarkable facts regarding the sun have been discovered. It has been found that sun-spots are more numerous at some times than at others. In some years scarcely a spot is seen. This was the case in 1923. Then they begin to appear more frequently, and in about five years they become so common that the sun's face will seldom be free from these dark blotches. Then they gradually fade out and again almost disappear. This process is repeated about nine times in 100 years.

But while these spots are appearing on the sun some strange things are happening on the earth. When there are many spots, the magnetic needle suffers many disturbances, or we are said to have 'magnetic storms', and at the same time also displays of the aurora, or northern lights, are common and brilliant. Just why these things happen at the same time we cannot say. It is still a mystery.

The Sun's Prominences and Corona

The bright face of the sun which we see is called the *photosphere.* It is so dazzling that we canont see anything which may be just beyond it or near it in the sky. But by means of an instrument called the spectroscope it is possible to explore around the edge of the sun's disc, and we find some interesting portions of the sun there. The layer, or envelope, which overlays the photosphere is called the *chromosphere* and from it there rise up some remarkable shapes called *prominences.* (32) They are crimson in colour and take fantastic shapes. There is much hydrogen gas and calcium vapour in them. This picture shows the sun as revealed by telescope and spectroscope. Some of these prominences change very little during a week, while others show rapid motion. (33) Here is a prominence photographed on June 8, 1918. It looks much like a wild animal blowing fire from its nostrils. The white dot represents the earth on the same scale. In the next picture (34) are three views of a prominence photographed on May 29, 1919. In the lowest view it was 125,000 miles high; 1 hr. 16 min. later it was 137,000 miles high (middle view); and 2 hrs. 36 min. after this it was 200,000 miles high (top view).

These prominences can be seen with the naked eye during a total eclipse of the sun. At this time the moon comes directly in front of the sun and shuts off the strong light of the photosphere, and we are then able to see the fainter outer portions of the sun.

The way an eclipse of the sun is produced is shown in the next picture. (35) Here are our little celestial travellers again, watching how the eclipse occurs. The long slender shadow cast by the moon strikes the earth, and as the moon moves forward in its orbit this shadow trails across the earth's surface. A person within this shadow-path will not be able to see the sun while the shadow is passing over him, which usually takes two or three minutes. In addition to the prominences, one can see then a wonderful halo of pearly white light surrounding the sun. This is called the sun's *corona* (which is the Latin word for 'crown') and it is one of the most beautiful and impressive of celestial spectacles. (36) In the picture is shown the corona as photographed by the Canadian Expedition to the North-west coast of Australia to observe the total eclipse of September 21, 1922. The black round object you see is the moon; the body of the sun is directly behind it.

What is in the Sun?

Though the sun is so far away, the astronomers have found out what it is composed of. This has been done by means of the spectroscope, the wonderful instrument which has already been mentioned. And what do you think the sun is made of? Iron, copper, zinc, calcium, hydrogen and many other substances which we find on the earth! Is not that remarkable? The sun and the earth made of the very same materials! Surely they were at one time joined together in a single mass.

When we look at the sun and the moon up in the sky they seem to be of about the same size, and you may be surprised to learn that the sun is actually 400 times as large as the moon. It appears of about the same size because it is 400 times as far away. The moon's distance from the earth is, on the average, 238,000 miles. This is small compared to most distances met with in astronomy. A locomotive engineer running between Toronto and Montreal (330 miles) six trips a week would travel as far as the moon in two years, but as far as the sun in 800 years!

The moon's diameter is 2,163 miles, a little more than one-quarter that of the earth, and there is enough material in the earth to make 81 moons.

As we have already learned, the moon revolves about the earth. Also, you must remember that the moon is a dark body and can be seen only as it is lighted up by the sun. These two facts cause the moon to show phases. You must understand how they are produced, and the explanation is easy. (37)

In this diagram you must consider the sun to be far off to the right. You see the rays coming from it. When they fall upon the moon they illuminate one-half of it, just as they always illuminate one-half of the earth. The moon revolves about the earth in the direction indicated by the arrow. When it is at *A,* in the line drawn from the earth to the sun, the bright face of the moon is turned from the earth and we cannot see it at all. When in this position the moon is said to be 'new'. About three days later the moon reaches position *B*. A person on the earth can now see a portion of the illuminated hemisphere of the moon, but not the whole of it. The part he sees looks like a crescent, as shown in the figure. The moon is said to be three days old. About four days later the moon arrives at *C,* and from the earth we see one-half of the illuminated face. It looks like a bright half-circular disc. The moon has now travelled one-quarter of its orbit and it is said to be at 'first quarter'.

By the time the moon is ten days old it has reached *D* and its shape is said to be 'gibbous' or 'swelling'. About two weeks after new moon it is found at *E*. From the earth we now see its entire bright hemisphere and it is said to be 'full'. In this case the moon, the earth and the sun are in line, the earth being between. A week later the moon reaches *G*. Its shape is now a half-circle again and it is at its 'last quarter'. In about one week more, or after a month in all, it arrives at *A* once more and we have new moon again. The complete performance, from one new moon to the next, requires 29½ days.

When the moon is strictly new we cannot see it at all. It has to be about two days old before we see its slender crescent. About two days before it becomes new, or when it is about 27 days old, it shows a similar crescent. In this case one must look for it in the east just before the sun comes up. When it is young—two or three days old—we must look for it in the west just after the sun has gone down.

Remember, also, that the horns of the crescent are always turned away from the sun and that the line joining them is at right angles to the line joining the moon and the sun. In the spring the horns of the young moon are turned upward so that they could "hold water"; in the autumn they are tilted so that the water would spill out. But in neither case has the new moon anything to do with wet weather.

Views of the Moon

It is interesting to study the moon with the naked eye. (38) In this slide there are four pictures. That at the lower right is a photograph of the full moon. It shows how the moon appears when viewed with a small telescope or a field glass. In the upper left picture is seen the "man in the moon". See his eyes, nose, mouth and chin. As the full moon is coming up in the autumn the "man in the moon" is well seen. At the lower left is shown the woman reading. She has a hat on and is holding the book up before her. Then in the upper right picture is seen the 'crab'.

