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Wonders of the Universe

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WONDERS OF THE UNIVERSE

A SIMPLE ACCOUNT OF THE
ELEMENTS OF ASTRONOMY

BY

H. E. TAYLOR, F.G.S.

AUTHOR OF "WONDERS OF THE EARTH'S CRUST"



LONDON

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PREFACE

IN a recent broadcast talk, Mr. H. G. Wells suggested that all young people should be taught something about geology and astronomy in order to give them some idea of their place in time and space.

This book and *Wonders of the Earth's Crust* have been written as attempts to produce this effect by broadening the lines on which nature study and science are taught in the schools. Simple astronomy may well form a portion of the work of senior pupils about to leave school.

In spite of the difficulty experienced by pupils in finding stars in the sky from diagrams in books, one chapter has been devoted to some of the more conspicuous constellations and stars. By using the diagrams on pages 164 to 167 in the way suggested, the child should have little trouble in locating the brighter stars and constellations, and so cease to see just a confused mass of bright specks.

Experiments and exercises are included in the text to assist in making clear some of the more difficult points and to give some idea of methods of observation which may be used by those who have no elaborate apparatus. Many diagrams are also included. Wherever possible, these should be translated into simple experiments, for diagrams, however clear to the adult, are often imperfectly understood by younger people and are therefore soon forgotten.

Some paragraphs have been included because of their bearing upon other subjects, such as physics and geography. They form a useful means of revising previous work by presenting it from a slightly different point of view.

London school pupils are advised to visit the astronomy section of the Science Museum, at South Kensington, where many beautiful photographs, interesting models, and examples of astronomical instruments can be seen.

The author wishes to thank the many people who have assisted him by allowing photographs to be reproduced, or by giving valuable advice and criticism: especially the Astronomer Royal, Greenwich Observatory; the Royal Astronomical Society; the following observatories and museums: Mt. Wilson Observatory, Pasadena, California; Observatory of Michigan; The Lowell Observatory, Flagstaff, Arizona; The Norman Lockyer Observatory, Sidmouth, Devon; Radcliffe Observatory, Oxford; Dominion of Canada Astrophysical Observatory; Natural History Museum, London; Dr. Max Wolf, of Heidelberg; Dr. J. Klepestra, of Prague, Czechoslovakia; Mr. H. J. Shepstone, Mr. G. F. Morrell, Mr. H. J. Burtt, and others whose photographs are acknowledged in the body of the book.

H. E. TAYLOR.

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MANY of the wonderful and beautiful pictures in this book are reproductions of photographs taken by famous astronomers. They have been taken through the best and biggest of telescopes, in some of the most important observatories of the world.

Many people are very disappointed when they look through ordinary telescopes and fail to see the wonderful sights shown in photographs such as these. The reader should realize that such results can only be obtained with the best of instruments, and as the result of much careful work by skilful operators. He should, however, take every opportunity to examine celestial bodies through small telescopes, or even through field glasses, for many interesting things can be seen with very small optical aid, and much useful astronomical work has been done by amateurs with quite small instruments.

Men of science are anxious to spread knowledge of their science. It is due to this fact that this book is so well illustrated. We should all be pleased that astronomers of various countries have been very willing to allow their best photographs to be reproduced here.

One could wish that the same spirit of friendliness, helpfulness, and co-operation which exists among men of science would rapidly spread to those engaged in other spheres of life.

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WONDERS OF THE UNIVERSE

CHAPTER I

Introduction

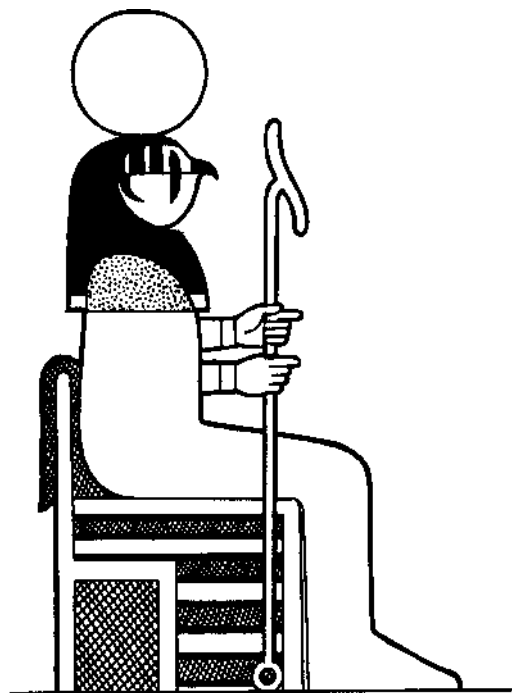
Twinkle, twinkle, little star,
How I wonder what you are !
Up above the world so high,
Like a diamond in the sky.

You have probably wondered what to make of the sights seen in the sky on bright, starry, or moonlight nights. You have probably often heard the above verse recited, and have often lain in bed watching the stars, or gazing at the moon as it seemed to sail majestically among the clouds. It is certain that you have often scanned the heavens to search for the sun on cloudy days, and watched and admired the wonderful colours of the clouds as the sun sets. The glories of the sky have attracted the attention of all people—ancient and modern, old and young.

Sun Worship. Primitive man watched the heavenly bodies closely and recognized the sun as the giver of light and warmth. In many widely separated countries the sun has been worshipped as the supreme giver of life. The Egyptians looked upon Ra—the sun god—as the chief of their many gods, and built many temples in his honour. In ancient Egypt there was a town called by the Greeks Heliopolis (helio—sun; polis—city), which was supposed to be the home of the sun-god. Ruins of temples used for sun worship have been found in Syria, Persia,

Rome, and Peru; and many people believe that Stonehenge, on Salisbury Plain, was used by prehistoric man as a temple of the sun-god.

We do not now worship the sun as a god, but we



Ra

FIG. I. ONE FORM OF THE SUN GOD OF THE EGYPTIANS

do recognize it as the source of all our heat, light, energy, health, and even as the source of life. Sun-bathing has become a fashionable habit in the summer months, and many people go abroad in winter in order to follow the sun as it "journeys south." Such phrases

as *A place in the sun* and *Follow the sun for health* show what great value we still attach to its rays.



FIG. 2. A COMET PANIC IN OLDEN TIMES

The moon and the planets were also worshipped by the Egyptians, who had two moon-gods; and from the times of the Chaldeans astrologers have thought that the

planets have some influence upon the lives and actions of men. Those born under the influence of Jupiter were to be endowed with glory. If Mars was their planet they might be warlike and gain military honours. Mercury gave success in arts, and Venus was the goddess of love.

Times of eclipse of the sun and moon have been times of terror, and the appearances of comets in the sky were considered for ages to be signs of coming disaster to nations and kings, or warnings of pestilence, famine, war, or other national calamity.

Heavenly Bodies and Time.

Primitive man needed some means of measuring time. Observations of the sun and stars enabled him to judge the

TIMES OF THE DAY operations, and we thus have such phrases as *seed time* and *harvest*. The day has been divided into periods such as *sunrise*, *noon*, and *sunset*. The American Indians often reckoned time by the moon. They spoke of an event as happening "*so many moons ago*," and of a person as "having seen so many moons." It is evident that they had noticed the regular reappearance of the moon. We ourselves use the month (moon-th) as a division of time, and obtain our correct time from observations of the apparent movements of the sun, moon, and stars.

Time by Shadows. On a sunny morning erect a pole in the garden and mark the position and length of its shadow every hour. Notice that the shadow moves as the hours go by. It becomes shorter and shorter until noon, after which it grows longer and longer until sunset. The following **day you will** observe that the shadow falls in the same places at **the** same times. Shadows may therefore be **used**

to tell the time and, as we shall see later, to give other information. The natives of Borneo still sow rice by the length of the shadow cast by a stick of a definite length.

On the Thames Embankment there stands a large stone obelisk known as Cleopatra's Needle, which was brought from Egypt, after an adventurous voyage, and erected in its present position. It was originally set up in Heliopolis in honour of a king and of the sun-god. It seems probable that such obelisks, besides being used as monuments, were also used by the priests to make astronomical observations, and to measure time in some such way as we might use the pole in the garden.

Fixed in the walls of old churches and houses, or placed on ornamental pedestals in large gardens, we often see sundials. In

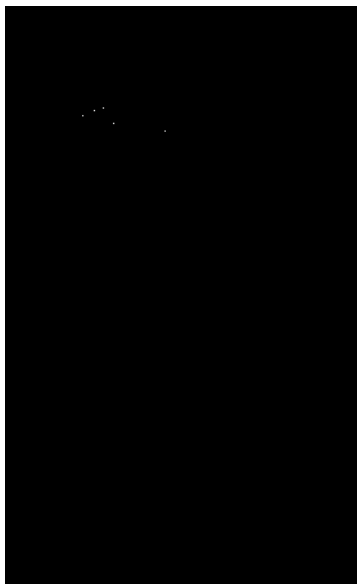
the days before the invention of clocks and watches they were used for telling the time by shadows. The portion of a sundial which throws the shadow is known as the *gnomon*. The gnomon is not fixed in a vertical position like Cleopatra's Needle or our pole in the garden, but it is inclined to the horizontal at an angle equal to the



H.E.T.

FIG. 4. CLEOPATRA'S NEEDLE
ON THE WESTMINSTER
EMBANKMENT, LONDON

latitude of the place where it is to be used. This angle for London is $51\frac{1}{4}^{\circ}$. Such sundials were very commonly used in sunnier lands, but in climates such as ours they



By courtesy of J. Carter & Sons

FIG. 5. A SUNDIAL

are not very convenient instruments, for the sun is often obscured by clouds, and so no shadows are thrown.

A Flat Earth or a Globe. We have all learnt that the earth is a globe, but early man thought that it was, as it appeared to be, a flat surface broken by hills and vales and surrounded by a boundless ocean. A Hindoo legend speaks of the earth as being supported by four white elephants standing on the back of a tortoise which was swimming in a sea of milk. Another strange idea was that

in the evening the sun sank down into the sea where its fire was quenched, and that the gods were busy all night making a new sun to be placed in the east in the morning. What a waste of good suns!

Some people thought that as the sun was about to sink into the ocean a god took it through the underworld in a barge during the night to the east, where it was used again the next day.

Others, who saw the sun set behind mountains, were of the opinion that during the night it passed behind long ranges to the north of them and reappeared the next morning in the east.

The great Greek philosopher, Aristotle (384-322 B.C.), believed that the earth was a globe suspended in space at the centre of the universe, and that the sun, moon, and stars revolved round it. Until the time of Columbus, most people in Europe continued to believe in a flat earth. They thought that if they ventured far out into the unknown seas they might fall over the edge. Columbus, however, had learnt sufficient astronomy to know that astronomers said the earth was a globe. He therefore thought that by sailing west from Europe it would be possible to reach the rich lands of the east, the old route to which had recently been closed by the Turks. It was this idea which made him set out across the Atlantic and led to his discovery of the continent of America.

Evidence for a Round Earth. As there are still just a few people who try to argue that the earth is flat, it may be well to mention some of the evidence for its being round.

I. Aristotle stated that when the moon is eclipsed by the earth's shadow, the line marking off the dark portion from the light portion is always an arc of a circle. As people in all parts of the world see eclipses of the moon,

and as the shadow of the earth is always circular, it seems likely that the earth is round.

2. Although Columbus did not reach the east by sailing west in 1492, yet Magellan did this in 1520. Now we may buy a ticket to travel round the earth by many routes.

3. If the earth were flat the sun would appear to rise and set at the same time in all parts of the world. Of course you know it does not do so.

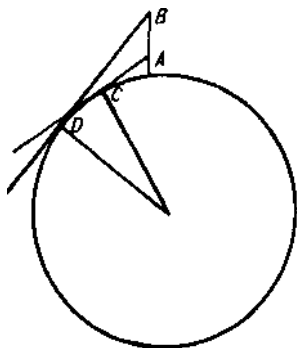


FIG. 6

The horizon for an observer at A is C, but if he mounts to B the horizon is extended to D

4. It is common knowledge that the horizon is nearer to us when we are on the seashore than when we are on top of a high cliff. A study of Fig. 6 shows that this should be so if the earth is round. Sailors on the look-out mount to the crow's-nest at the top of the mast in order to see farther in all directions.

5. As an argument for the spherical shape of the earth Aristotle stated that certain stars were seen above the horizon in Egypt but were not visible farther north.

Tennyson, in *The Voyage*, says—

New stars all night above the brim
Of waters lighten'd into view;
They climbed as quickly, for the rim
Changed every moment as we flew.

We now find the latitude of a place by noticing the altitude (height) of the Pole Star. At the equator it is on the horizon; at the North Pole it is overhead or in the *zenith*] at London (latitude $51\frac{1}{2}^{\circ}$) its altitude is $51\frac{1}{2}^{\circ}$.

Steamers approaching an island do not appear to an

observer on shore as a whole. The smoke is seen first, then the funnels and masts, and lastly the hulls. As this

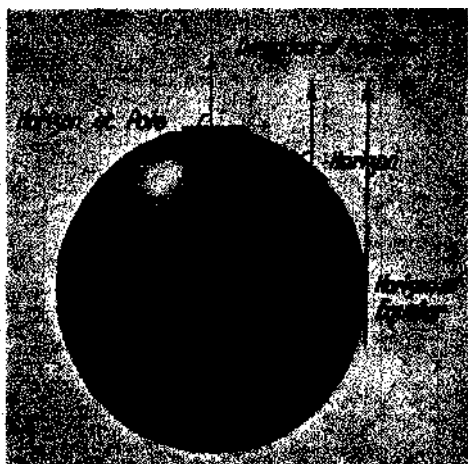


FIG. 7

Showing that the altitude of the Pole Star is 90° at the Pole and 0° at the equator; therefore the latitude is given by the altitude of the Pole Star

is the same from whatever direction they approach, the sea must be curved in all directions.

The ship was cheered, the harbour cleared,
Merrily did we drop
Below the kirk, below the hill,
Below the lighthouse top. Ancient Mariner.



FIG. 8. STEAMERS APPROACHING THE OBSERVER

Direction on a Sphere. The terms *north*, *south*, *east*, and *west* are names of direction, and not of any particular

places. If the earth were flat we could travel to the east or west ends of it, but, as it is a globe, no matter how far we travel we may always go farther in the same direction. In fact we may go on travelling to the east or west for

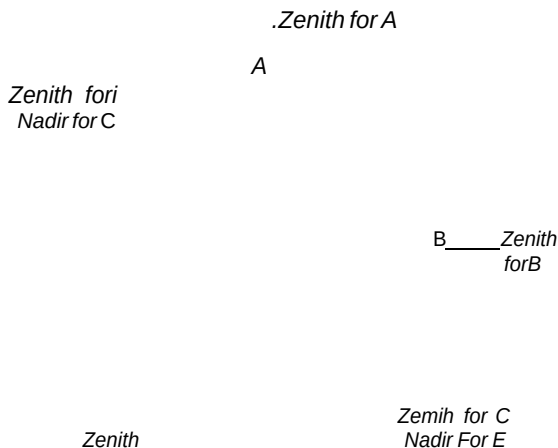


FIG. 9. SHOWING HOW THE ZENITH ALTERS WITH THE POSITION OF THE OBSERVER

The zenith for C is the nadir for E

ever, and never arrive there. With north and south it is a little different. If we go far enough north we reach the North Pole. This, of course, is not the same as reaching the *north*, for if we still proceed in the same direction we should be approaching the equator or the South Pole.

If you could imagine that you lived at the North Pole in a square house with a door in each side of it, then, by whichever door you left the house you would be bound to travel *south* (i.e. towards the equator). Similarly, from the South Pole there is only one possible direction in which you may travel—north. If you find difficulty in seeing this, try it with a globe.

These peculiar results are the effect of taking directions which really refer to a plane (or flat) surface and trying to make them refer to a spherical surface. The position of a place on the earth may be fixed by naming its latitude and longitude, but not by the use of the words north, south, east, and west alone.

The Celestial Sphere—"That Inverted Bowl We Call the Sky." When we look up at the sky on a clear evening we appear to be in the centre of a great hemisphere bounded by the horizon. This hemisphere is half of a whole one known in astronomy as the celestial sphere.

To describe the position of a star on this sphere we need other words than north, south, east, and west. The point immediately over your head is known as the zenith. This is not a fixed point, but moves with the observer. Thus a balloon ascending towards the zenith from points *A*, *B*, *C*, *D*, or *E* on the earth, will ascend in the directions shown by the arrows in Fig. 9. The position of a star may be fixed by: (1) the *altitude*—i.e. the distance above the horizon, measured in degrees along the line from the zenith through the star and continued to meet the horizon (see Fig. 10); (2) the azimuth, or number of degrees from the north to the foot of the line from zenith and star to the horizon (see Fig. 10).

The more usual way of fixing the position of a star is by reference to the celestial pole and the celestial equator. The celestial pole is a point in the heavens marked approximately by the North Star, which is above the north pole of the earth. The celestial equator may be considered as an extension of the earth's equator to meet the celestial sphere.