Other fanciful objects have been sketched—but the objects shown here are very easy to see, if you look for them. (39)

Here we have a photograph of the full moon, showing it as seen in a telescope, that is, up-side down, compared with a naked-eye view. Note the dark portions, mostly roundish in shape. They are called 'seas'. When first discovered they were supposed to be bodies of water, and, although we now know that there is no water on the moon, they are still called seas. They bear fanciful names. The oval one half-way up on the left side is the Sea of Crises. Immediately to the right of it is the Sea of Tranquillity, and directly below this, also oval in shape, is the Sea of Serenity, while the big one below and to the right is the Sea of Showers. Notice also, the bright spot near the top with bright rays running out from it. It is not a sea, but a crater, and it is called Tycho (ty'-ko). (40)

Next we have a photograph of the moon at its first quarter, or when it is about seven days old. Some of the seas are shown very well, but notice particularly the numerous round objects, seen especially well along the right-hand edge. These are craters, perhaps due to volcanic action in long-past ages. The largest one on the moon is seen half-way down the right-hand edge. It is called Ptolemy and is 115 miles across, while the largest crater on the earth is only seven. Look also at some detached white spots in the darkness just beyond the ragged edge to the right. These are the tops of mountains which are lighted up by the rising sun. (41)

The next slide is from a photograph taken with the largest telescope in the world, namely, that on Mt. Wilson in southern California. This shows a portion of the moon (the north part) as seen at third quarter. Here is the Sea of Showers. Perhaps you would like to know the names of some of the objects in this picture. They are given in the next slide and we shall return to this one. (42) Notice the Sea of Showers. On its upper left shore are the Apennine Mountains, at the lower left are the Alps.

Notice the 'Valley' in the Alps. Then there is the crater Plato, 58 miles across, Rainbow Bay, and up higher are the craters Archimedes (ar-ki-me'-dees), Eratosthenes (era-tos'-the-nees) and Copernicus. Also note the sharp rock at the left side of the Sea of Showers. It throws a very black shadow. In what direction must the sun be?

Now let us turn back to the last slide—pick out the Sea of Showers, Rainbow Bay, Apennines, Alps, the Valley, Plato, Archimedes, Eratosthenes, Copernicus and the rock casting the black shadow. There are many other interesting objects and a name has been given to each.

The surface of the moon is almost certainly a waste of rock and sand. There is no atmosphere and during the day-time when the sun beats down upon the moon it must become very hot, but at night the temperature must fall very low. All is dead, deserted and silent there.

PART III

PLANETS ONE BY ONE; COMETS, METEORS

The Planet Mercury

We now come to the planets. The one nearest the sun is called Mercury. Its average distance is 36 million miles, though it varies from 28½ to 43½ millions. It is the smallest of the family as we have already seen. (43)

In the ancient Greek and Roman mythology Mercury was the messenger of the gods. He was represented as a fine youth with wings on his heels, and one of his distinguishing characteristics was the speed with which he rushed through space when performing his official duties. Here is a photograph of a fine statue of Mercury produced in Italy about 1575. It is in a museum in Florence, Italy.

Now the planets are named after the old heathen gods and the name of Mercury was naturally given to the nearest planet, since it moves the swiftest of all. It never travels at less than 23 miles per second and it sometimes reaches 35 miles per second— a second remember, not an hour. It requires only 88 days to make its circuit about the sun, or Mercury's year is not quite three of our months. Its diameter is 3,030 miles and its mass is about 1/20 that of the earth.

Astronomers for a long time have patiently watched the planet with the telescope in the hope of recognizing some marks on its surface which would allow them to see how long it takes Mercury to rotate on its axis, but they have not been very successful. It is generally believed that Mercury always presents the same face to the sun; also that it has little or no atmosphere. Hence on one face it must be a burning desert; on the other a frozen waste.

The Planet Venus

The planet next in order is Venus, its distance from the sun being 67 million miles. Of all the ancient deities Venus was the most beautiful, and Venus is the loveliest of all the planets. As an evening star in the west or a morning star in the east she easily outshines all the other planets and the stars and excites the admiration of all.

At the speed of 22 miles per second Venus pursues her path and makes a complete revolution in 225 days or 7½ months. The diameter of the planet is 7,700 miles, which is almost the same as that of the earth. Indeed Venus and the earth are twin sisters. (44)

Venus Shows Phases

Let us consider the behaviour of Venus. You must remember that Venus has no light of its own but shines only as it is illuminated by the sun. At all times, of course, one-half of the planet's surface is illuminated, namely that hemisphere which is turned toward the sun. Also we observe it from the earth which is 93 million miles from the sun.

In the picture we see a young astronomer on the earth watching Venus as it moves round the sun. When Venus is at 1 it is at its greatest distance from the earth, being 93 plus 67, or 160, million miles away. This is a great distance and consequently the planet appears small. The planet really cannot be observed when it is in this position as it is lost in the blaze of the sun's light. It will usually be a little north or south of the sun but so close to it in the sky that it cannot be seen. If at this time the moon comes in front of the sun and shuts off its intense light, then the planet can be seen, and in a telescope it shows a round bright disc. This is, of course, exactly what we should expect since its illuminated hemisphere is turned directly toward us.

When it reaches its position 2 it is near the earth and hence looks larger, but we cannot now see the entire illuminated hemisphere. With the naked eye one cannot make out the shape of the disc at all but a small telescope will show that it has the gibbous form shown in the picture. On reaching position 3 it is closer and brighter and it looks like a half-moon. As it moves along in its orbit it becomes still brighter until it comes to position

4. The telescope now reveals its crescent shape. Five weeks later it reaches position 5. At this time its distance from the earth is 93 minus 67, or 26, million miles. But as its illuminated face is turned from the earth we cannot see the planet at all. Venus hides her beautiful form from us! Then in five weeks more the planet moves to position 6 where its shape is similar to that in position 4; and then moves to position 7 and 8 and 1 again. We thus see that Venus shows phases like the moon.

Morning Star and Evening Star

We have not finished with this picture yet. When Venus is at positions 2 or 3 or 4, a person on the earth will see the planet up in the sky to the left-hand of the sun. Look up now at the sun and think of Venus being on your left hand, that is, east of the sun. Then as the sun moves across the sky during the day, Venus will follow after it, and when the sun has set in the west Venus will still be above the horizon, and we call it an evening star. But when Venus is in positions 6 or 7 or 8 it will appear in the sky to the right, or west, of the sun. Hence as the sun moves across the sky the planet will move along ahead of it and will set before the sun, but it will come up before the sun in the east. It will then be a morning star. The ancient people thought the evening and the morning star were two different bodies and called them Hesperus and Phosphorus respectively. (45) Here we have a photograph of Venus when showing the crescent phase —as it does at positions 4 and 6 in the last slide.