The height of the star above the celestial equator is known as the *declination* of the star. Declination is similar

to latitude on the surface of the globe. Instead of longitude we use *right ascension*. On the globe we commence counting longitude from a particular meridian which passes through Greenwich. On the celestial sphere we

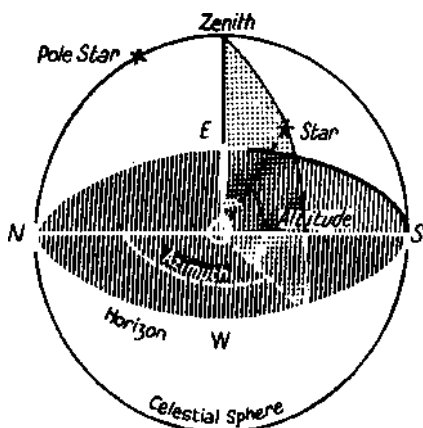


FIG. 10. SHOWING ALTITUDE AND AZIMUTH OF A STAR

The observer is at *O*. Altitude = the angle from the horizon. Azimuth — the angle from *N* to foot of line from zenith through the star to the horizon

need a similar starting place. This is fixed as the "first point in Aries," i.e. a particular star in the group or constellation of stars known as "Aries"

Just as we say a place is so many degrees east or west of Greenwich, so we say a star is so many hours, minutes, and seconds east or west of the first point in Aries. As the earth spins round, the first point of Aries will arrive on the meridian, i.e. due south at some particular time. Other stars may be on the meridian at the same time, or they may have passed it some time before, or they may not reach it for some time. The number of hours that a star is in front of

The diagram illustrates the celestial sphere with the following components:

- Zenith:** The point directly above the observer.
- Celestial pole:** The point where the Earth's axis of rotation extends into space.
- Star:** A point on the celestial sphere.
- Declination:** The angular distance of the star from the celestial equator, shown as the angle between the line from the center to the star and the line from the center to the celestial equator.
- Path of Star:** The trajectory of the star across the sky, shown as a dashed line.
- Celestial Equator:** The great circle that divides the celestial sphere into northern and southern hemispheres.
- Horizon:** The line that separates the visible sky from the Earth's surface.
- Celestial Sphere:** The model used to represent the positions of objects in the sky.
- Points N, S, E, F:** Markers on the celestial sphere. N and S are on the celestial equator, while E and F are on the horizon.

FIG. 12. DECLINATION AND RIGHT ASCENSION OF A STAR
Declination = Angle Star OC = distance above celestial equator
Right Ascension = Angle FOC shaded black
 F = First point of Aries

or behind the first point of Aries is the right ascension of that star.

It might be well to point out that the altitude of a star alters with the movement of the earth during the evening but the declination does not. Similarly, the azimuth alters, but the right ascension does not.

Historical Ideas. The Hindoos, the Chinese, and the Chaldeans acquired a considerable amount of astronomical knowledge as long ago as 2000 or 3000 B.C.; but it was the Greeks who gathered up the observed facts and made the first real attempt to make astronomy a science. *Pythagoras* (572-497 B.C.) was probably the first to suggest that the earth was a globe. *Aristotle* (384-322 B.C.), although he agreed with Pythagoras about the shape of the world, still believed that the sun, moon, and stars revolved round the earth, which was situated at the centre of the universe. One famous Greek astronomer, *Aristarchus* (310-230 B.C.), put forward the suggestion that the sun and stars were still, and that the earth revolved round the sun in a great circle. His idea, however, was not accepted by most of the Greeks. They preferred the *Geocentric* (earth at the centre) idea to the *heliocentric* (sun at the centre) one, and worked out elaborate schemes to explain the motions of the sun, moon, and planets. One of the most generally accepted was that of Ptolemy. It was recognized as the best scheme until the time of *COPERNICUS* (A.D. 1473-1543), who revived the heliocentric idea of Aristarchus. Ptolemy (A.D. 120), like Aristotle, believed that the earth was a sphere, and that the sun, moon, and planets revolved round it in perfect curves or circles. The stars he regarded as shining points fixed in a gigantic sphere which also revolved round the earth as a centre. He soon found out, however, that the observed movements of the planets in the heavens could not be explained in this simple way.

To account for their seemingly irregular movements, he supposed that each planet revolved in a small circle, the

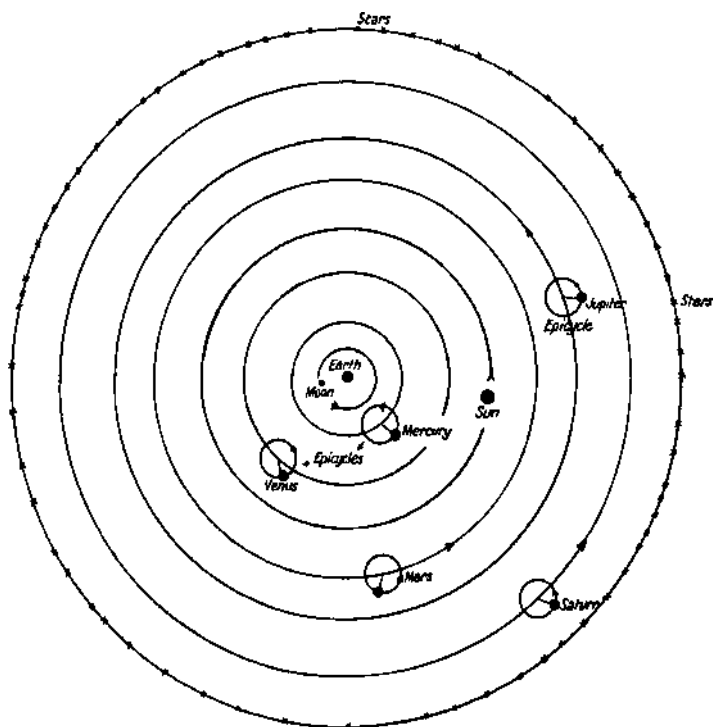


FIG. 13. THE PTOLEMAIC SYSTEM, WITH EPICYCLES FOR THE PLANETS

(Cf. Fig. 14)

Note this is not drawn to scale

centre of which moved round the original large circle. These small circles were known as epicycles. The sun and the moon did not need epicycles to explain their movements. A plan of the universe on the Ptolemaic idea is shown in Fig. 13. This system was complicated, and

predictions made by using it usually showed considerable errors. In spite of that fact, the Ptolemaic explanation, with slight changes, remained the accepted one throughout the dark ages.

The Solar System. We now believe in the Copernican idea that the sun is at the centre and that the planets and the earth—which is a planet—revolve round it. Copernicus thought that the planets moved in circles, but it has since been shown that they move in elliptical orbits (paths) which are nearly circles but not quite. Although we have banished the idea of epicycles, we may still think of the moon as moving in an epicycle, for that body revolves round the earth and at the same time travels with it round the sun in a larger orbit. Figure 14 shows a plan of the solar system as we now believe it to be constituted. The sun is regarded as the parent of a large family of planets which revolve round it, accompanied in many cases by satellites (attendants) sometimes known as moons. Besides the planets and their satellites there is a large number of smaller bodies known as asteroids, which revolve round the sun in orbits situated between the orbits of Mars and Jupiter. Some, if not all, of the comets also revolve round the sun in orbits which are very elliptical.

If we tried to make a model of the solar system to scale we should have great difficulty, because of the immense distances in space as compared with the sizes of the planets. If we suppose the sun to be reduced to the size of a ball or globe 9 ft. in diameter then the planets would need to be represented in size and distance according to the table below. If you can imagine a model of the solar system made on this scale you will understand that there must be immense distances between each of the planets, and between the sun and even its nearest planet. In the

following chapters we shall consider each of the members of the solar system in more detail.

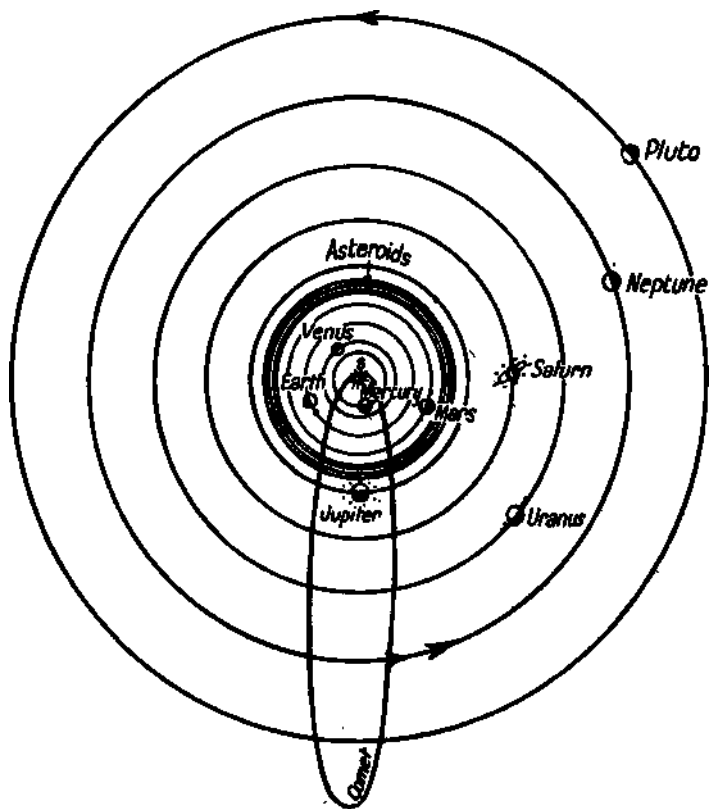


FIG. 14. THE SOLAR SYSTEM
Not drawn to scale

EXERCISES

1. Make a list of the sources of heat. Try to see how they can be connected with the sun as the source of all our heat.
2. Erect a stick in the garden and at hourly intervals **mark the position of the shadow cast by it. Examine this daily and**

PLANET	SIZE	DISTANCE
Mercury	A large pea	127 yd. from the sun.
Venus	A ball of 1 in. diameter	235 yd. from the sun
Earth	A ball of 1 in. diameter	325 yd. from the sun
Mars	A marble $\frac{1}{2}$ in. in diameter	495 yd. from the sun
Asteroids	A number of specks	Between Mars and Jupiter
Jupiter	A 11 in. globe	1 mile or 1,760 yd. from the sun
Saturn	A 9 in. globe	1 $\frac{3}{4}$ miles or 2,080 yd. from the sun
Uranus	A 4 in. globe	3 $\frac{1}{2}$ miles or 6,160 yd. from the sun
Neptune	A 5 in. globe	5 $\frac{1}{2}$ miles or 9,680 yd. from the sun
Pluto	A marble $\frac{1}{2}$ in. in diameter	7 miles from the sun

On the same scale our moon would be represented by a small pea 30 in. from the earth.

tell the time by it. Check by means of a reliable clock. What do you notice after some weeks?

3. Construct a sundial with the gnomon placed at the correct angle. Mark the shadows at hourly intervals and label each position. Put a new set of figures so that you may tell the time during the summer months.

4. If the time by a sundial is seen to be 12 noon on a day in August, what is the time by your watch, which gives British summer time?

5. Write out the arguments you would use to show that the earth is round and not flat.

6. Examine a globe with poles and lines of latitude and longitude marked upon it. Try to move your finger from the North Pole in any direction but south.

7. Take a large piece of drawing paper and try to draw the orbits of the planets to scale of 100 yd. = $\frac{1}{10}$ in. Use the figures given in the table on page 18. Insert planets with their moons, but do not attempt to draw them to scale.

8. Lay your face on a globe and look with one eye across Europe. Persuade a friend to move a toy soldier slowly towards you, starting from Eastern Asia. Notice how the

soldier gradually comes into view above the curvature of the globe.

9. While your face is on the globe, notice how much of its surface you can see. Very gradually raise your head, an inch or two at the time, and notice that your view becomes more extensive.

10. From this formula calculate the distance of the horizon from a boat 4 ft. above sea-level, and from a tower 36 ft. above sea-level. (Formula:— $\sqrt{\text{height in feet}} \times \frac{1}{5} = \text{distance in miles to horizon.}$)

II. Find true north by means of a stick and shadows. Mark the shadow thrown by an erect stick at 10 a.m., 11 a.m., 12 noon, 1 p.m., and 2 p.m. Bisect the angle between the 10 a.m. and 2 p.m. shadows. This will give true north. Find out, from this, the difference between true north and magnetic north as given by a compass needle.

12.

Oh ! dream of joy ! is this indeed
The lighthouse top I see ?
Is this the hill ? Is this the kirk ?
Is this mine own countree ?

Ancient Mariner.

Make a rough sketch showing the arrangement of church, hill, and lighthouse. Compare with the previous quotation from the same poem.

CHAPTER II

The Sun and Us

Distance of the Sun. From the plan of the solar system already given, you may have gained some idea of the great distance between the sun and the earth. Astronomers

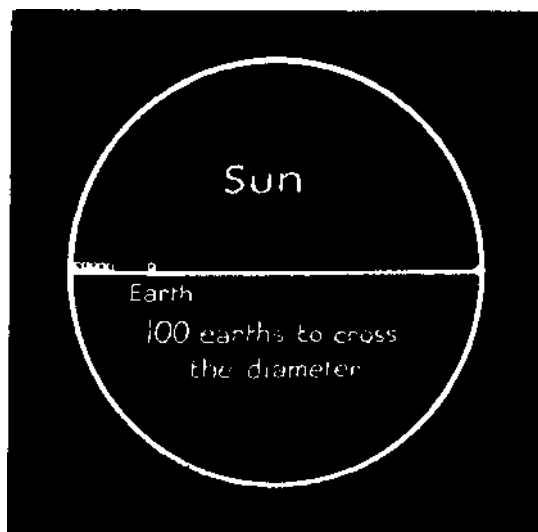


FIG. 15. SHOWING COMPARATIVE SIZES OF THE SUN AND THE EARTH

have taken great care in measuring this distance, because it forms the astronomical unit by which they measure other distances. Since we move round the sun in an elliptical orbit, and as the sun is not at the centre of it, but at one of its foci, it follows that sometimes we must be farther from the sun than at other times. The average distance is about 92,500,000 miles.

To gain some idea of this immense distance, suppose that you are travelling in an aeroplane at the rate of two miles a minute. If you keep on at this speed, day and

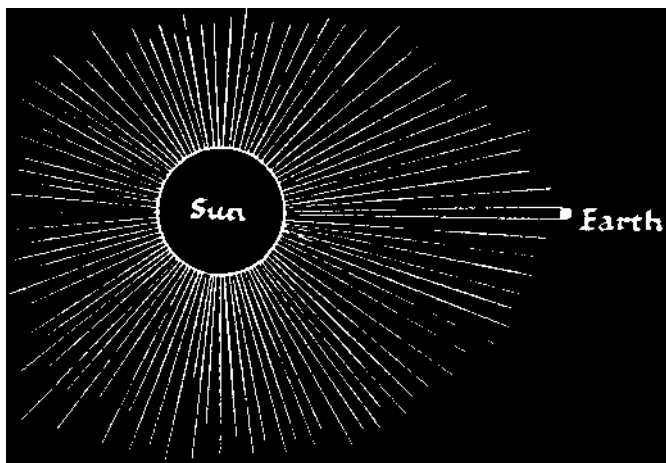


FIG. 16. A SKETCH TO SHOW THAT ONLY A VERY SMALL FRACTION OF THE RAYS GIVEN OFF BY THE SUN FALL UPON THE EARTH

Note the earth is drawn too big, c.f. Fig. 15

night, it would take you ninety years to travel from the earth to the sun.

The cross-wires in telescopes and microscopes are made of the finest spider's web. It has been calculated that 1 lb. of this web would stretch round the earth—25,000 miles. In order to make a line long enough to reach the sun we should require 1.8 *tons* of it! Since the sun is so far away from us, it naturally appears much smaller than it really is. It would take over 1,300,000 earths, all rolled into one, to make a body as big as the sun. One hundred earths placed in a line would only form a narrow belt

across the sun's disc. Examine Fig. 15, which may help you to gain some idea of the size of the sun compared with that of the earth.

Amount of Heat and Light Received from the Sun.

The sun is an extremely hot body which is continually giving out light and heat in all directions. On a summer's day we often find the full glare and heat of the sun to be very trying; yet we receive only a very small fraction of the light and heat given out by it. Most of it misses us altogether and goes on out into space. Look at Fig 16 and you will realize what a very small fraction we do receive. It is estimated that we receive only $\frac{1}{400,000,000}$ part of the heat radiated. The amount of heat received in different parts of the earth varies with the season and with the climate. In summer we are farther from the sun than we are in winter, and thus receive less heat. This seems strange, but you will understand it when you read about day and night, and the seasons.

Sunset and Sunrise. It is commonly stated that the sun rises *in* the east and sets in the west. Although this is very nearly true in tropical regions, yet here, in Britain, it is far from true. Careful observations made regularly once a week throughout the year will show that such a statement is not accurate. Only in March and September will the sun be found to rise even nearly in the east, or set in the west. From March to June it will rise, each week, a little farther north of east, and will set farther north of west until it may appear to rise in the north-east and set in the north-west. From June to September the sun's rising and setting will gradually return to east and west respectively, and then from September to December it will rise and set to the south of east and west until it may rise in the south-east and set in the south-west. From January to March the directions will again approach east and west.