It is believed that Venus always presents the same face to the sun. If that is so, one hemisphere must be very warm and the other very cold. The planet is covered with a thick atmosphere and we cannot see its solid surface.

The Planet Mars

Of all the planets, however, Mars has excited the greatest interest. It seems to be more like the earth than any of the others and everybody is anxious to know if there are living beings upon it. The planet's distance from the sun is about 142 million miles, or $1\frac{1}{2}$ times the earth's distance, and it completes its circuit about the sun in 687 days, travelling continually with a speed of 15 miles a second. The diameter of Mars is 4,200 miles, not much more than one-half that of the earth, and its mass is 1/9th that of the earth. (46)

Orbits of the Earth and Mars

Let us look into the motion of the earth and of Mars. In this diagram the inner orbit is that of the earth; the outer is that of Mars. The orbits are really ellipses, but they do not differ much from circles. The position of the earth on the first day of each month is given. It occupies these places year after year.

The position of Mars on the first day of each month in 1926 is also shown. As it takes nearly two years to go round the sun, it passes over only a little more than one-half of its orbit in one year. The line joining the two bodies represents the distance between them on the various dates and it is interesting to see how these change. The number beside the line gives the distance in millions of miles. On January 1 the planet was 208 million miles from the earth, but on February 1 it was only 188 million. The distance continually diminishes until November. On November 4 Mars and the earth are in the positions shown, at which time sun, earth and Mars are in line. At this time a person on the earth sees the sun and the planet on opposite sides and the astronomer describes this by saying 'Mars is in opposition to the sun'. At this time the sun sets in the west as Mars rises in the east and it is a prominent object in the sky all night long. At this particular opposition Mars was about 43 million miles from the earth.

From one opposition to the next is about 780 days. Thus there was an opposition on August 23, 1924, at which time the distance of Mars from the earth was less than 35 million miles The diagram shows where they were. This was the closest approach of the two bodies for many years past or to come. Then the next was about 780 days from November 4, or about December 21, 1928, and the distance was about 55 million miles.

When Mars is at a very great distance from the earth, as it was in January, 1926, it is not very bright—about like the Pole Star; but when it is near, it becomes one of the most brilliant objects in the sky. It has a ruddy, fiery colour, and one is not surprised that it was named after the old Roman god of war.

Marks on the Surface of Mars

When a large telescope is turned upon Mars we see interesting features on its surface, quite unlike Mercury and Venus, on which we cannot see any definite markings at all. (47) Here is a drawing made at the Lick Observatory in California in 1924. A couple of hours later the planet would show quite a different face. (48) This is nicely shown in the next slide which contains three photographs. The right-hand one was taken at 10.15, the middle one at 11.15 and the left-hand one at 11.37. There is quite a difference between the first and the last, due to the rotation of the planet. By watching the markings on the planet the time required for a complete rotation can be found out. It is 24 hrs. 37 min. 23 sec. This is the length of a day on Mars. (49)

The planet also has seasons but they are nearly twice as long as ours and are much colder, since Mars is much farther from the sun. In the long winter the temperature falls very low and beings like ourselves could not exist on Mars. In this picture is shown the appearance of a portion of the planet in winter (left) and in summer (right). (50)

The Canals

Within the last fifty years astronomers have detected some fine lines on the surface which have been called 'canals'. Here are four pictures showing four views of Mars, and the faint straight lines (best seen in the upper right view) are the canals. The reddish part of the pictures is supposed to be desert and the greenish part vegetation of some sort. Just what these canals are no one yet knows. Some people think they are built by intelligent people while others are very doubtful about that. (51)

Some years ago H. G. Wells wrote a book called "The War of the Worlds", in which he represented the people of Mars as very advanced in knowledge—their brain having grown until they had become very wise while their bodies had wasted away. An artist shows in this picture what he imagines they may be like!

Mars and Its Tiny Moons

Mars has two small moons, which were discovered in 1877 by an astronomer named Hall. (52) In the summer of that year Mars was very close to the earth, and a telescope 26 inches in diameter, the largest in the world at that time, had recently been erected at Washington, the capital of the United States. Night after night in August Mr. Hall searched the sky near the planet to see if there could be any moons revolving about it, and he was about to give up, but his wife urged him to continue. He did so, and on the night of the 11th he discovered one moon and six days later the second. They are named Phobos and Deimos (dy'-mos). They are only a few miles across and give out very little light. But they are very close to the planet and revolve about it very rapidly—the nearer one in 7 hrs. 39 min. and the farther in 30 hrs. 18 min. Our moon, you remember, takes four weeks to go around the earth.

The Planet Jupiter

Thus far we have been learning about the four inner planets—those members of the sun's family which are found near to the great body about which they move. They are all comparatively small and composed of heavy, or dense, matter. Let us now travel farther away to see the four other members of the family as they pursue their courses at their immense distances from the great sun.

The first one we reach is the mighty Jupiter, the greatest of all the planets. Its distance from the sun is 5.2 times that of the earth, or 483 million miles, and it requires nearly 12 of our years to make a revolution. It travels at the rate of 8 miles per second. (53)

Jupiter's Moons, and Other Features

Jupiter is a very pretty sight in a small telescope as it hangs up there in the sky. In addition to the big disc of the planet, four little sparkling stars are to be seen in a line, like pearls on a straight string. These are satellites or moons. These were the very first objects in the sky discovered by Galileo in 1610 with his newly invented telescope. They are invisible to the naked eye, but can be seen with a good field-glass if it is held very steady. (54)

In a larger telescope we see interesting bands and other markings on the planet, and we also recognize that Jupiter is not a perfect sphere but is decidedly flattened at the poles. It is clearly shown in the drawing. Actual measurement shows that while the equatorial diameter is 90,000 miles, the polar diameter is only 84,000 miles.

Why is Jupiter so flattened? We would suspect that it rotates on its axis very rapidly, and such is the case. It actually rotates in 9 hrs. 55 min. A point on its equator travels over 28,000 miles per hour!

Jupiter contains enough material to make 317 earths, but it is not so dense as the earth—indeed only about one-fourth as dense. This is about the same as the density of the sun and some people have thought that Jupiter must be very hot. But it does not give out any light of its own; we see it only as it is illuminated by the sun's rays.

The Motion of Jupiter's Satellites

A pleasing exercise for a person with a small telescope is to watch the four satellites. They are numbered I, II, III, IV, in order of their distances from the planet. They are all larger than our moon and their times of revolution vary from 42 hours to 16 days. It is very interesting to follow their motions as they move about the giant planet. Sometimes they pass in front of it and cast a shadow on its face. The satellite and its shadow slowly move across the face of the planet and disappear at its edge. (55) This is beautifully shown in this slide. Here we have two drawings of Jupiter. In the left-hand one a satellite and its dark shadow are seen close together as they move across the face. In the right-hand picture the dark round shadow is easily seen near the right-hand side in front of a bright band. The satellite itself which produces this shadow is directly to the left of the shadow, a little to the right of the centre of the disc. You can hardly see it as it is a bright object and is in front of the bright band. (56)

In this slide are given the positions of the satellites at 1 a.m. on six days in July, 1926. The arrow indicates the direction in which the satellite is moving and it is interesting to follow the motions of each satellite from one day to the next.

Besides these four satellites Jupiter is known to possess five more, all discovered in recent times, but they are so faint that they can be seen only with large instruments. (57)

Some good photographs of Jupiter have been taken. Here is one of them. But it does not show as much detail as can be seen with a good telescope.

The Planet Saturn

The next member of the solar system as we proceed outward from the sun is the most remarkable of all the family. It is the planet Saturn. (48) At 9½ times the earth's distance, or 880 million miles, from the sun it moves along its path at the rate of six miles per second and completes a revolution in 29½ years.

Its great belted globe is surrounded by a wonderful series of rings and as it moves majestically along its appointed way it is attended by ten satellites which forever revolve about it, some quite close, others a long way off.

The equatorial diameter of the ball is 75,000 miles and the polar about 7,000 miles less, or 68,000 miles. Thus it is much flattened at the poles and we should expect it to turn about its axis rapidly. And so it does; to make one rotation requires 10 hrs. 14 min.

The matter of which Saturn is made is about as heavy as dry oak or maple wood and so it would float on water. All the other planets would sink. (59)

There are three rings in the system, as this picture clearly shows. The outer one is separated by a dark space from the middle one, which is wider and brighter than the outer one, and then this is followed by a faint inner one.

The outside diameter of the outer ring is nearly 170,000 miles while its thickness is less than 100. If you should take a piece of writing paper and cut out a circular disc 17 inches in diameter, to represent the size of the rings, the thickness of the paper would represent their thickness.

What are the rings made of? They are composed of separate small bodies, like boulders or big stones, which are so close together that little or no light passes through the ring; but these bodies revolve about the ball as though they were a close-packed swarm of moons. (60)

As the planet revolves about the sun the rings show different phases as illustrated in this picture. When either the earth or the sun is in the plane of the rings they cannot be seen. This happens about every 15 years. They disappeared in 1907 and will be invisible again in the years shown on the slide. (61)

Though Saturn when closest to the earth is yet about 800 million miles away, some wonderful photographs of it have been taken. Here are four from negatives taken at the Lowell Observatory. They show the phases very nicely. (62) The next slide is from a photograph made with a large telescope 5 ft. in diameter at Mt. Wilson Observatory, in California.

To the naked eye Saturn gives a dull steady light. It is much less brilliant than Venus or Jupiter.

For many centuries it was thought that Saturn was the most distant of all the planets, and that its orbit formed the outmost boundary of the solar system; but a startling discovery, made in 1781, showed that it was necessary to travel out at least twice as far before reaching the end of the sun's kingdom.

On March 13th of that year William Herschel, a professional musician living at Bath, Eng., was studying the sky with a telescope which he himself had made. Herschel had found that to understand fully the theory of music he had to study algebra, geometry and other branches of mathematics. From these he was led to study optics, or the science of light, and the telescope; and having used a small telescope to observe some of the objects in the sky he desired to obtain a larger one. He inquired the price, but it was more than he could pay and so he determined to make one himself.

There are two kinds of telescopes. In one a lens is used to collect the light; in the other, a mirror. The former is called a refractor; it is the kind you ordinarily see. The latter is called a reflector. Now it is much easier to make a mirror than a lens, and it was a mirror telescope (or reflector) which Herschel constructed. Indeed it is quite a favourite exercise for an amateur astronomer to make his own telescope and many good ones have been made. To do so requires patience and care. (63)

Here is a telescope constructed by a Toronto lawyer, who is seen observing with it. The mirror is in the lower end of the tube and the eye-piece, into which the astronomer looks, is at the other end. The tube here is of galvanized iron and it is supported on a wooden post. The largest telescopes in the world are constructed on this principle.

The telescope which Herschel was using on the above date was 6¼ inches in diameter and 7 feet long. It was his custom to rush home after a practice or a concert and spend the rest of the night in observing the heavens. As he was examining star after star in the constellation Gemini (the Twins) he came upon one which looked peculiar. In a good telescope a star appears simply as a bright point, but to his sharp eye this one looked larger—like a tiny disc. He tried a higher power and the disc looked larger. A star does not act in that way, and this showed that it was not an ordinary fixed star. A few days later he examined it again and it had moved among the stars. He decided it was a comet. The idea that it was a planet did not enter his mind.

After a few months it was proved to be a planet and the name Uranus (yew'-ra-nus) was at length given it.

King George III knighted Herschel, gave him a pension and made him the king's astronomer. He constructed many larger and better telescopes, which were famous all over Europe, and he devoted much time to observing the heavens. He became the greatest of all observational astronomers. (64)

Here is a drawing of Herschel's planet and the earth on the same scale. The planet is 1,800 million miles from the sun, and its orbit is so great that, though it moves forward with a speed of 4 1/3 miles per second, it requires 84 years to complete its circuit of the sun. Its diameter is about 32,000 miles and so 66 earths could be stowed away within its outer shell, but the material in it is not nearly so heavy as that of the earth. It 'weighs' only 15 times as much as the earth. (65)

Uranus has four small satellites, which can be seen only in large telescopes, but though they are so tiny and so far away they have been photographed. The four wee dots shown on the slide are the satellites and their names are given in the key down in the corner. (In this photograph the two bright lines across the planet do not belong to it. They are due to two rods across the telescope tube and could not be avoided.)

The Planet Neptune

There is one more known planet in our solar system. Its name is Neptune. Uranus was met with almost accidentally; Neptune was discovered by the mathematician in his study.