Actually the sun only rises in the east and sets in the west on two days of the year—21st March and 22nd September—which are known as the equinoxes [*aequus*—equal; *nox*—night).

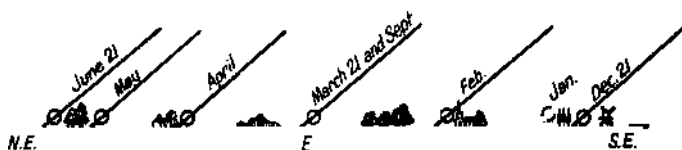


FIG. 17. THE SUN RISES AT DIFFERENT POINTS OF THE EASTERN HORIZON

DECIUS : "Here lies the east: cloth not the daybreak here ? "

CASCA : "NO."

CINNA : "Oh, pardon sir it doth; and yon grey lines
That fret the clouds are messengers of day."

CASCA : "You shall confess that you are both deceived.
Here, as I point my sword, the sun arises;
Which is a great way growing on the south,
Weighing the youthful season of the year.
Some two months hence up higher towards the north
He first presents his fire; and the high east
Stands, as the Capitol, directly here."

Julius Caesar.

Many mistakes in direction have been made through want of knowledge of these facts, although primitive man probably knew them. Certain stones of Stonehenge are placed in such a position that the sun, when viewed from the altar stone on 21st June, appears to rise over the top of one of the stones placed in the north-east, and on 21st December, over another in the south-east.

In our latitudes we never see the sun in the north; but in arctic regions, during the summer, the sun does not set at all, but travels right round the sky. In these regions the sun sets farther north each day until it gives daylight

its axis. As the earth spins round we see the sun from different positions.

Place yourself so that a bright light is situated on your left and then slowly rotate yourself in such a way that you follow your left hand. While turning, notice how the light appears to change its position until it appears on your right hand, and finally is behind you. This is just what happens daily with the earth and sun. When you stood with your left towards the light it was sunrise; when you faced the light it was noon; when the light was on your right it was sunset, and when behind you it was night.

Day and Night. We see then that it is the rotation of the earth on its axis that causes day and night. If the earth were spinning on an upright axis, the length of the days and nights would always be equal in all parts of the world. In summer we, in Britain, have long days and short nights, and in winter long nights and short days. This is due to the fact that the earth spins on an axis which is inclined to the plane of its orbit at an angle of $66\frac{1}{2}^{\circ}$.

Foucault's Pendulum. In the Science Museum at South Kensington, in London, there is a working model of the pendulum originally set up by Foucault in 1851 in the Pantheon in Paris, to show that the earth really does rotate. The pendulum is 79 ft. long, and is suspended from the roof of the Museum. When allowed to swing it travels backwards and forwards over a scale on the floor. After a time it seems to change its direction of swing across the scale. In an hour it moves through an angle of $11^{\circ} 45'$. This is because the floor has moved as the earth rotated.

Position of the Sun at Noonday. Another set of observations of the sun should be made at noonday and carried out at monthly intervals throughout the year. This may be done in two ways, and it may be well to try both.

1. At noon on each occasion notice how high above some

chimney pot the sun appears to be. Make a sketch of the house and draw the sun in its correct position above the

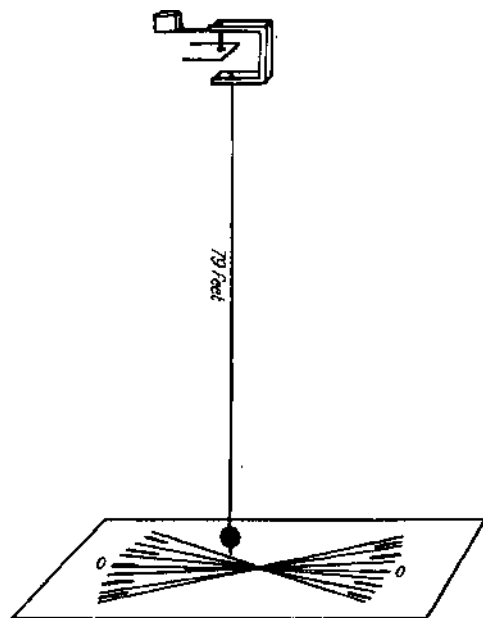


FIG. 19. FOUCAULT'S PENDULUM

The pendulum starts swinging along line *OO*, but gradually changes its course and swings along other lines

house each month (see Fig. 20). Take careful notice of the position from which you make your first observation and take all other observations from the same spot.

2, Erect an upright pole and fix it so that it cannot be moved. Mark and measure its shadow at noon each month. Make a drawing to scale of the pole and its shadow (Fig. 21).

From these two sets of observations you will see that the sun appears to move higher up in the heavens in the summer than it does in the winter.

In the tropics the sun appears overhead at certain times during the year, but it never does so in Britain.

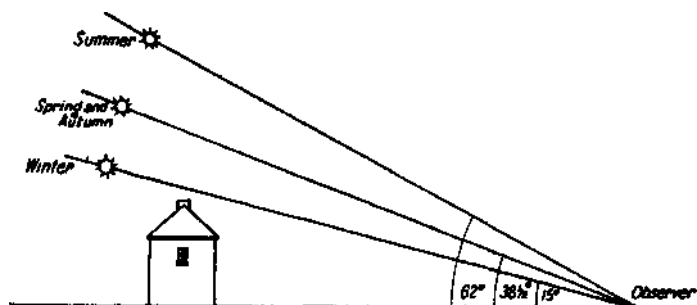


FIG. 20. SHOWING THAT THE HEIGHT OF THE SUN BECOMES GREATER AS SUMMER APPROACHES

Altitude given for London

This apparent motion of the sun through the heavens is due to the revolution of the earth round the sun, with its axis inclined at an angle of $66\frac{1}{4}^\circ$ to the orbit. From Fig.

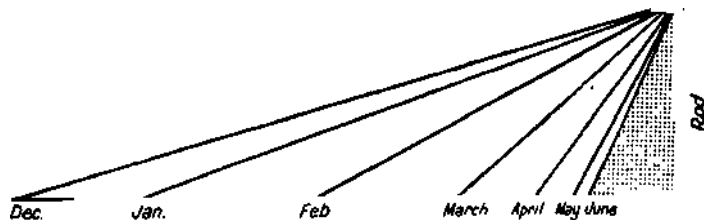


FIG. 21. THE SHADOW THROWN BY THE ROD GROWS SHORTER FROM DECEMBER TO JUNE

22 it will be seen: (1) that the arctic regions have no sunshine in winter, and no darkness in summer; (2) that places on the equator have the sun overhead in spring and autumn; and (3) that the sun is overhead at the Tropic of Cancer in June, and at the Tropic of Capricorn in December,

If we wished to keep the sun overhead at noonday throughout the year we should have to travel from the equator to the Tropic of Cancer, back to the equator and

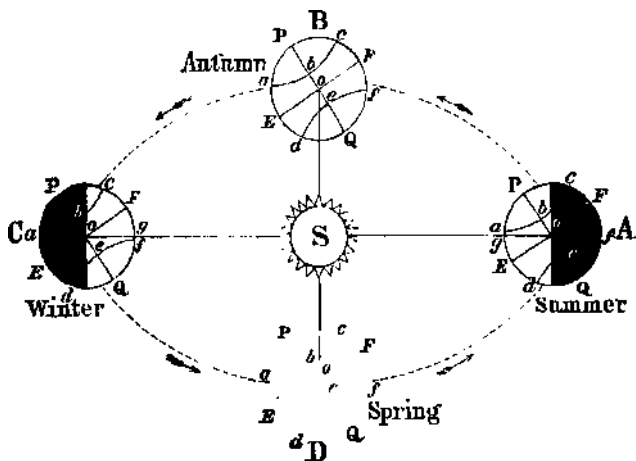


FIG. 22. THE SEASONS

Earth in position A, no darkness near P, no light near Q ; earth in positions B and D, equal days and nights; earth in position C, no light near P, no darkness near Q. EF = equator, abc = Tropic of Cancer, def = Tropic of Capricorn

on to the Tropic of Capricorn, and then back once more to the equator.

Make a model from a lamp and a ball marked with poles, equator, and tropics, and experiment with it until you find the diagram easy to understand.

The Seasons. We are now ready to see why it is that although the sun is farther away from us in June than in December, yet we have our summer in June and winter in December.

Already we have noticed that the sun is higher in the heavens in summer than it is in winter. When the sun's

rays fall perpendicularly upon the earth's surface they cover a smaller area than when they fall in a slanting

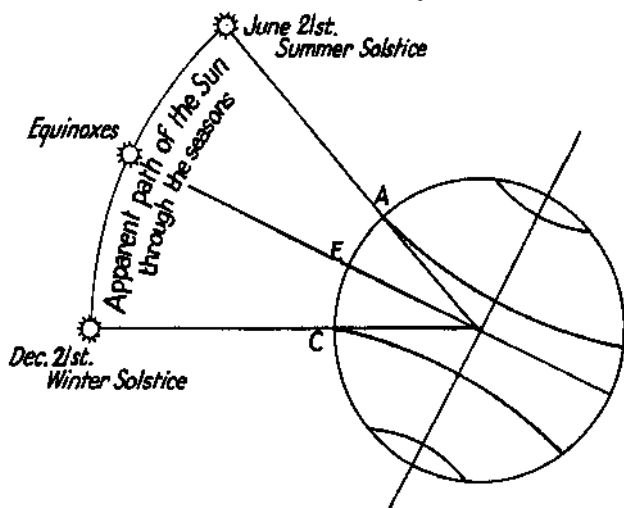


FIG. 23. SHOWING THE SUN IS IN THE ZENITH
At A in summer solstice; at E in equinoxes; at C in winter solstice

direction (see Fig. 24). As a consequence the smaller area will receive more heat.

We have also seen (Fig. 18) that the sun is above the horizon for a longer period in summer than in winter, and therefore it has more time to heat the earth upon which it shines. From Fig. 25 it will also be noticed that the slanting rays have to pass through more atmosphere than the vertical rays, and will therefore lose more



FIG. 24. SHOWING THAT EQUAL
NUMBERS OF RAYS FALLING
AT DIFFERENT ANGLES ARE
SPREAD OVER UNEQUAL AREAS

heat. These three things cause the summer to be hotter than the winter, although the sun is farther away.

Zones. The hot or Torrid Zones of the earth are those

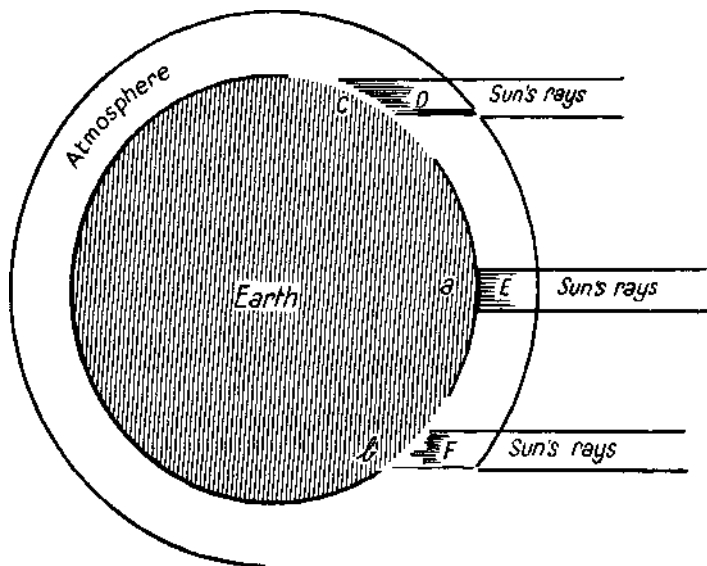
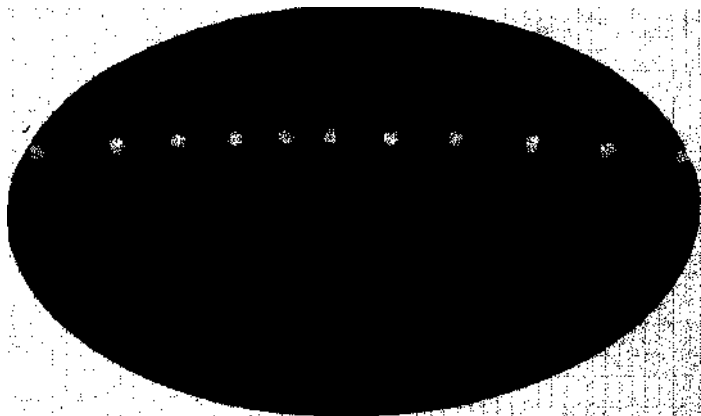


FIG. 25

Equal numbers of rays falling vertically at C and more obliquely at C than at B. Compare the amount of atmosphere passed through at D, E, and F, and also compare the amount of surface covered at A, B, and C

which have the sun in a vertical, or nearly vertical, position most of the year. They lie north and south of the equator between the tropics of Cancer and Capricorn. The sun is overhead at the equator in March and September (the equinoxes), at the tropic of Cancer in June, and at the tropic of Capricorn in December. 21st June and 21st December are known as the summer and winter solstices (standing still of the sun). The two Frigid Zones, of the Arctic and Antarctic, are regions where the sun is

never high in the sky, and where during some portion of the year it does not rise at all. These regions extend $23\frac{1}{2}^{\circ}$ from the poles. The Temperate Zones lie between the



By courtesy of

H. J. Shepstone

FIG. 26. AN UNUSUAL PHOTOGRAPH

It shows the position of the sun at intervals during the shortest day of the year at Walker's Peak, Alaska. The sun rose at 11 a.m. and set two hours later at 1 p.m. Note that the sun was never far above the horizon

Frigid and Torrid Zones. In summer the sun appears higher in the sky and remains above the horizon longer than it does in winter.

EXERCISES

1. Find direction by means of a watch. Point the hour hand of your watch in the direction of the sun. Bisect the angle between that hand and 12 o'clock. This gives roughly the north and south line, the south being mid-way between the sun and 12 o'clock. How would you modify this experiment when your watch shows British summer time?

2. Make a model earth marked with zones, axis, and equator, and use it to show: (1) that the arctic and antarctic have perpetual day in summer, and perpetual night in winter:

(2) that the North Temperate Zone has a long day in June while the South Temperate Zone has short winter days.

3. Fix a torch behind a cardboard screen which has a small hole punched in it. Allow the beam of light, which passes through the hole, to fall on a ball representing the earth. Notice that if the light falls vertically on the equator it illumines a smaller area than if it falls obliquely.

4. In what direction does the sun set in (a) March, (b) August, (c) December, and (d) October, in Britain?

5. Set up a stick and make observations of its shadow length each month. Take the readings at the same time of day (preferably noon) each time. Keep a record by making a drawing to scale.

6. Make observations of the altitude of the sun each month, taking observations at noon. Make a drawing to scale.

7. Make a series of sketches showing the apparent path of the sun across the sky in March, June, and December.

8. How would you arrange to travel in order to keep the sun overhead every day throughout the year?

9.

The sun came up upon the left,
Out of the sea came he!
And he shone bright, and on the right
Went down into the sea
Higher and higher every day,
Till over the mast at noon—

Ancient Mariner

In which direction was the ship sailing, and what part of the earth did the ship reach?

10. Read the poem *The Ancient Mariner*, by Coleridge, and notice the references to astronomy in it.

CHAPTER III

The Sun Itself and Sunlight

Some Figures. As the sun is such an important body, astronomers have spent a great amount of time in trying to find out all they can about it. We have already seen that its distance from the earth has been measured and found to be about 93,000,000 miles. This has been done in several different ways with great care and accuracy,



FIG. 27. TO FIND THE DIAMETER OF THE SUN
E = Eye. *C* = Coin, a sixpence

because astronomers need to know the diameter of the earth's orbit when measuring other astronomical distances.

The diameter of the sun's disc has been measured and found to be approximately 866,000 miles. You may make a rough calculation of its size in the following way. In Fig. 27 let *E* be your eye, *C* a sixpence, and *S* the sun. Hold the coin at such a distance from the sun that it just covers the disc. Measure the distance of the coin from the eye. Then the diameter of the sun is to the diameter of the sixpence as 93,000,000 miles is to the distance of the coin from the eye—a simple sum of proportion. (Remember the warning: Look at the sixpence and the sun through a dark coloured glass.)