After Uranus had been observed for some months astronomers were able to calculate the size and position of its orbit and it then became possible to predict where the planet should be found day after day. But as the years went by it did not occupy precisely the positions given for it. It did not go far from its path but yet far enough to make astronomers anxious, and at last they decided that there must be some other far-distant body which was luring the lonely Uranus from its appointed path.

Two mathematical astronomers, Adams in England, and Leverrier in France, each without any knowledge of the other, undertook to calculate just where the unseen trouble-maker was. It was a very difficult problem but they both solved it. They stated just where in the sky to look for the stranger, and on the 23rd of September, 1846, an astronomer at Berlin, Germany, pointed his telescope to the place and found it. The discovery caused a great sensation.

Neptune is 2,800 million miles from the sun. It moves in its orbit 3 1/3 miles per second and requires 165 years to perform a revolution. Thus it has not completed half a revolution since it was discovered. It requires a telescope to see it. (66)

Here is a drawing of Neptune and the earth. Neptune's diameter is about 34,000 miles. It is large enough to contain 85 earths but the matter in it, or its mass, is sufficient to provide only 17 earths. (67)

Within a month of the discovery of the planet a little moon was detected revolving about it. Though at such an enormous distance from the earth, it has been found possible to take a photograph of the planet and its lone satellite. In the photograph on the screen the large bright dot at the right is the planet, the little dot beside it is the satellite. It is about as far from Neptune as our moon is from the earth.

The Planetoids or Asteroids

We have now come to the frontier of the solar system but there are one or two things we must consider before we leave it.

Let us go back to the wide space between the orbits of Mars and Jupiter. For many years it was thought that there must surely be some planets, probably small, revolving here about the sun. At last a number of astronomers united themselves into a society which was jokingly called the "celestial police," to hunt for these members of the sun's family which were hiding from view. The first culprit was arrested on January 1, 1801; and since then over 1,000 have been discovered, latterly by photography.

The method is as follows. (68) The astronomer points his camera to a part of the sky where he suspects one of these planetoids, or asteroids, may be, and he keeps his camera moving so that it exactly keeps up with the motion of the sky. The stars then appear on his plate as round dots. Now a planet is continually moving among the stars and if there is a planet there it makes a trail on the plate. In the picture on the screen there are two of these short trails, recording two planetoids. The exposure was one hour.

The planetoid family has now grown so large that it requires much time and labour to keep a record of their doings. They are mostly very small bodies only a few miles in diameter. Only one is bright enough to be seen without a telescope. Its name is Vesta and it was discovered in 1807. Its diameter is perhaps 300 miles.

Comets and Meteors

Comets and meteors also may be considered to belong to the solar system since they revolve about the sun; but they do not always stay with us. (69) This picture shows very well how a comet behaves. When first seen it is very faint as it comes from the depths of space. Then as it approaches the sun, as shown by the arrow, it develops a tail, and becomes larger and brighter. When it gets to that point where it is nearest to the sun it is said to be in *perihelion,* and its tail is longest. Then it moves off, always having its tail directed from the sun. It gets fainter and fainter and at last disappears, never to be seen again!

But sometimes the comets do come back, in which case they may very properly be counted members of the sun's family. That one which returns most frequently is named Encke's comet, (Encke pronounced eng′-ka) after an astronomer who studied its motions. (70) It is shown in the picture. It is too faint to be seen with the naked eye, and, as you see, it has no tail. It returns every 3.3 years.

But some comets are remarkable objects. (71) Here is one discovered by Brooks, of New York State, in 1911. Look at the wonderful tail as it streams away from the head of the comet.

Another comet, discovered in 1908 by Morehouse, (72) exhibited some strange changes during the few months when it was visible. Here you can see the many filmy ribbons of the tail as they are driven backward. Indeed at one place there is a great lump as though the tail had been broken and a large portion was flying off into space. (73) But the most famous of all comets is that named after the English astronomer Halley. It returns every 76 years. It came to the sun in 1910 and will return in 1986. Here is a photograph of it taken on May 13, 1910. The exposure was 30 min. Notice the peculiar expansion in the tail; also the bright spot near the bottom of the picture. That is the planet Venus. Look also for a faint straight streak a little to the right of the comet's head. That was made by a shooting star. Thus in this photograph there are four different kinds of heavenly bodies —a comet, a planet, a shooting star and the fixed stars.

Shooting Stars

Shooting stars such as that one recorded on this photograph are familiar to all. Usually there is a faint streak of light in the sky, which lasts but a moment and is gone.

These streaks are due to bits of matter, perhaps like grains of sand, which are rushing through space and come into our atmosphere. By the friction against the air they become white-hot and probably burn up.

But occasionally something bigger comes along, perhaps a rock a foot or more in diameter, and as it ploughs its way through the atmosphere it makes a great display. (74) In this case it is called a fire-ball; and a remarkable one is shown in this photograph. An astronomer named Klepesta, at Prague, in Czecho-Slovakia, was taking a long-exposure photograph of the stars on the night of September 12, 1923, and at 11 p.m. a brilliant fire-ball moved across the sky and left its mark upon the plate.

It fell slowly like a burning sphere, the brightness continually increasing, and it was followed by a train of yellow luminous powder which lasted for about 10 seconds. When the fire-ball was apparently near the great nebula in Andromeda (seen at the right-hand side of the picture) it exploded like a rocket, and lighted up the whole country about. You can see the double streak made by the two pieces.

When the body was first seen it was 85 miles above the surface of the earth and after travelling 55 miles, at the rate of 37 miles a second, it disappeared at a height of 35 miles above the earth. Only 7½ miles of its path is on the photograph and then its height was 50 miles.

Sometimes these bodies fall to the earth, in which case they are called meteorites. Many have been found. Some are almost solid iron, but they are generally like a stone.

PART IV

THE STARS, NEBULAE AND CLUSTERS

The Stars

There is much yet to learn about the solar system, but we cannot longer delay. We must now turn from our own family affairs to look into the great celestial world beyond.

You are all accustomed to study maps of the earth's surface and you know that one map may cover only a small portion of the country, such as a mining district, while another may include an entire continent. So it is with maps of the sky. Some refer to large areas while others take in single constellations, or even less. There is one thing, however, which you must always remember. In the case of the earth we view it from the outside, while it is the inner surface of the celestial sphere which is presented to us.

North Polar Stars

Let us then study some maps of the sky, and those which we shall look at first will cover large portions of it. (75) The first map contains the stars which you see when you face the north and look upward toward the Pole Star. These stars can always be seen on a clear night, but they are not always in the same position. They are continually revolving about the pole of the sky and besides their positions vary with the seasons. In the autumn in the early evening the Big Dipper is seen below the Pole Star; in the spring at the same hour it is above it.

At the left of the slide are the stars as you see them in the sky; on the right is a key giving the names of the constellations and of the brighter stars. Around the circumference are the names of the months. The month November is at the top. The map now shows the positions of the stars at 9 p.m. in November. To find their positions for any other month, you turn the map until that month is at the top.

The star very near the centre of the map is the Pole Star, usually called Polaris by the astronomer. Some distance below it is the Big Dipper, which is part of the constellation Ursa Major (the Great Bear). The shape of the Dipper is traced out by seven bright stars. In star maps it is usual to denote each bright star by a letter of the Greek alphabet; but in this map only the first two letters, Alpha and Beta, are used. They look like our letters *a* and *B*. Alpha and Beta of the Big Dipper are named 'The Pointers.' They are about five degrees apart. If you draw a line from Beta through Alpha and extend it about 30 degrees beyond Alpha, it will come almost to the Pole Star.

The star Alpha is named Dubhe (doob'-he) and Beta is Merak. The star at the bend of the handle of the Dipper is Mizar (my'-zar). A sharp eye will see another little star near it, which bears the name Alcor. The stars in the Big Dipper are said to be of second magnitude. There are some stars in the sky which are much brighter than these. They are said to be of the first magnitude.

Return now to Polaris. It is at the end of the handle of the Little Dipper which, you will agree, is not as well shaped as the Big Dipper. Polaris also is of the 2nd magnitude. The two stars at the outer edge of the bowl are named the 'Guardians of the Pole'. The brighter one of these is of the 2nd magnitude; the fainter, of the 3rd magnitude. The Little Dipper is a portion of Ursa Minor (the Little Bear).

On the other side of the Celestial Pole from the Big Dipper is the constellation Cassiopeia. Five of its chief stars form a sprawling M or a W turned upside down. Three of the neighbouring constellations are named Cepheus, (see'-fuce) Andromeda and Perseus (per'-suce). They are all well-known in the old mythology. According to the Greek legend, Andromeda was the daughter of Cepheus and Cassiopeia, who were the King and Queen of Ethiopia. Cassiopeia having boasted herself equal in beauty to the sea-nymphs who constantly waited upon Neptune, the god of the sea, that person became angry, and to punish the King and Queen he sent a great flood upon the land and also a sea-monster which destroyed the people and the animals. Neptune let it be known that no relief would be given until the king gave up his daughter to be torn to pieces by the monster. So she was taken to the shore of the sea, chained to a rock, and there left to her fate. Here she was found by a fine young man named Perseus, who slew the monster and married her.

The ancients imagined that they could trace the shapes of these fabulous persons in the stars, but modern watchers of the skies fail to see anything of the kind.

With a map like this one it is easy to identify the other constellations, and there is much pleasure in doing it.

Let us now face the south and study the stars in a wide belt along the celestial equator. As this belt is so long, running as it does around the entire celestial sphere, we shall consider it in four parts. (76)

We shall begin with the winter stars as they are the finest. In this map the straight line across it is the celestial equator; the curved one is the ecliptic, which you remember is the path in the sky which the sun appears to follow.

The sun is at the right-hand end, where the ecliptic cuts the equator, on March 21, at the left-hand end on September 22, and at the middle, where the ecliptic is highest above the equator, on June 21.

At the top of the key-map are the names of the months. The stars under the name of a month are 'on the meridian', that is, directly in the south or overhead, at about 9 p.m. during that month.

The most prominent constellation is Orion (o-ry'-on), whom the ancients represented as a mighty warrior. We shall see his picture a little later. The three stars almost in a straight line and about one and a half degrees apart are on his belt. They are of the 2nd magnitude. Then 8 degrees north of the belt is a fine red star named Betelgeuse (bet'-el-juice). It is of the 1st magnitude. Ten degrees south is a splendid blue-white star, also of the 1st magnitude, named Rigel (ry'jel). This is the finest constellation in the sky. It is the only one which contains two 1st magnitude stars.

Next, follow along the belt to the left about 20 degrees and you come to Sirius (pron. like 'serious'), the Dog Star, in the constellation Canis Major (the Great Dog). It is the brightest star in the entire sky. Then, following along the belt to the right about 20 degrees you come to Aldebaran (al-deb'-ar-an), a red 1st magnitude star in Taurus (the Bull).

Orion is just at one side of the Milky Way. On the other side, up (that is, north in the sky) and to the left (that is, east) of Orion is the constellation Gemini (jem'-in-i, the Twins). The two brightest stars in it are Castor and Pollux. Travelling from Castor through Pollux and swerving a little towards Orion you reach Procyon (pro'-si-on), a bright star in Canis Minor (the Little Dog). Some distance to the left of the line joining Pollux and Procyon and forming a great triangle with these two stars, is Regulus, in Leo (the Lion). It is almost exactly on the ecliptic. Regulus and five more stars in the Lion form the 'Celestial Sickle'.

The other stars on the map can easily be located from those we have already taken up.

(77) In this map we have the stars of Spring. In March the constellation Cancer (the Crab) is well seen but it has no bright stars in it. But about half-way between Pollux and Regulus is a cluster of stars named Praesepe (pree-seep'i) or the 'Bee-hive'. It is interesting to try to find it. In April and May Virgo (the Virgin) is easily found. It contains one bright white star named Spica (spy'-ca) which is near the ecliptic and south of the equator. North of the equator is the constellation Bootes (bo-o'-tees) the 'Herdsman,' with its very bright yellow star Arcturus. (78)

We now come to the stars of summer. One of the finest stars then seen is Vega, in Lyra (the Harp). It is a glorious white star and is almost overhead in the early evening early in August. East of Lyra is Cygnus (the Swan), sometimes called the Northern Cross, since five stars in it trace out a distinct cross. At the head is Arided (or Deneb) and at the foot is Albireo. The Cross is in the midst of the Milky Way. Between Lyra and Bootes are Hercules and Corona (the Crown). In Hercules four stars, not very bright, form a 'flower pot' or a 'keystone'. In one side of the 'pot' is a faint star which you can just see with the naked eye. In a small telescope it looks hazy and you hardly know what to think of it. In a large telescope it looks like a magnificent cluster of jewels. You shall see a photograph of it a little later. Down near the equator is Altair, in Aquila (the Eagle) and much farther south is the red star Antares (an-tar'-ees) in Scorpio (the Scorpion). (79)