Comparison of the mass of the sun with that of the earth shows that the sun's mass is 333,432 times as great as the

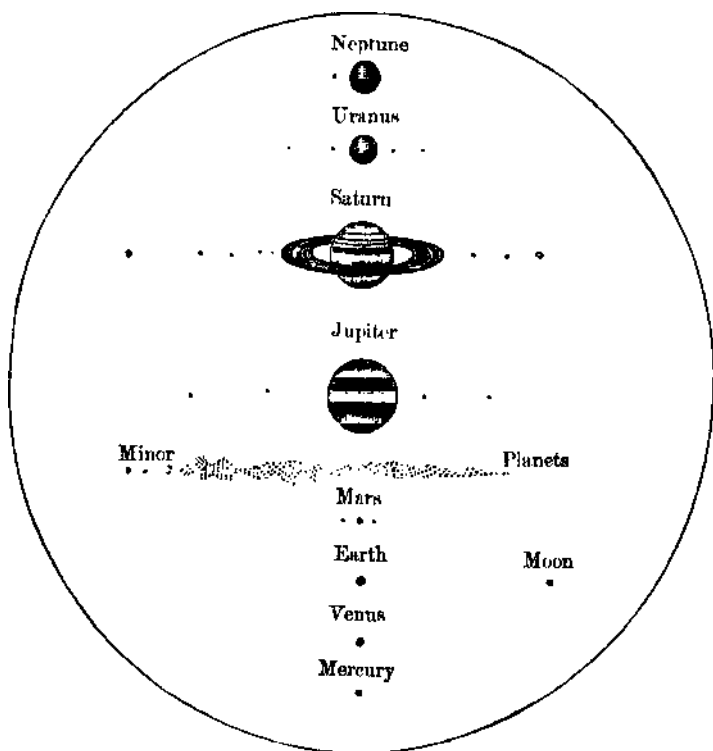


FIG. 28. THE SIZES OF THE PLANETS COMPARED WITH THE SIZE OF THE SUN

earth's, and many times greater than the mass of all the planets together. In fact, there is enough material in the sun to make over 740 sets of planets. Fig. 28 gives some idea of the size of the sun compared with the planets.

It is estimated that the sun is at a temperature of from 5,000 to 7,000 degrees Centigrade, and gives out light

equal to that of 15,750,000,000,000,000,000,000 standard candles.

A question arises, naturally, as to the source of all this heat and energy which the sun gives out continually.



By courtesy of

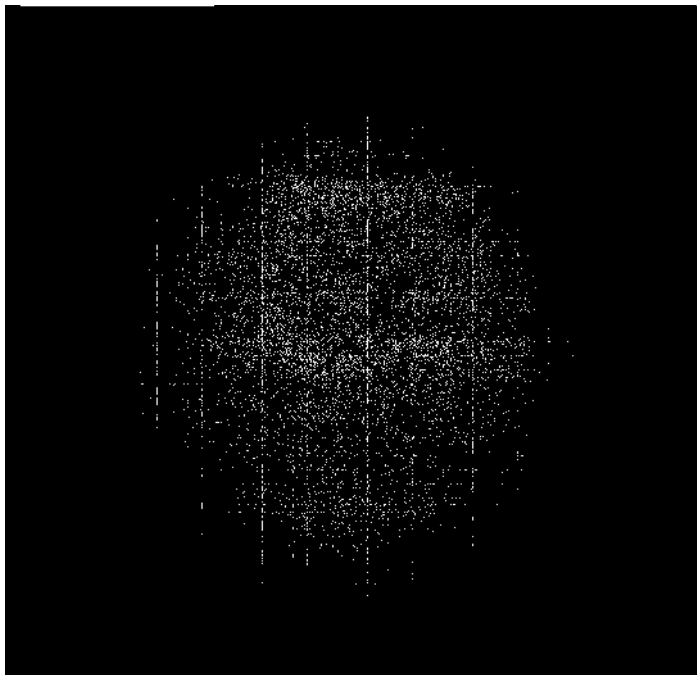
Mt. Wilson Observatory

**FIG. 29. A PHOTOGRAPH OF THE SUN'S SURFACE, TAKEN
UNDER SPECIAL CONDITIONS**

Note the sun-spots, which appear like whirlpools, and the many
flames

Helmholtz calculated that, by contracting in size, the sun would give out enough heat to last for about 20,000,000 years. Geologists, however, wanted much more time than this for the formation of all the rocks of the earth's crust as we know them to-day. Since the discovery that radium and other radio-active substances can emit energy by destroying their atoms, it has been found that the geologists may have all the

time that they want, and that the sun will go on emitting heat and light for many more millions of years.



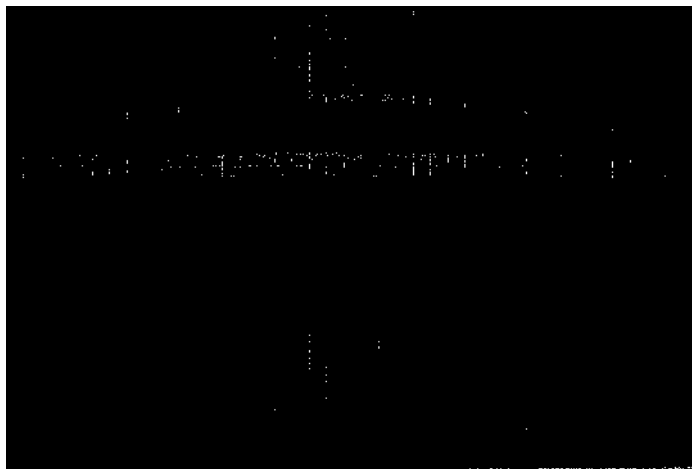
By courtesy of

The Royal Observatory, Greenwich

FIG. 30. THE SUN, 25TH JANUARY, 1920

Notice the two groups of sun-spots. The outer edge of the sun appears less bright than the central portion. The fine lines are the cross wires in the eyepiece of the telescope

Structure of the Sun. The telescope and spectroscope show that the sun consists of a central hot body (or nucleus) with a brilliantly luminous envelope of extremely hot metallic vapours about 500 to 1,000 miles thick, which is known as the *photosphere*. Outside this, and



By courtesy of

Yerkes Observatory

FIG. 31. SOLAR PROMINENCES, 10TH OCTOBER, 1910

Such flames are so much bigger than the earth that it could be lost in them



By courtesy of E. C. Slipher

Lowell Observatory

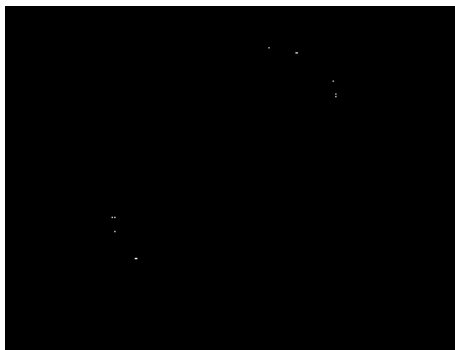
FIG. 32. SHOWS THREE TYPES OF PROMINENCES

Note the jagged edge of the moon

Photo taken on 8th June, 1918, with 40 ft. tower telescope

invisible to us through the telescope, except at times of eclipse, are the *chromosphere* and the *corona*.

The *chromosphere* is a red and glowing mass of flaming Hydrogen and calcium vapours, which may extend outwards from the photosphere as far as 5,000 to 10,000 miles. Some flames 500,000 miles high have been observed.



By courtesy of *The Royal Observatory, Greenwich*

FIG. 33. ECLIPSE OF THE SUN, 29TH MAY, 1919

Prominence nearly 100,000 miles high and 200,000 miles long
Note the earth's diameter is only 8,000 miles

The *corona* can only be seen at times of total eclipse. It is then seen as a beautiful silvery halo extending from 1,000,000 to 2,000,000 miles out into space. The photosphere has a granular appearance (known as "rice structure") which is caused by luminous clouds which are in a state of constant movement as though it were a boiling ocean of white-hot metallic vapours. By means of the spectroscope—to be described later—it has been found that most of the metallic elements known on earth occur in the sun as vapours.

Sunspots. When Galileo first saw through his telescope dark spots on the surface of the sun, he was greatly

surprised and rather troubled because, until this time, the sun was looked upon as the symbol of purity. Since Galileo's time these dark areas or sunspots have been carefully observed and photographed (see Figs. 30 and 34.) They vary both in size and in number, and they appear



By courtesy of

The Royal Observatory, Greenwich

FIG. 34. SUN-SPOTS

to move across the disc from east to west- This shows that the sun rotates like the earth from west to east in about twenty-five days.

Although the spots appear dark they are only black in comparison with the extreme brightness of the rest of the photosphere. You may have noticed that a glowing fire seems to glow less brightly if the sunshine falls upon it.

A diameter of 500 miles is small for a sunspot; and a really big one is so large that we can imagine forty earths being poured into it as peas are poured into a cup.

Sunspots appear to be something like great whirlpools in the flaming vapours, from the edges of which rise great flames known *a.sfaculae* (little torches).

Spots are not always to be seen on the sun's disc, and



By permission of

The Astronomer Royal, Greenwich Observatory

FIG. 35. ECLIPSE OF THE SUN, 29TH JUNE, 1927, AT
GIGGLESWICK

Note: (1) Prominences; (2) Corona; (3) The jagged edge of the moon

the number present varies considerably. Every eleven years there seems to occur a period when spots are large and numerous. Some people think that the number of sunspots may influence our weather, the appearance of auroras, and even may account for magnetic storms. The chief reason for believing this is that these phenomena seem to vary in eleven year periods. It seems to be

proved that, when there are many spots, the sun gives out more heat than when they are few or none. The corona appears to alter its character as the number of spots varies. When there are many spots it has streamers of light in all directions, but when there are few spots short tufts of streamers proceed from the poles and long curved ones from the equatorial regions of the sun.

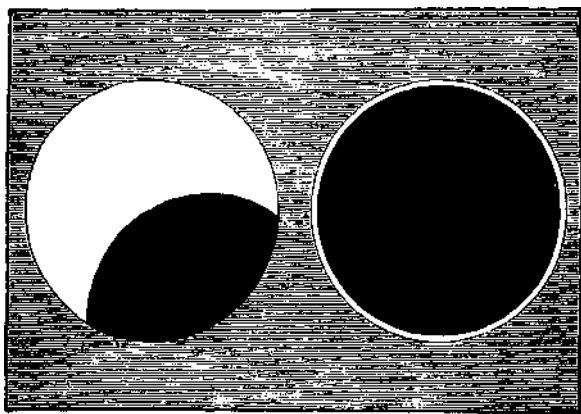


FIG. 36

A PARTIAL ECLIPSE

AN ANNULAR ECLIPSE

Prominences. Besides the faculae around the edges of sunspots, large red flames or *prominences* are sometimes seen extending from the edge of the sun's disc. Figs. 31 and 32 give some idea of these great prominences, in which the earth could be enfolded many times over. Such prominences are seen at times of total eclipse of the sun by the moon. The big "Anteater" prominence (Fig. 33) was about 350,000 miles in length when the photograph was taken. Later, it was seen to increase in height until it was nearly 480,000 miles high.

Eclipses of the Sun. The moon, although much smaller

than the sun, appears to be about the same size. This is because the moon is much nearer to us than the sun. The moon travels round the earth in an elliptical orbit, and is sometimes nearer to us than at other times. As a result of this, when the moon comes between us and the sun, it may either "quite or partially hide the sun from view. In the first case we have a total eclipse of the sun; in the second, we see the moon as a dark, round mass with a

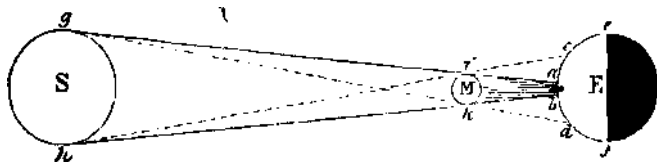


FIG. 37. TOTAL ECLIPSE OF THE SUN

S = Sun	<i>Ikab</i>	— Umbra
M = Moon	<i>lac and kbd</i>	— Penumbra
E = Earth	<i>ab</i>	= Breadth of the area of shadow

luminous ring of the sun around. This is called an annular (ring) eclipse.

Figs. 37 and 38 show that sometimes the *umbra* (dark part of the shadow) of the moon reaches the earth and sometimes does not. If it does reach the earth, as in Fig. 37, it will only cover a small portion of the earth's surface, about 150 miles across at the most. As the earth rotates, this umbra will pass over the earth's surface, forming a narrow belt. An observer placed between *a* and *b* will see a total eclipse of the sun. Observers in the bigger penumbra, *ac* or *bd*, will see a partial eclipse. Those in *ac* will be able to see the top part of the sun over the top of the moon, and those in *bd* will see the bottom of the sun below the moon. If, as in Fig. 38, the umbra does not reach the earth, then observers in *ab* will see an annular eclipse, and those in *ac* and *bd* a partial eclipse as before.

In any one place, the longest period of total eclipse may be about $7\frac{3}{4}$ min., but it may be only a few seconds. The total eclipse in Britain in 1927 lasted only 23 sec. At the end of 23 sec. we had passed out of the shadow cast by the moon.

Eclipses in History. Eclipses have been observed throughout the ages, and have often been looked upon as signs of ill omen, as forshadowing the deaths of kings and

FIG. 38. ANNULAR ECLIPSE

Umbra *Ikb* does not reach the earth. Observers from area between *ab* will see the portions of sun *gm* and *nh*, but the moon will cover *nm*

the falls of empires. The Chinese thought that a great dragon was swallowing the sun. Some of our forefathers, the Northmen, thought that two wolves pursued the sun and the moon and endeavoured to devour them. Sometimes whole tribes were assembled to shout and beat drums in order to drive away the animals and thus save the sun. To be sure, they were always successful; for the sun or moon was soon disgorged and shone again in its usual glory!

Astronomers have long been able to predict the day and exact time of an eclipse. This has always been a source of great astonishment to the ignorant, and no doubt many wise men have used their knowledge to intimidate those who did not know so much.

Columbus, who knew something of astronomy, was able to force natives of Central America to provide food for his men by threatening them with the vengeance of

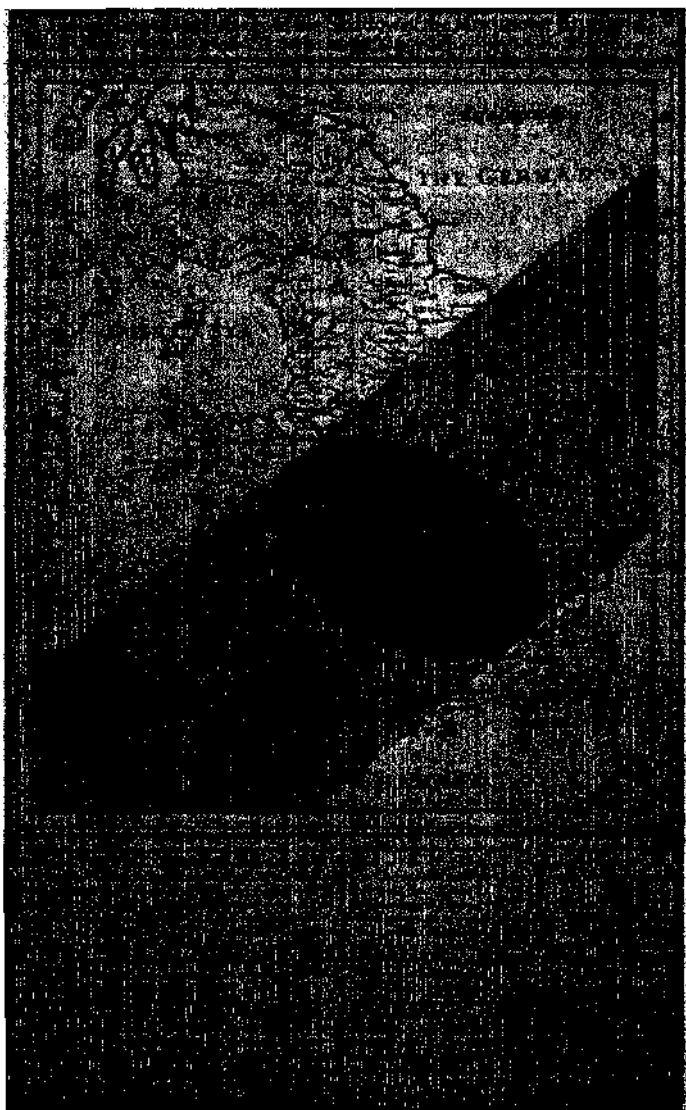


FIG. 3Q. THE TRACK OF THE MOON'S SHADOW DURING
THE SOLAR ECLIPSE, 22ND APRIL, 1715

the gods. To show his power he told them that the sun would be hidden from view at a certain time the next day. He knew that an eclipse was due at that time, and used his knowledge to impress the natives with his power.