Lastly let us look at the autumn sky. Lyra and Cygnus can still be seen somewhat west of the overhead point (the zenith). High in the sky to the south is Pegasus (peg'-a-sus) the 'winged horse,' on which Perseus rode when he went out to fight the monster which intended to destroy Andromeda. There are four bright stars which form the Great Square. Actually one of these is in the adjoining constellation of Andromeda. It bears the name Alpheratz. The two other chief stars of Andromeda are named Mirach (my'rak) and Almach. These three are almost in a straight line. About ten degrees to the west of Mirach (near the letter E in Andromeda) is a wonderful object, called the Great Nebula in Andromeda. You shall see a photograph of it later. To the east of Andromeda is Perseus which contains a remarkable star named Algol (which means the Demon). This star is usually as bright as Polaris, but every 69 hours it loses three-fourths of its light and in a few hours recovers it again.

The Number of the Stars

When, out in the country, away from the city lights, you stand under the open sky on a perfectly clear moonless night, the stars seem countless in number. But are they really so? One way to test this is to choose some definite area of the sky such as 'the bowl' of the Big Dipper or the square of Pegasus and actually count the number of stars in it. You will find there are comparatively few.

The stars visible to the naked eye have been counted by several astronomers and the number is about 6,000. Now one can see only one-half of the celestial sphere at any time and hence about half of this number will be above the horizon at one time. But the haze in the air near the horizon always prevents the faint ones there from being seen, and so it is probable that not more than 2,000 can be seen at one time by the unaided eye. In a city, where the streets and houses are lighted, it is doubtful if as many as 1,500 can be seen at once. That is far from countless!

But with a simple opera glass at least 100,000 can be seen, while our large telescopes show probably more than 100 million; and photographs reveal even more. There is certainly an enormous number of stars, but not an infinite number, that is, a number which cannot be calculated.

About 75 years ago a German astronomer made charts of all the stars north of the celestial equator which he could see with a telescope 2½ inches in diameter. (80) There were 324,198 in all. In this slide is shown a portion of one of his charts. It covers an area 8 degrees square and includes 1,442 stars. You see two little squares to the left. They show the stars which can be seen in the same area with the naked eye—in the upper one, those which you can see on a clear moonless night if you are out in the country, 24 stars; in the lower one, those seen in the country if the moon is full, or in the city with its bright lights, 8 stars.

The stars in this slide are those in the belt of Orion and the area just north of it. The three stars in the belt are at the bottom. It is interesting to pick out those in the big chart which can be seen with the unaided eye.

In some parts of the sky the stars are much more numerous than in others. This is especially the case in the Milky Way, the faint band across the sky which has been referred to already and which is familiar to all. (81)

In this picture is shown a portion of the Milky Way in the southern hemisphere. On the original negative 400,000 stars were recorded. (82) Here is another portion of the Milky Way. The stars at the centre seem packed so close that they form a white cloud. Note the two bright streaks, one at the top and the other at the bottom. They were produced by two shooting stars which happened to come along while the astronomer was taking his long-exposure photograph.

Some of the Constellations; the Nebulae

We have already learned how to pick out the constellations. Let us look at a few of them more closely. (83) One of the best known is Ursa Major (the Great Bear). In this slide we have the stars visible to the naked eye and also the animal as the ancient astronomers pictured it up in the sky. Anyone who can see the form of a bear in these stars must have a great imagination.

You notice that the Big Dipper is only a small part of the constellation, the handle of the Dipper being the tail of the Bear. It would seem that long ago bears had long tails. (84)

In the case of Orion the great giant seems to fit in among the stars somewhat better. You see the three bright stars in his belt from which hangs his sword. There are many fine stars in this constellation. The brightest is Rigel which is in the giant's left foot; and Betelgeuse, which is orange-red in colour, is in his right shoulder.

In recent years the astronomers have succeeded in measuring the diameter of this star and the world has been astonished at the result. The diameter is 240 million miles! If the sun and earth were carried off and set down with the sun at the centre of Betelgeuse, the earth would be 30 million miles within the outer surface of the star!

The white star in Orion's left shoulder is Bellatrix and three stars are in his left jaw; while some ten stars in a curve trace out the lion's mane which he holds as a shield on his left arm.

Note the circle on the sword. This shows the position of a remarkable object. (85) With the naked eye it looks like a star, in a field glass it looks like a hazy spot, but in a large telescope or a good photograph it is simply wonderful. Here is a picture of it.

It is called the Great Nebula in Orion. 'Nebula' is the Latin word for cloud. This nebula has no regular shape but spreads out in all directions in great curved sheets and irregular masses. What is it made of? There is much hydrogen gas in it as well as gas of a sort we do not know on earth. (86)

You remember Orion had a big club in his right hand. He has it drawn up ready to drive back the great Bull which threatens to charge him. Notice the large star just at the Bull's right eye; that is Aldebaran. Also on the Bull's neck is a little group of six stars. It bears the name of the Pleiades. These stars have been famous in many nations for thousands of years. (87)

And here is poor Andromeda chained to the rocks. The bright star near her left ear is Alpheratz, that one at the left side of her girdle is Mirach while Almach is at the edge of her skirt. Ten degrees above Mirach, near the right side of her girdle, there is a little circle. This shows the position of another of those strange nebulae. (88) We see it in the next photograph.

This is the Great Nebula in Andromeda and it is the only one which can be recognized as a nebula by the naked eye. It is well placed for observation in the summer in the east and in the autumn almost overhead. In an opera glass it looks like an oval patch of bright cloud but its beauty and magnificence is revealed only by photography. This is a fine picture of it.

If you examine it closely you will see a bright central nucleus from which lead two arms—one from above, one from below. These wind about it and about each other.

Is this nebula also composed of gas? Probably not. It is believed to be made up of a multitude of stars and that it is perhaps as large as our Milky Way but so far away that it looks like a little cloud in the sky.

Just next to Andromeda is a little constellation named The Triangle, which contains another famous nebula. (89) It is shown in this slide. It is a lovely spiral. Here you can see the central nucleus and the two arms running out from opposite sides of it. It looks much like a pin-wheel spinning round and throwing off sparks. Surely this nebula must be rotating; and how long will it require to turn round completely? About 160,000 years! (90)

Here is another fine spiral nebula. It is in the constellation Hunting Hounds and is not far from the end of the handle of the Big Dipper. As before, there are two arms starting out from the great central nucleus and winding themselves about it.

This nebula cannot be seen with the naked eye and even in a good telescope its form cannot well be made out. But what a beautiful object this photograph shows it to be! This one also has been examined for motion and its period of rotation is given as 45,000 years. It is moving in the direction to wind up the arms —the top is moving to the right as we see it in the picture.

These last two spirals are seen full in the face. The nebula in Andromeda is seen with face turned somewhat away from us, but the next photograph (91) shows a spiral with edge turned toward us. In this position it looks quite thin. The bright nucleus is nearly spherical and the dark streak down the middle is the very edge of the nebula.

There are thousands of these spiral nebulae in the sky and one is led to wonder how they were made and what they will become. (92)

There is another style of nebula found in Lyra (the Harp). A small telescope shows its shape very well but a photograph reveals it much better. It is shaped like a ring. Other ring nebulae have been found but none as fine as this one.

There are many other strange nebulae but we shall look at only one more. (93) It is named the Network nebula and is found in Cygnus (the Swan). It looks like filmy lace blown about by the wind, but you must remember that far away where this nebula is there are no air currents such as we have on the earth.

The Distance of the Stars

Up to the present we have said nothing about the distances of the stars and nebulae. To measure these distances is about the hardest task the astronomer has to do. It requires the utmost skill and care—all because the stars are so far away.

We say that the sun is 93 million miles from the earth but that means little to the ordinary person; and when we learn that the nearest of the stars is 275,000 times as far away as the sun, we are simply lost in the figures. They have no meaning to us. Let us try another method.

The speed with which light travels is very great but it has been measured very accurately. It is about 186,330 miles per second, or 11 million miles per minute. We think sound travels quickly, but it would take 36 hours to go around the earth. Light however, can encircle the earth seven times in a single second. For it to go from the sun to the earth requires 8 1/3 minutes; to Neptune, the farthest planet, 4 hours. How long to the nearest star? Not a day, or a month, or a year, but 4 1/3 years! The distance is said to be 4 1/3 light-years.

You have all seen the fine web spun by the spider. It is extremely slender and light. It has been found that a pound of it would be long enough to encircle the earth completely and 10 lbs. of it would reach to the moon. How much do you think would be needed to reach to the nearest of the stars? It would require 500,000 tons! To ship it would demand a train of cars 150 miles long drawn by 500 powerful locomotives. And that is the distance to the nearest star!

Sirius, the brightest of all the stars, is over 8 light-years away, Vega is 26, while the Pole Star is 466. And there are many beyond that.

You see then that the sun and its system occupies a very small portion of space, while in all directions, at inconceivable distances, are the stars and nebulae. It is a grand universe—magnificent, stupendous!

Dark Holes and Markings in the Milky Way

There are other wonderful things yet to see. (94) Here is a portion of the Milky Way. Toward the left of the centre you see a dark area. There are stars at the edge, but none in the middle. Look also at the dark spot close to the right edge of the photograph and at the strange snake-shaped figures. The stars seem to be absent from these dark spaces and of course we should like to know why.

Two explanations have been given. It may be that these dark spaces are actual openings through the star clouds of the Milky Way and that there are no stars in those parts of space at all; but few astronomers accept that view. They think it more probable that there is some kind of matter—dust or fine dark matter of some sort—far out in the depths of space which is between us and those parts of the Milky Way and prevents us from seeing them. (95) Here is another photograph of the same sort—a perfectly black hole in the midst of a very thick cloud of stars. The two or three stars which are seen out in the dark area are probably separate stars which are nearer to us than the dark matter which is in front of the star cloud. (96).

Here is another photograph of the same sort. Just south of the farthest left star in the belt of Orion is the remarkable object shown in this picture. It is known as the Dark Day Nebula. This great dark mass hides any stars which may be behind it, and the edge of it is faintly illuminated by the stars in the neighbourhood.

(97) We have already referred to the little group of stars called the Pleiades, on the neck of Taurus (the Bull). This is a photograph of it. With the naked eye 6 stars can be easily seen while better eyes can see 8. Indeed very sharp eyes have seen 11. But a photograph shows about 1,000. (98)

On giving a very long exposure the photograph brings out something else. It shows that these stars are simply buried in nebulous matter and indeed that all the space near them is full of it.

There are so many things in the sky which we cannot see—probably more than we actually can see! (99)

Here is a cluster of stars not quite so open as the last. This is Praesepe (the Bee-hive) and its position in Cancer (the Crab) is shown on our star maps. You can recognize it with the naked eye but you cannot pick out the separate stars. (100)

But the finest clusters are those in which the stars seem packed together into a globular form and the most perfect one in the northern hemisphere is shown in this picture. It is found on the side of the 'flower-pot' in the constellation Hercules and was pointed out when we were speaking of the summer stars. This photograph was taken at the great observatory at Victoria, B.C., and the exposure was one hour.

At the centre the stars are close together but yet you can detect the individual ones. Farther out many fainter ones are seen and if a longer exposure is given, still more of these come into view.

How many stars do you think there are in this globular cluster? An attempt has been made to count them, and we are told that there are upwards of fifty thousand; and although in this picture they look close together, actually they are at least a million (perhaps a million million) miles apart. Remember, also, that each is a sun like our own, perhaps with planets revolving about it. Can you think of a more wonderful object?

What are the Stars made of?

Finally, consider for a moment what is in the stars. Though they are at enormous distances they are continually sending forth messages which are carried by means of their light waves, and with the assistance of the spectroscope the astronomer can interpret what they say.

We learn that these millions of suns, scattered throughout space in all directions, are composed of iron, hydrogen, sodium, carbon and other substances which are known on the earth. All the heavenly bodies are built up from the same materials. There is a wonderful unity, or oneness, in the entire universe and the thought comes to us that it is constructed according to a definite, intelligent plan, and we feel there is an Infinite Mind behind it and controlling it.

When with the mind's eye we look out upon the planets revolving about the sun, and the satellites revolving about the planets, each following its appointed path and at the same time rotating on its axis; and then, looking farther away, behold the hosts of the stars and the nebulae, almost infinite in number, in distance and size, but all made of the very same substances that we are familiar with on the earth; we surely can agree with the Psalmist when he exclaims:—"The Heavens declare the Glory of God and the firmament showeth His handiwork".

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