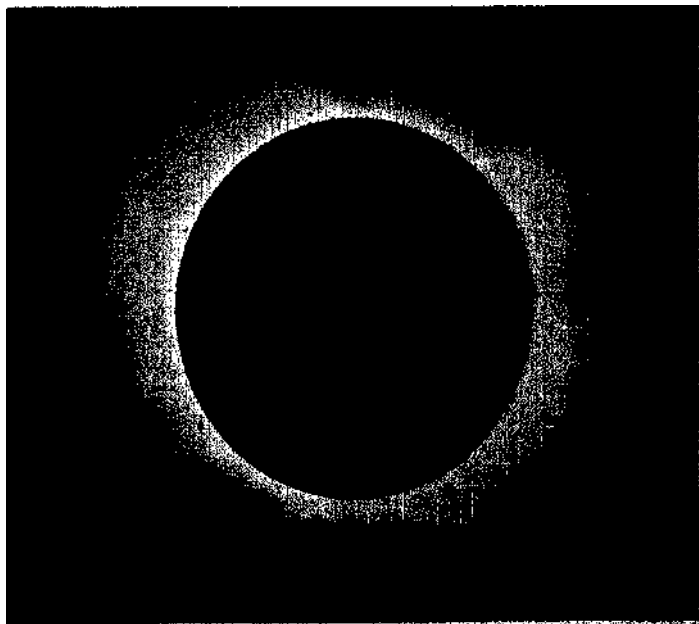


Photo by

E. E. Barnard

FIG. 40. ECLIPSE OF THE SUN, 1900

Note the corona with streamers near the top and bottom

When the eclipse did occur, the natives were so frightened that they begged Columbus to intercede for them, and promised to give him all the help and food that he required. Upon this, Columbus assured them that the sun should appear again as usual in a short time—i.e. when the eclipse should be over.

Times Of Eclipse. The sun may be eclipsed four times in

a year, but it is very rare for any particular place to have a total eclipse. As the moon goes round the earth twelve times a year there should be twelve eclipses. This does not happen because the orbit of the moon is inclined to that of the earth. As a consequence, the moon does not often come into a direct line with the sun and the earth,



FIG. 41. ILLUSTRATING BAILY'S BEADS

but usually passes either above or below that line. As the times of total eclipses are so rare, astronomers make long, careful preparations for them. They travel long distances to the most out-of-the-way places, in the hope that they may be able to study the chromosphere and corona of the sun and make observations or discoveries.

They do this, although they know the eclipse will only last, at most, a few minutes, and although they know that it may be hidden altogether by cloudy skies.

By the time the eclipse is due, all instruments are perfectly ready, and every one must know exactly what his particular work is, and how he is to do it. This requires experiments and practice with telescopes, cameras, spectroscopes, and developing apparatus for photographic plates. The work done in a few moments during an

eclipse may provide work for months, or even years, afterwards.

Description of an Eclipse. Observers of total eclipses

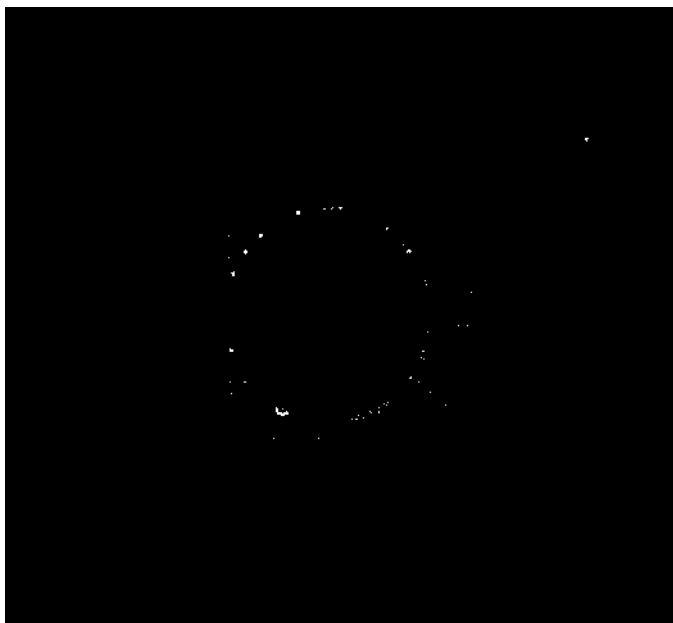
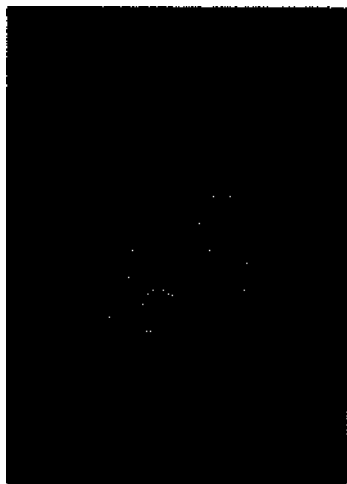


FIG. 42. THE SUN TOTALLY ECLIPSED, 1882
Showing stars and a comet

have described this rare and awe-inspiring spectacle. As the moon gradually covers the sun's disc the glory of the sun seems to fade, the temperature begins to fall and even birds and beasts seem to be strangely affected. Immediately before the moment of total eclipse some observers have noticed the shadow of the moon sweeping over the earth at immense speed. When the disc is almost covered and immediately before totality, it is sometimes possible to see small portions of the sun through the irregularities of

the moon's surface. Small bright spots appear round the edge of the moon, which are known as Baily's Beads, after the first describer of them. As the moon covers



By courtesy of E. C. Slipher, Lowell Observatory

FIG. 43. AURORA BOREALIS,
14TH MAY, 1921

Photograph showing great auroral streamers about 40° long in the north-eastern sky. Star trails are also visible as short white lines. (Foreground shows trees and electric wires)

the disc, the corona appears as a beautiful, shimmering, silvery halo, extending hundreds of thousands of miles out into space. Near the surface of the moon is seen the red ring of the chromosphere with its red flaming prominences shooting out into the silvery corona. The surrounding sky becomes dark, and stars and planets may be seen as at night. Even comets may be seen and photographed, as shown in Fig. 42. Unfortunately such a spectacle is soon over; for, as soon as the sun's disc begins to appear, all these wonderful sights vanish as if by the touch of some magic wand.

Study some of the photographs of eclipses and notice the prominences, the coronas of various shapes, and particularly notice the irregular jagged edge of the moon in Fig. 35, which is a photograph of the eclipse which occurred in England in 1927.

The Aurora or Northern Lights. Travellers in northern regions tell us of the glories of the wonderful lights seen in the sky at night which are known as the Aurora Borealis. No two auroras are exactly alike, but they may

consist of silvery luminous arcs, or bands of light, or may take the form of curtains or flowing draperies of crimson, gold, violet, or green.

The auroras appear to be at a height far above the clouds, and recent conclusions seem to show that they occur from 52 to 186 miles up from the earth.

Until recently the origin of auroras has been imperfectly understood, but lately it seems likely that they are connected with the activities in the sun's atmosphere which produce sunspots and great prominences. Probably they are due to invisible streams of electrically charged particles shot out from the sun into space. When the earth passes



FIG. 44. SKETCH OF AURORA BOREALIS, SHOWING DRAPERIES

through these streams the lighter electrons are stopped by the upper layers of atmosphere, and the heavier protons penetrate farther into it, causing a glow something similar to that formed by an electrical discharge passing through the vacuum tubes used as signs outside shops.

In 1929 observers of the sun at Mt. Wilson Observatory predicted that an aurora would very likely be seen on 14th August. On 15th August a fine aurora of the drapery kind, was seen in northern latitudes; and even as far south as Sidmouth, in Devon, lights were seen in the sky.

Magnetic Storms. Already we have read that sunspots, auroras, and magnetic storms seem to be connected. On

the 15th August, 1929, there was a magnetic storm at the same time as the aurora was seen.

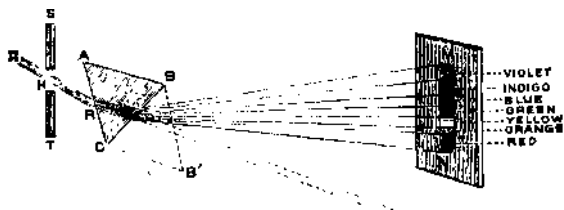
You have probably learnt that the earth behaves as a magnet, with one pole at the north and one at the south. This may be due to the fact that the earth is a conductor revolving in an electrical field produced by the streaming of electrified particles from the sun. If this is so, we should expect the earth's magnetism to vary in strength with the activity on the sun, and consequently our magnetic instruments would behave in an unusual manner. During magnetic storms our magnets do behave erratically, and even telegraphic signalling and submarine cabling may be impossible because of stray electrical currents produced in the wires.

The Heaviside Layer. Wireless enthusiasts have probably heard of the Heaviside layer of the atmosphere, which is so important in long distance wireless broadcasting and signalling. It is probable that this layer may be electrically charged by electrical particles emitted from the sun, for it has recently been shown, by means of the spectroscope, that there is always a faint aurora present in the upper reaches of the atmosphere.

The Composition of Sunlight. Sir Isaac Newton was the first to discover that sunlight was made up of a combination of colours. He was able to split up a beam of sunlight, by means of a triangular glass prism, into a band of colours known as the spectrum. In this spectrum he was able to recognize the seven colours: red, orange, yellow, green, blue, indigo, and violet. He also showed that, if lights of these colours are mixed in the right proportions, they produce white light very similar to sunlight.

It has since been shown that sunlight consists of an immense number of waves of varying length, and that these waves really produce many more than seven colours,

only our eyes are unable to distinguish them. Some of the waves, indeed, do not affect our eyes at all, but are recognizable by the heat which they produce or by their action upon certain chemicals used in photographic plates. The invisible heat rays are known as *infra* red rays and it is they that produce warmth. The invisible chemical rays are known as *ultra-violet* rays. These are used in photography, and they are the rays which do us good when we go sunbathing. It is also these rays which hurt our eyes



• FIG. 45. NEWTON'S PRISM AND SPECTRUM

or cause dangerous sunburn when we are exposed to them too much.

Rainbows. The rainbow, seen when the sun is shining during a rainstorm, is a spectrum produced by the sunlight shining through the raindrops. The light is split up in a similar way to that in which the glass prism disperses sunlight.

You may examine a spectrum similar to the rainbow by spraying water from a hosepipe into the sunshine and looking through the spray at some dark background.

EXERCISES

1. Taking the distance of the sun from the earth as 93,000,000 miles, find its diameter by using a sixpence in the way explained in the text.

2. Make sketches of the sun to show what is meant by "Corona," "Prominences," "Baily's Beads."

3. Make a drawing to explain why some people see a total eclipse while others see a partial eclipse, and still others no eclipse.

4. Make sketches showing an annular eclipse, and show: (1) the position from which it will be seen; (2) the position from which only a partial eclipse will be seen.

5. What phenomena may be connected with sunspots?

6. Explain why there is not an eclipse of the sun every month.

7. Allow light from a candle to pass through a narrow slit in a piece of cardboard, and fall upon a triangular glass prism. Look through the prism at the slit and observe the spectrum. How many colours can you distinguish?

8. Describe what is noticed during an eclipse of the sun.

9. Try to form a spectrum by watering the garden.

10. How do we know that the sun rotates?

11. Look up the words "annual" and "annular" in a dictionary and learn their meanings.

CHAPTER IV

The Moon

Satellites. Most of the planets in the solar system have satellites (attendants) which are sometimes called moons. The earth has only one satellite—our moon. Mars has two satellites; Jupiter nine, four of which are easily visible in a small telescope; Saturn nine; Uranus two, and Neptune one.

Our Moon. Although we have only one satellite it is a very big one compared with the planet which it attends. It has a diameter of 2,163 miles, just a little more than a quarter of the diameter of the earth. It is just under one-fiftieth of its volume, or, in other words, the material of forty-nine moons would be required to make the material of the earth. When we look at the moon in the sky and compare it mentally with the sun it appears to be almost exactly the same size. This is because it is so very much nearer to us than the sun is. It has been stated previously that the sun is nearly 93,000,000 miles away. Careful measurements of the moon's distance from the earth show that the moon is less than a quarter of a million miles off—roughly 240,000 miles. As the moon revolves round the earth in an elliptical orbit, sometimes it is farther from us than at other times, and therefore it does not always appear to be the same size. During some eclipses of the sun we have seen that the moon appears big enough to hide all the sun, while, at other times, when the moon is farther from us, it is unable to do so, and we get an annular (ring) eclipse of the sun. To illustrate this, take a threepenny piece and hold it between your eye and the

moon. At a certain distance the coin will hide all the moon, but if it is removed a little farther from the eye a



FIG. 46. FULL MOON (AGE 14 DAYS 7 HOURS)

Can you see the crab's claw? To see the familiar "Man in the Moon" this photo should be observed from a distance of about 9 yards

ring of the moon will be seen round the edge of the coin. The orbit of the moon is inclined to that of the earth, and so sometimes when the moon is new it is above the sun, and at other times below it. This is the reason why

we do not get an eclipse of the sun every month, for the moon's shadow does not always fall upon the earth.

How the Distance of the Moon was Measured. To measure the distance across a river, a surveyor may proceed as follows. Place two pegs, *A* and *B*, at a measured distance from each other, on one bank of the river. From

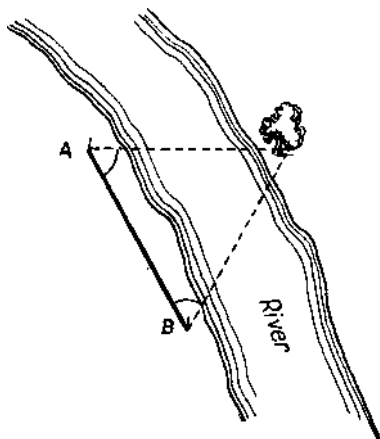


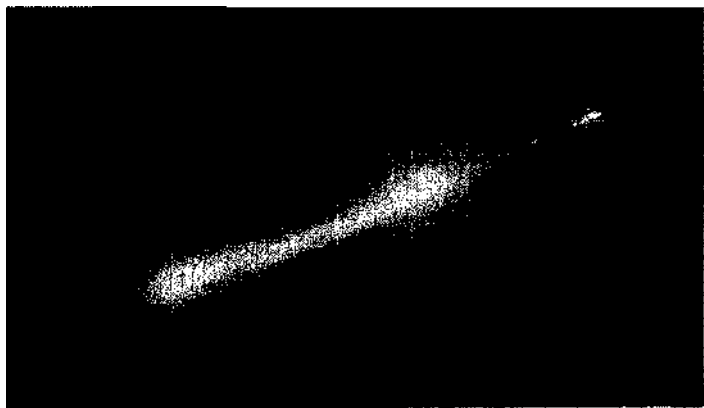
FIG. 47. MEASUREMENT OF DISTANCE ACROSS A RIVER

each of these pegs measure the angles made by *AB* and the imaginary lines joining *A* and *B* to a tree on the opposite bank. Now make a drawing of a triangle, making *AB* to scale of 1 in. = 1 yd., and making the angles equal to the angles observed. On the drawing, drop a perpendicular from *T* to the base line *AB* and find its length by measurement. Then by using the scale find the distance from the tree to the line *AB*.

To find the distance of the moon a similar method was adopted. The base line was the distance between two observatories, one in Greenwich and the other in Cape Town. The angles between this line and a fixed point on

the moon were carefully measured, and thus the distance of the moon was calculated.

Light of the Moon. The moon does not emit light as the sun does, but it acts as a reflector to reflect sunlight. We see the moon, therefore, in the same way as we see



H.E.T.

FIG. 48. A PHOTOGRAPH OF THE PATH OF THE MOON

The differences in brightness are due to the passing of light clouds during the exposure, which was several hours. The real width of the moon is shown by the bright line to the right of the photo

any object on earth—by reflected sunlight. What is called moonlight is really only second-hand sunlight. In days gone by it was thought that moonlight falling on sleeping people made them mad, and so we have such words as "lunacy" and "lunatic" from *luna*—a moon. Even now we sometimes use the word "moonstruck." Although most people do not believe that moonlight has any real evil influence upon us, yet some people in the tropics will never venture to sleep where the moonbeams might fall on them.

At times when the moon is low in the heavens it appears

to be reddish in colour and bigger than usual. The rays of light from the moon in this position have to pass through a thick layer of atmosphere. They are therefore bent and dispersed, and some of the blue light rays do not reach our eyes. It is thought that it only appears larger

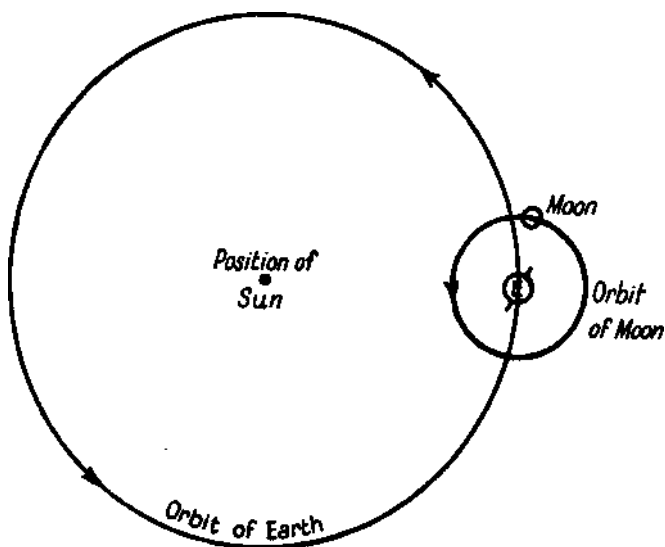


FIG. 49

than usual because it is nearer to some object with which we can compare it. Its apparent largeness is therefore only an optical illusion.

Movements of the Moon. The moon *does* revolve round the earth as the early astronomers thought, but not in one day as it appears to do. Like the sun, the moon appears to rise in the eastern portion of the sky and set in the western portion once in twenty-four hours, and, as in the case of the sun, this motion is only an apparent one due to the real motion of the earth on its axis.

If we observe the moon carefully for a period of days, we find that each night it rises later than it did the night before. In the course of a month (twenty-seven days to be more exact) it has become a whole day late. This is because the moon is really moving round the earth from the west to the east, and has therefore moved from its place by the time the earth has made a complete rotation.

Use two balls to represent the earth and moon. Make the earth rotate from west to east and the moon to revolve round the earth in the same direction only very much more slowly. By experimenting in this way the reader will better understand the above motion of the moon than by reading pages of description.

No matter when we look at the moon we always see the same markings on it. This proves that the moon is always turning the same side towards the earth. In order to do this it must necessarily rotate on its axis in the same time as it takes to revolve round the earth. To make this clear, walk round another person who is standing in the middle of the room to represent the earth. If you always keep your face towards the earth, you will face each side of the room in turn, and must therefore have turned round upon your own axis while you were walking round the earth.

The moon has also another motion, besides the two mentioned, for it travels with the earth on its annual trip round the sun.

You may gain a fairly good idea of the complicated motions of the moon if you imagine a man and a child waltzing round a room in the old-fashioned waltz. As the man revolves round the room he rotates on his axis in small circles. He represents the earth revolving and rotating. The child always faces her partner, and therefore rotates on her axis as she revolves round him. At

the same time she travels with him as he journeys round the room. The child then roughly represents the moon.

In Chapter I we read how the older astronomers thought of the planets moving in epicycles. The moon's motion is very similar to the old idea of a planet's motion in epicycles, only the moon is travelling round the sun, whereas the planets were thought to be moving round the earth.

jEclipse of the Moon. Periodically the moon, like the

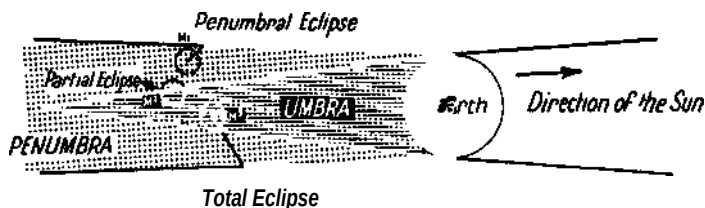


FIG. 50

Showing the moon in three different positions in the shadow of the earth, thus giving total, partial, and penumbral eclipses

sun, is eclipsed or hidden from view. This occurs when the shadow of the earth prevents the sun from shining on the moon, or, in other words, when the sun, earth, and moon are in a straight line and the earth lies between the sun and the moon (Fig. 50). If the moon is only partly hidden by the umbra of the earth's shadow, we get a partial eclipse of the moon, as at Fig. 51, 1; but if the moon passes right into the umbra, as at Fig. 51, 2, we get a total eclipse of the moon. A penumbral eclipse of the moon is caused by the moon's passing through the penumbra of the earth's shadow. This type of lunar eclipse usually passes unnoticed.

The earth, being much bigger than the moon, has a larger and longer shadow than the moon, and there is no occasion when the shadow of the earth is not big enough to cover the moon, and thus produce an annular eclipse.

A total eclipse of the moon lasts much longer than a total eclipse of the sun, for it takes the moon from one to four hours to pass through the umbra of the earth's shadow.

When we see a total lunar eclipse an observer on the moon—if there were such—would see a total eclipse of the sun, for the earth would be hiding the sun from view. During a total eclipse of the moon, the moon does not

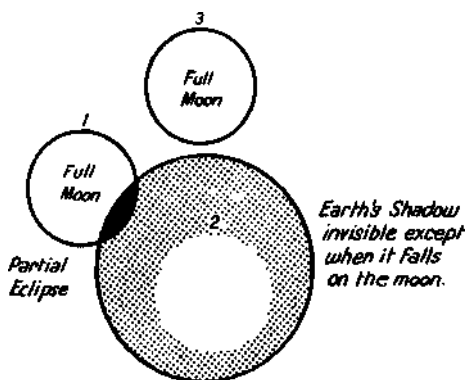


FIG. 51

- | | |
|----------------------------------|-------------------|
| 1. Full moon entering the shadow | = Partial eclipse |
| 2. Full moon within the shadow | = Total eclipse |
| 3. Full moon above the shadow | = No eclipse |

usually disappear, as might be expected, but it is seen as a coppery disc in the sky. This is because some of the red rays of sunlight are bent so much, as they pass through the earth's atmosphere, that they fall on the moon, although it is in the earth's shadow.

Phases of the Moon. No one can help noticing how the moon's appearance alters from time to time; sometimes it appears as a full, round moon; at other times as a semi-circle; and at others as a more or less thin crescent: The Babylonians thought that these different phases of the moon were due to the fact that it had a bright side and a

moved so that its face is towards you, the earth. Now observe the shape of the lighted portions which you can see in each position. You will notice that the rubber portion will give you all the shapes seen in the moon during the month.

This experiment also shows that the dark part of the moon is always present between the cusps (points) of the crescent moon; and therefore that it is impossible to see a star between the horns of the moon, as it is sometimes depicted in advertisements, and even on some foreign stamps. While performing this experiment you should

notice that the curved portion of the moon is always turned towards the sun as though it were a bow shooting an arrow straight at the sun (see Fig. 54).

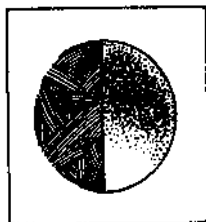


FIG. 56

Showing card surrounding ball of wool half covered with a rubber ball. This position shows half moon or first quarter

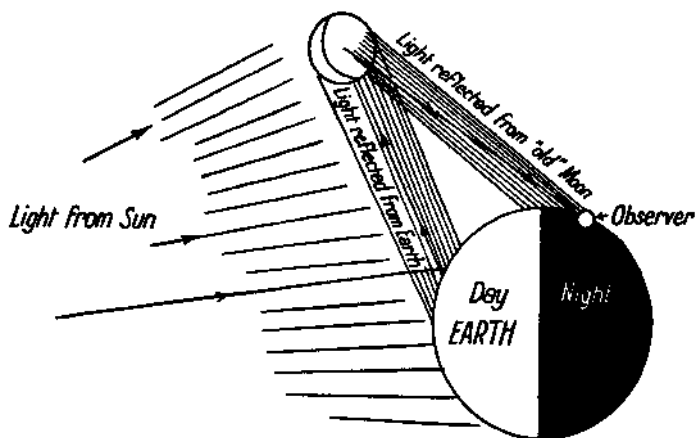


FIG. 57

An attempt to show that earthshine is sunlight reflected from earth to moon and then back to the observer at 0. "Third-hand" sunlight

Earthshine. The earth reflects sunlight just as the moon does, and an observer on the moon would possibly speak of the beauties of an "earthlight night." When the moon is in the crescent phase, we may often see the earthshine reflected back to us. People sometimes speak of the "old

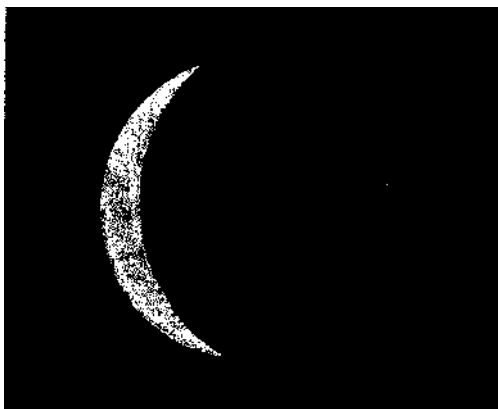


FIG. 58. SHOWING EARTHSHINE AT TIMES OF CRESCENT MOON

The new moon looks slightly bigger than the old moon because it is brighter

moon in the arms of the new." The light of the new crescent is reflected sunlight, but the light of the "old moon" is reflected earthshine, or sunlight which has been reflected from the bright part of the earth to the dark part of the moon, and from that part of the moon back again to the dark part of the earth.

The Moon and Weather. An old country saying states "The moon on its back carries rain in its lap," and many country folk still believe that the weather will be bad if they see the crescent moon on its back. Of course, there is no connection whatever between the crescent moon and

the likelihood of rain. In our latitude the crescent moon is on its back in spring time and upright in the autumn. In the tropics it is always on its back, and in the arctic regions always on end.

Newton and the Moon. One day whilst walking in his orchard Sir Isaac Newton was wondering why the moon

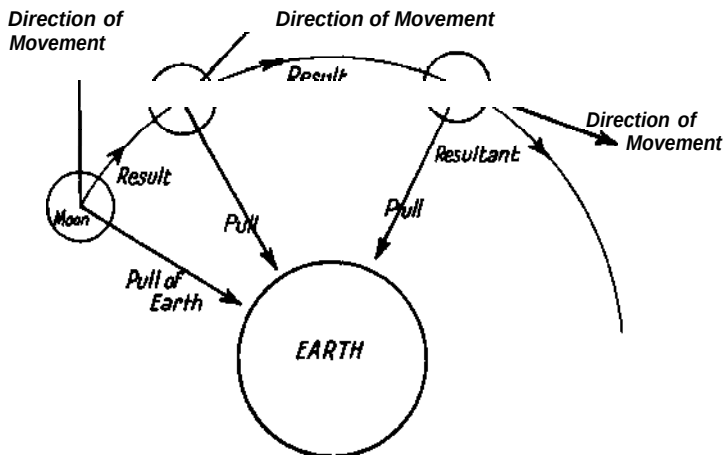


FIG. 59

Showing that the moon moves in an orbit because of the force of gravity, which prevents it flying off in the direction of its movement

revolved round the earth instead of flying off into space. Presently, an apple falling from a tree made him think that possibly the same force, which made all things fall to the earth, might be acting upon the moon and other celestial bodies. He pondered over this idea and made a number of calculations, but it did not seem to help him until some years later, when some fresh information about the distance of the moon altered his calculations. He then published, at the request of Halley, an astronomer, an account of his discovery, and gave us the law of universal

gravitation. In this he stated that all bodies attract one another with a force which depends upon their masses and the squares of the distances between them. Newton had now found the force he needed to explain the motion of

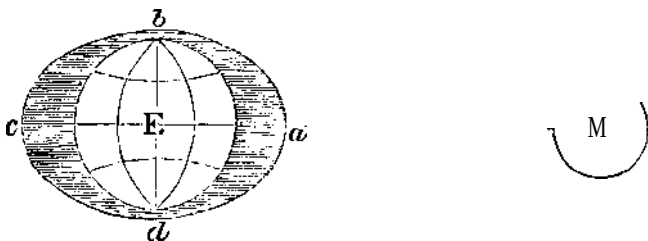


FIG. 60. THE TIDES PRODUCED BY MOON

the moon. The moon is at all times tending to fly away from the earth, that is, to continue its motion in a straight line. At the same time it is always being pulled by the earth towards itself. As a result of these two forces, the



FIG. 61. THE SUN AND MOON PULLING THE SAME WAY AND PRODUCING SPRING TIDES

moon continues to revolve round the earth. Fig. 59 will perhaps help to explain this to you, especially if you have learnt about the parallelogram of forces.

. **Tides.** Visitors to the sea coast cannot fail to notice the rise and fall of the sea, which we call the tides. Times of high tide follow one another daily at regular intervals of about twelve and a half hours, but sometimes the tide

comes farther up the beach than at other times. The moon is the chief cause of the tides, but the sun also helps to form them.

We have already seen that every body attracts every other body with a force which depends upon the sizes of the bodies and their distances. It follows that both the sun and the moon will attract the waters of the earth, but the moon will attract them more than the sun, because

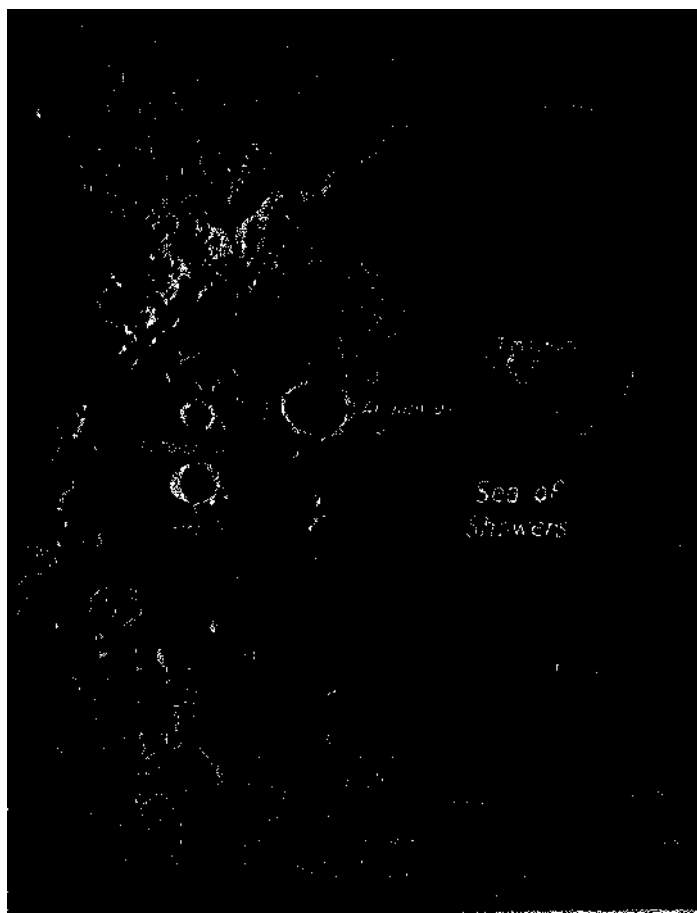


FIG. 62. SUN AND MOON PRODUCING TIDES AT DIFFERENT PLACES

Resulting in neap tides at *a* and *c*

it is so much nearer. The moon acting alone would form high tides and low tides at the places shown in Fig. 60. When the moon is new or full, the sun will be acting in the same direction as the moon, and so help to make the tides higher. At other times during the month, the moon will be pulling one way and the sun in a different direction. In Fig. 62 the moon is forming high tides at *A* and *C* and low tides at *B* and *D*, while the sun is forming a smaller high tide at *B* and *D* and low tide at *A* and *C*. This causes low water to be higher and high water to be lower than it should be.

The tides produced by the sun and moon acting together



By courtesy of

Mt. Wilson Observatory

FIG. 63. A PORTION OF THE MOON FROM ERATOSTHENES
TO PLATO

Showing mountains, craters, sea of showers, and a valley in the Alps

Photo taken through 100 in. reflector

are known as *spring tides*, and those produced when sun and moon are pulling at right angles to each other are

known as *neap tides*. Spring tides come up the beach a long way and go out a long way. Neap tides do not come up so far or go out so far. Spring tides occur every fortnight, and it is then that owners of bathing huts and boats have to take care of their property on the fore-shore.

In the open ocean the rise or fall of a tide is from one to two feet, but tidal waves sweep into narrow seas and estuaries, where the rise may be as much as fifty feet, as is the case at Bristol, in the Bay of Fundy, and in the estuary of the Seine.

The Appearance of the Moon. When we observe the moon with the naked eye, we notice the bright and dull patches which form what is popularly known as the face of the man in the moon. Other people fancy they can see a lady reading a book, or a crab's claw, or a man splitting wood on a block with a hatchet. Look carefully and see if you can see them. You have doubtless learnt before, that these bright and dark patches are the mountains and "seas" of the moon, and perhaps you have noticed the irregular inner curve of the crescent moon with isolated spots of light representing the top of mountains, which the sun's rays show up before they reach the lower levels.



By courtesy of Yerkes Observatory

FIG. 64. A PORTION OF THE MOON SHOWING MANY CRATERS. The large one, Theophilus, shows a central peak. Note that sometimes the craters appear as blisters. This is an optical effect. You should look away for a moment and then look again until they appear as indentations

Galileo, when he turned his telescope on the moon, was able to recognize individual mountains, craters, valleys, and seas. You may do the same with a good pair of field glasses or quite a small telescope.

Since Galileo's time, the face of the moon has been well studied, and now the geography of the half of the moon which is turned towards us is as well known as that of the



FIG. 65. THE SUN SHINING ON PLATO, PRODUCING LONG SHADOWS

earth. With the aid of our powerful telescopes objects on the moon which are only 500 ft. in diameter can be seen.

Mountains. The ranges of mountains are named after ranges on earth, and we have the Carpathians, Caucasus, Alps, and Apennines. Craters and peaks are named after famous astronomers, such as Tycho, Copernicus, Aristotle, and Ptolemy. The mountains on the moon appear to be higher than those on the earth because they have suffered far less from being worn away by frost, rain, storm, and river action. The shadows cast by the tall mountains are black and sharp, and have been used to calculate the heights of the mountains. The mountains seem very high because they are measured from their bases, whereas our mountains are measured from sea-level.

Craters. The large number of craters seen on the moon

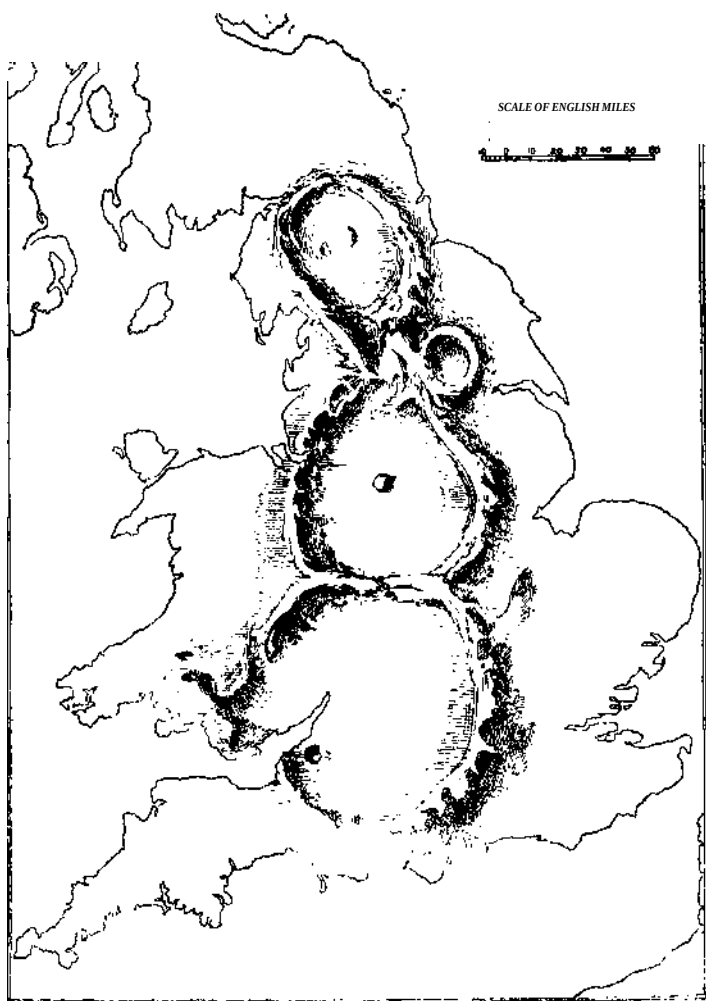


FIG. 66. LUNAR CRATERS COMPARED WITH AREA OF ENGLAND

Ptolemaeus, diameter 115 miles; Alphonsus, diameter 83 miles
Arzachel, diameter 65 miles

seem to show that at one time volcanic activity was very great, but according to most astronomers it has now ceased altogether. Tycho is such a large crater that it might almost be mistaken for a sea, for it is 3 miles deep and 50 miles wide. The largest lunar crater is Ptolemy, which is 115 miles across. Compare this with the largest crater on earth, which is only 7 miles across.

Some people believe that such large craters may be more like huge volcanic blisters which have burst than what we know as craters. Others believe that the so-called craters are due to meteors which fell into the moon's crust while it was still soft and semi-plastic. The crater-like depression formed by a meteorite in Arizona seems to give some support to this explanation. (*Note.* A large stone thrown into thick mud will form a crater-like depression and raise walls round the sides of the depression.) It is quite possible that some of the craters may have been formed in one of these ways and other craters in other ways, but they are most generally believed to be of volcanic origin.

" **Seas.**" The dark patches known as the Sea of Tranquillity, Sea of Showers, Sea of Serenity, Sea of Crises, etc., are not now believed to be seas, but great plains which may possibly have been the beds of seas once, if the moon ever had sufficient water to form them. At present there is no evidence of any water in them, and they are thought to be great barren wastes of basaltic rock or volcanic ashes without any covering of vegetation.

A Dead World. The moon is usually looked upon as an example of a dead world, with no atmosphere, water, or clouds, and no life of any kind. Professor Pickering, however, claims that he has seen clouds coming from some volcanoes, and that there is ice or snow to be seen in some



FIG. 67. VIEW FROM THE SURFACE OF THE MOON

of the valleys before the heat of the sun has had time to melt it. He further claims to have noticed changes in the appearance of certain low parts, which would be best explained by the presence of some kind of vegetation which springs up during the long lunar day, only to die during its long, cold night. Professor Pickering has made a very prolonged study of the moon, but his ideas have not been generally accepted by other astronomers.

Atmosphere. If, as most astronomers believe, there is no atmosphere on the moon, there can be no breezes, no scent borne upon the breezes, and no sound, for sound waves travel through the air. The appearance of the heavens, to a lunar observer, would be very different from that to which we are accustomed. There would be no blue sky, but the sun, stars, and planets would shine put from the black depths of space. The sun would appear as a much more glorious object, because the flames of the chromosphere and the lovely corona would be visible at all times, stretching far out into space.

Other Strange Things. The earth would appear as a great "moon" giving light seventy times greater than we get on our best moonlight nights. At times, the earth would eclipse the sun; but no eclipse could be annular, for the earth would always be big enough to blot out the sun, its chromosphere, and most of the corona.

As the moon is so much smaller than the earth, it would attract things to it with much less force. It would require about one-sixth of the force we use to lift a given weight. A 12-stone man would weigh only 2 stone if weighed by a spring balance, and a boy who could jump 5 ft. on earth would be able to jump 30 ft. on the moon.

As the moon takes a month to rotate on its axis, so each day and night would be a fortnight long. As a consequence of this the long day would be excessively hot,

probably about boiling point, and the long night excessively cold, 200° to 400° below zero.

EXERCISES

1. Explain why the poet is wrong in this verse of *The Ancient Mariner*—

From the sails the dew did drip—
Till clomb above the eastern bar
The horned moon, with one bright star
Within the nether tip.

2. What is the meaning of satellite? Which planets have no satellites and which have more than one?

3. Hold a threepenny piece in such a position that it just covers the moon. Find the distance of the coin from your eye.

4. Use the result of No. 3 and distance of moon = 240,000 miles, to find the diameter of the moon.

5. Why do we not get an eclipse of the sun every month at new moon?

6. Explain how the distance of the moon from the earth was measured?

7. Why does the moon appear copper-coloured when eclipsed?

8. What are the real motions of the moon?

9. Make a sketch to illustrate total and partial eclipses of the moon.

10. What would an observer on the moon possibly say was happening when we were having: (1) An eclipse of the moon; (2) an eclipse of the sun?

11. Study the phases of the moon, by diagram and experiment.

12. When may we see: (1) A rising crescent moon; (2) a setting crescent moon?

13. What do you understand by earthshine?

14. What keeps the moon revolving round the earth?

15. Imagine that you have visited the moon. Write an essay describing anything of interest that you might have noticed.

16. Why do we not believe that the moon can be inhabited by men.

17. Why does the rising moon appear red?
18. Find the distance across a road or river without crossing it.
19. How much greater is the distance of the sun from the earth than the distance of the moon from the earth? Give an approximate answer.
20. Experiment with a ball and lamp as described on page 64. It is the best way to understand the phases of the moon.

CHAPTER V

The Sun's Family

PART I. THE DWARF PLANETS

THE sun's family, as we have seen, consists of the planets with their satellites or moons, together with the asteroids or minor planets, some swarms of meteors, and some comets.

According to the ancient astronomers, the number of planets was seven—the perfect number. As the earth was considered to be at the centre of the system, the sun and the moon were both considered to be planets. The other five planets known were Mercury, Venus, Mars, Jupiter, and Saturn. These planets were named after gods.

Now, the sun and moon are not considered as planets but the earth is. We have, for some time, known eight planets which include the five mentioned above, together with the earth, Neptune, and Uranus. Recently, in 1930, another planet was discovered by the aid of the camera; this has been given the name of Pluto. Still more recently, in 1932, newspapers have stated that still another planet has been found. This, however, is only one of the asteroids or minor planets.

The planets revolve round the sun in nearly circular orbits which are nearly in the same plane. All of them travel in the same direction, i.e. from west to east. The planets nearest to the sun travel with greater speeds than those which are more remote. The earth travels round its orbit at the rate of 18 miles per second, but Neptune

moves at the slower rate of 3 miles per second. Owing to the different distances they have to travel, and to their different speeds, the planets overtake one another. This causes their apparent paths among the stars to be of a wandering nature (see apparent path of Mercury, Fig. 68). The planets were so named because they appeared to wander about the sky. We may divide the

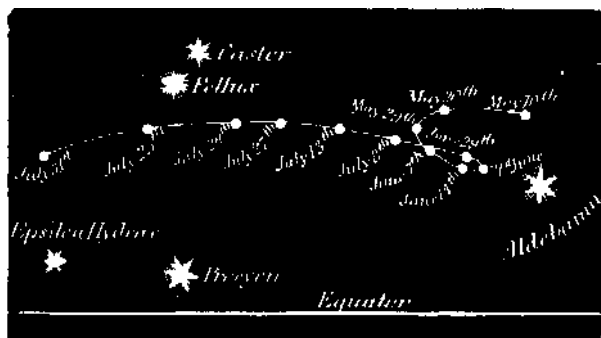


FIG. 68. THE APPARENT PATH OF MERCURY AMONG THE STARS DURING ONE REVOLUTION IN 1850

planets into three groups—the dwarfs, the giants, and the minor planets, or asteroids. The dwarfs are those nearest the sun, viz. Mercury, Venus, Earth, and Mars. The Earth is the largest of them and Mercury the smallest. The giants are Jupiter, Saturn, Uranus, and Neptune, of which Jupiter is the biggest by far.

Mercury. This planet, which is 36 million miles from the sun, is the nearest to it. Since it is the swiftest moving planet, it was appropriately named after Mercury, the messenger of the gods, who was noted for his swiftness. Its' speed of revolution is 23 miles per second, and it completes a revolution in .24 year, so that its year is 88 days—less than three months. This planet is difficult to see because it rises and sets at very nearly the same

times as the sun. It is rather remarkable that the ancients ever discovered this planet at all. In all probability Mercury is a dead world, because the time of its revolution is the same as its time of rotation upon its axis and, consequently, one face is always turned to the sun and the other always turned away from it. As the sun would appear nine times as big to Mercury as it does to us, and as Mercury is so much nearer to the sun, the side facing the sun must be scorched up, although the other side, which receives no heat from the sun, must be intensely cold.

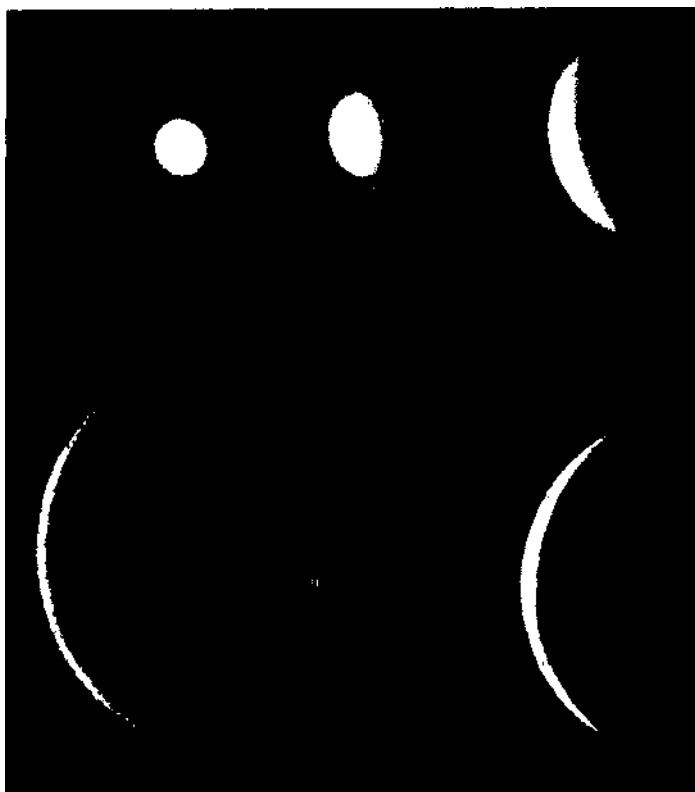
Mercury is much smaller than the earth. It has a diameter of just over 3,000 miles compared with the earth's diameter of 8,000 miles.

Venus. The most beautiful of the ancient goddesses was Venus, and the planet Venus is the most beautiful of the planets.

After the moon, it is our nearest neighbour, and it is nearly equal to the earth in size. Its surface is hidden from us by dense clouds, of which we see the silver lining because they reflect sunlight to us so well. It is these clouds that make Venus the most brilliant object in our sky. As we cannot see its surface, it is difficult to find out its time of rotation, but it is now thought to rotate in the same time as it revolves round the sun, that is, in 225 days. If this is correct, then it always has one face turned towards the sun in the same way as the moon always has the same face towards the earth.

The Evening and Morning Star. Venus is commonly known as the evening star, or the morning star. Ancient peoples thought that the evening star and morning star were two different bodies, and gave them different names—Hesperus and Phosphorus. We now know that they are the same body, and that that body is a planet and not a star.

When observed through a telescope, Venus is seen to have phases like the moon; but at "full Venus" it is



By courtesy of E. C. Slipher

Lowell Observatory

FIG. 69. VENUS

Photographs showing the phases of Venus and the great differences in diameter which result from the planet's revolution about the sun in an orbit lying inside that of the earth. When in the crescent form it is much nearer to the earth and it is then at its brightest

much farther from us than at "new Venus" and, therefore, it appears much smaller when full than when new (see Figs. 69-71).

In Fig. 70 it will be seen that Venus is to the left of the sun at *L* and to the right of it at *R*. If we now follow the sun across the sky, when the planet is at *L* we can see that the planet will remain above the horizon after the sun has set and thus form the evening star. On the other

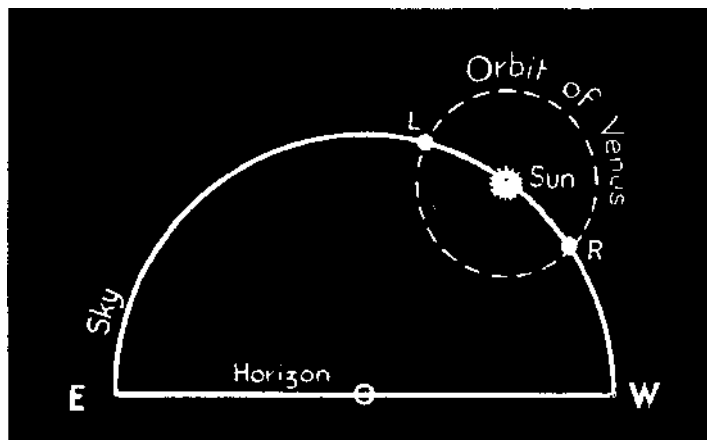


FIG. 70

When Venus is at *L* it is the "Evening Star," but when at *R* it will rise before the sun and become the "Morning Star"

hand, when it is at *R*, it will set before the sun in the evening and rise before it in the morning, thus giving us the morning star.

The sun was sunk, and after him the star
Of Hesperus whose office is to bring
Twilight upon the earth, short arbiter
'Twixt day and night.

Paradise Lost.

Transit of Venus. At times, Venus crosses the face of the sun as it passes between us and the sun. This is similar to the passage of the moon across the sun's disc, and might be described as an eclipse of the sun by Venus.

Venus, however, although bigger than the moon, is so much farther away from us that it cannot hide much of the sun, but only appears as a black dot crossing in front of it. It is, therefore, not called an eclipse, but is described as the "transit" of Venus. Such transits do not often occur. The last was in 1882 and the next will be on

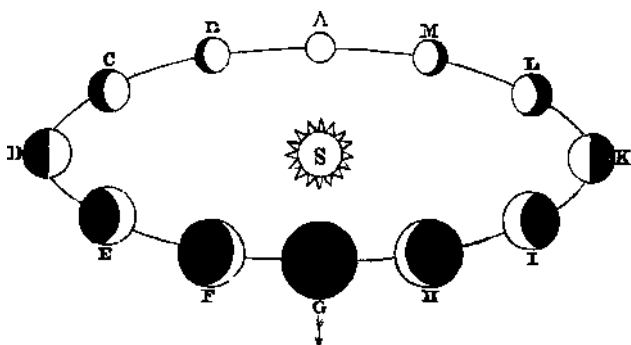


FIG. 71. THE PHASES OF A PLANET SUCH AS MERCURY OR VENUS

8th June, 2004, to be followed by another in 2012, on 5th June.

Phases of Mercury and Venus. Both Mercury and Venus, when seen through the telescope, exhibit phases something similar to those of the moon. There is this difference, however. These two planets revolve round the sun and not round the earth. As a consequence of this, when they are in the full phase they are very much farther from the earth than when they are in the new phase. Fig. 71 shows the difference in apparent size at the different phases of Venus. The position G is the "new" phase when the planet is nearest to the earth situated in the direction of the arrow, and position A is the "full" phase. It is quite apparent from the diagram that more light

will be received from the planet when it is in the crescent form than when it is in the "full" phase. Fig. 69 represents the apparent sizes of Venus in another way. The planet is brightest when in the crescent phase at the bottom right-hand corner of the picture.

How to Find Planets in the Sky. It is difficult to distinguish planets from stars with the naked eye, as they are not near enough to appear as round discs. They may, however, be distinguished very often by their brightness and by the fact that they do not usually twinkle so much as a star.

When you think you have found a planet, notice its position with regard to some other star and see whether it appears to move nearer to it or farther from it as the days go by. If it does, then you may be sure it is a planet and not a star. The best way, however, to find a planet is to look in *Whitaker's Almanack* to find out its position in the sky and track it down from that.

This, however, is rather difficult for the beginner.

The Dusty Earth. Our planet, the earth, may be called "the dusty planet/' for its atmosphere is always heavily charged with dust from various sources. Volcanoes throw up dust to great heights and there, in a very fine state, some of it remains for years. Ascending currents of air carry up the finest particles of wind-borne dust and smoke to great heights, and meteors entering our atmosphere provide the atmosphere with dust of extra-terrestrial origin. The dust from such sources provides the nuclei for the condensation of water vapour and the formation of clouds. If it were not for the dust, clouds would not form, and we should have disastrous torrents of rain whenever the air became saturated with water vapour.

The blue sky is due to the dust in the air, for sunlight

when passing through the air is dispersed by it. The blue rays—the most "bendable" rays—are scattered most and later reflected from other particles of dust to earth. Blue rays thus reach us from all parts of the sky and, therefore, it appears to be blue.

As every Londoner knows, the sun, during times of fog, often appears quite red. This is because the blue rays are stopped by the particles of dust and water vapour, and it is mainly the red rays which succeed in penetrating through the fog to us.

The beautiful rosy hues of dawn and the brilliant and much admired sunsets, are largely caused by the dusty state of our atmosphere. Some of the most glorious sunsets are seen in the smoky atmosphere of London and other industrial towns. After the famous eruption of Krakatoa, when a large portion of the island was blown to dust, unusually beautiful sunsets were seen for several years in quite distant parts. They were caused by the dust which was carried round the world by air currents in the upper atmosphere.

Diameter of the Earth. The diameter of the earth has already been stated to be about 8,000 miles. How is the diameter of the earth measured? Let us see how to find the circumference, and then it will be quite easy to calculate the diameter, for the circumference of a circle is $3\frac{1}{7}$ times the diameter. This ratio of $\frac{22}{7}$ is known as π . The Egyptians and Greeks noticed that at Syene the sun was at the zenith on a certain day at a certain time, and that at Alexandria some distance north of Syene it was not at the zenith at that time. The angle between the sun and the zenith was measured and the distance from Alexandria to Syene was also measured.

Let us take some figures as an example. From the diagram (Fig. 72), we see that the angle between the lines

to the sun and zenith is equal to the angle between the two zeniths. This gives us the angle between Alexandria and Syene. Suppose it is 3 degrees and that the measured distance is 208 miles. Then it follows that—

$$\begin{aligned} 360^{\circ} &= 208 \text{ miles} \times 120. \\ &= 24960, \text{ or roughly } 25,000 \text{ miles.} \end{aligned}$$

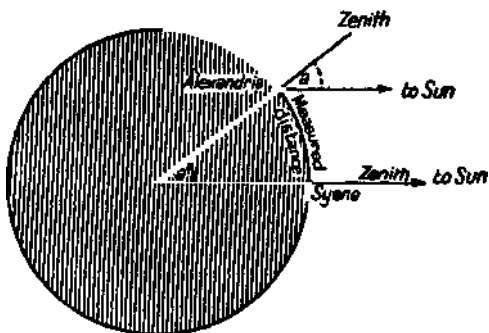


FIG. 72. MEASUREMENT OF EARTH'S CIRCUMFERENCE AND DIAMETER

The sun is overhead at Syene but not at Alexandria

From the formula—

$$\text{Circumference} = \pi d.$$

$$\begin{aligned} \text{Diameter} &= 25000 \times \frac{7}{22} \\ &= 8580 \text{ approx., or roughly } 8,000 \text{ miles.} \end{aligned}$$

How the Weight of the Earth can be Obtained. Every body attracts every other body with a force which is proportional to their masses. If a big lead ball be placed under a pan of very, very delicately balanced balances, the pan will be attracted by the lead ball, and a small weight will have to be placed on the other pan in order to restore the balance.

WONDERS OF THE UNIVERSE

Suppose we take some simple figures as an example of method.

Let the lead weight weigh 1,000 lb., and suppose the weight necessary to restore the balance is a very small one, say, .0001 lb.

If the earth pulls with a force of 1 lb.

then the earth and ball pull with a force of .10001 lb.

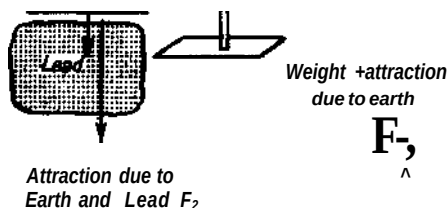


FIG. 73. HOW TO WEIGH THE EARTH

Thus, the weight of earth : weight of 1 earth + ball
as 1 : 1-0001 FORcc Foece

$$\therefore 1-0001 E = E + 1000 \text{ lb.}$$

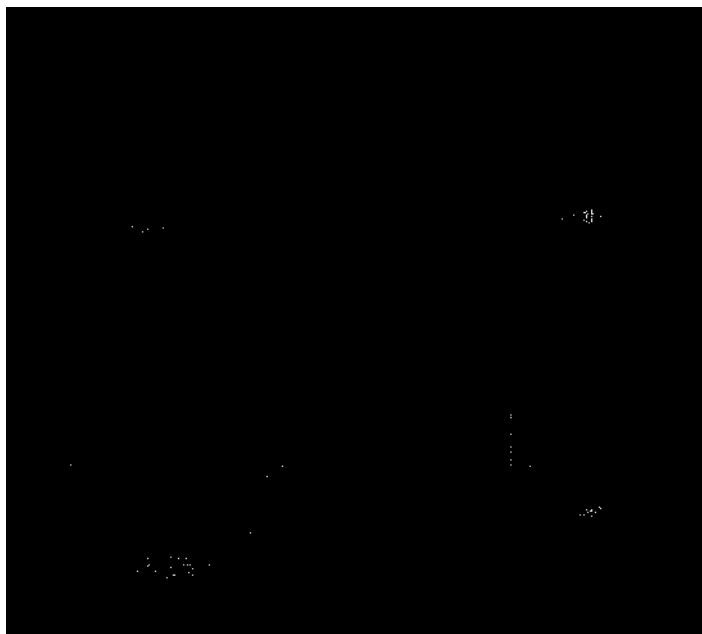
$$0001 E = 1,000 \text{ lb.}$$

$$\text{and } E = 10,000,000 \text{ lb.}$$

These figures are, of course, not anything like the correct figures, but if you can follow this example you can understand how by very careful experiment it is possible to use Newton's Laws to weigh the earth. The real weight of the earth is 6,000 million million million tons.

Many other facts about the earth's orbit and movements

have been given in earlier chapters, so we will now turn to the next planet, Mars.



By courtesy of E. C. Slipher

Lowell Observatory

FIG. 74. MARS

The two top images are direct photographs of Mars. The large image is a drawing from observation showing the "canals." The fourth image is a photograph of the drawing. Notice the snow caps

The Red Planet—Mars. Mars is the most easily recognized of all the planets, because it appears distinctly reddish to the naked eye. There are, however, red stars. Do not mistake them for Mars. Of all the planets, Mars is the one which most nearly resembles the earth, and is, therefore, most likely to have life on it something similar to that on the earth. Through the telescope we see that



By courtesy of E. C. Shipher Lowell Observatory

FIG. 75. TELESCOPIC PHOTOGRAPHS OF MARS

Note the gradual decrease of the polar snow and the darkening of the planet's tropics during the Martian summer. The darkening may be due to the growth of vegetation

Mars has continents and polar ice caps. The ice caps diminish in size with changes of seasons, just as our polar ice caps do.



By courtesy of E. C. Slipher

Lowell Observatory

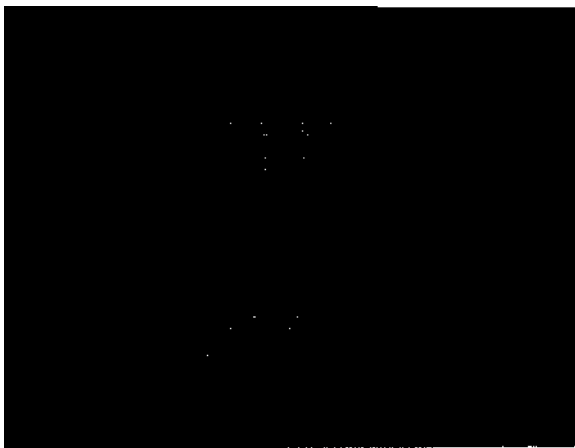
FIG. 76. MARS

Left, drawings; right, photographs showing the behaviour of a great white spot (area 300,000 sq. miles) in the tropics of Mars, 9th to 10th July, 1922. The spot appeared suddenly and lasted four days, but changed its position and appearance each night. It is thought to show a Martian storm

The orbit of Mars is more eccentric than the earth's, and, consequently, sometimes Mars is much farther from the sun than at other times. The greatest distance from the

sun is 154 million miles, and the least distance is 128 million miles. It takes nearly two years to complete one revolution.

From Fig. 78 you may see that, at certain times, Mars



By courtesy of E. C. Slipher

Lowell Observatory

FIG. 77. TWO SATELLITES OF MARS

Phobos is quite close to the planet and Deimos about two-thirds of an inch farther to the right

is very much nearer to us than at others. We are able to examine the surface of Mars best when the sun and Mars are on opposite sides of the earth. We then say Mars is *in opposition*.

Canals of Mars. At such times, by means of large telescopes, astronomers can see markings on its surface, which are popularly known as the Canals of Mars. These marks appear to become broader and alter in colour during the summer. Some think that they are belts of vegetation which spring up along watercourses formed by the melting of the polar ice caps. Others think that these "canals" may be the result of great irrigation works produced by

some living beings in order to keep in cultivation land situated in almost waterless districts. There is no doubt about the presence of these marks, but that there is any

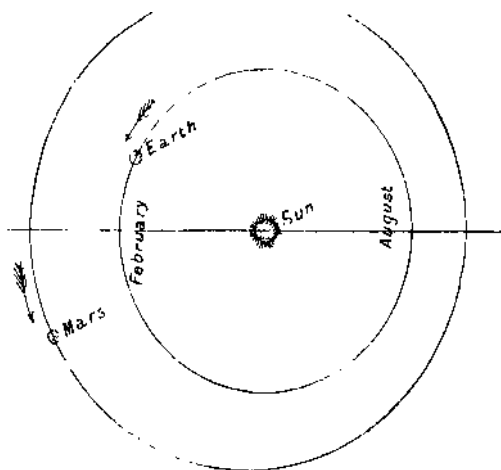


FIG. 78. ORBITS OF EARTH AND MARS

living creature able to construct such elaborate irrigation works is by no means proved.

Mars has a diameter about half that of the earth. It is more developed than the earth, is cooler, has less gravity, and little atmosphere. If life is present, it must be very different from anything we know upon earth.

Mars has two moons, one of which revolves round it three times during the day, which is $24\frac{1}{2}$ hours long.

CHAPTER VI

The Sun's Family

PART II. THE GIANTS OR OUTER PLANETS

THE giant planets are separated from the dwarf planets by a space containing many asteroids or minor planets. Only two of the giant planets, Jupiter and Saturn, were known to ancient astronomers; the others, Uranus, Neptune, and Pluto, are comparatively recent discoveries.

All the giant planets are so distant from the sun that the latter would appear very small if it could be observed from their surfaces. Fig. 79 gives some idea of the appearance of the sun when seen from the various planets. The light and heat received from the sun would be very small compared with the amounts received by us. Neptune, for instance, receives only 1/900 of the light and heat that we do in spite of its larger size.

All the major planets are now thought to be so cold that water vapour cannot exist on them. Their temperatures are believed to be in the neighbourhood of -150° to -170° C. Possibly, the cloud belts are of Carbon dioxide instead of water.

We do not see phases of the giant planets or of Mars as we do of the planets Mercury and Venus, which are nearer to the sun than we are. The outer planets, whenever seen by us always appear either full or slightly gibbous in shape. We never see them in the crescent phase. Experiments with balls and a lamp will make this clearer to you than any diagram or pages of explanation. Try it.

Jupiter. The first of the giant planets is Jupiter, which is the largest of all the planets. It is nearly twice as big as

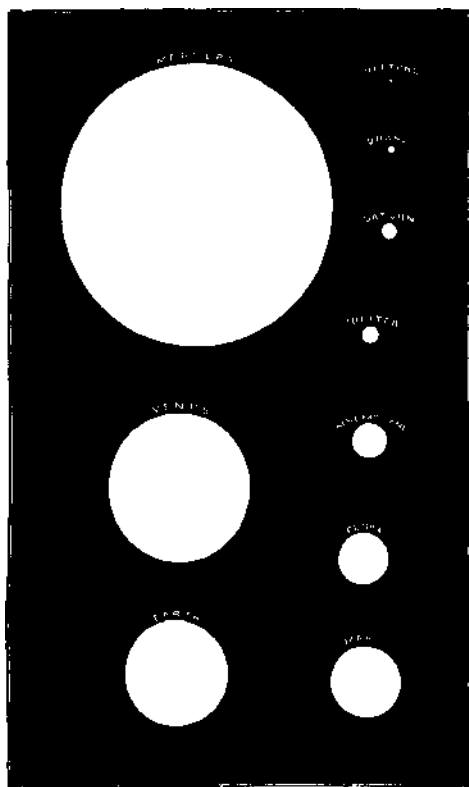


FIG. 79. THE APPARENT SIZE OF THE SUN WHEN VIEWED FROM THE DIFFERENT PLANETS

all the other planets rolled into one, and 1,400 times the size of the earth. It has a gravity 2-6 times that of the earth. You would, if on Jupiter, weigh two and a half times as much as you do now, and you would find it over twice as hard to lift a given weight or to jump a given height.

The surface of Jupiter is never seen because it is covered with belts of clouds (see Fig. 81). These clouds reflect sunlight so well that Jupiter is the brightest of the planets after Venus.

Jupiter rotates on its axis every 10 hours. To do this

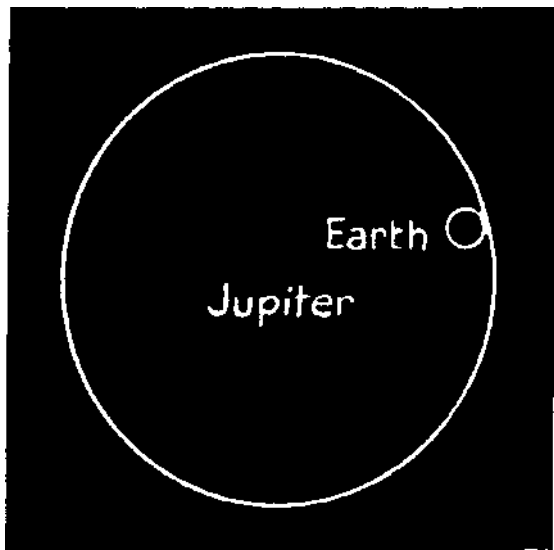


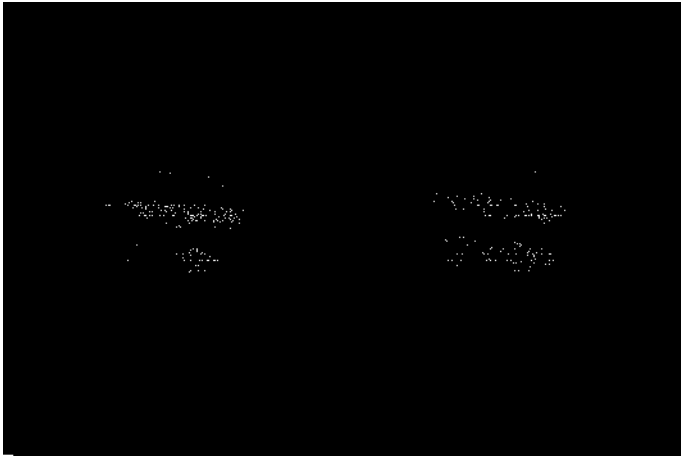
FIG. 80. THE SIZE OF JUPITER COMPARED WITH THAT OF THE EARTH

it must move at a great speed on account of its size. When viewed through a telescope, the planet appears to be oval or very much flattened at the poles. Its equatorial diameter is about 5,000 miles greater than its polar diameter. This flattening of the poles is due to its rapid rotation. The orbit of Jupiter has a diameter of 966 million miles, and it takes the planet 12 years to revolve round the sun.

As the inclination of Jupiter's axis to the plane of its

orbit is small, therefore there can be very little seasonal change.

Jupiter's Satellites. Accompanying Jupiter on its long



By courtesy of

Lowell Observatory

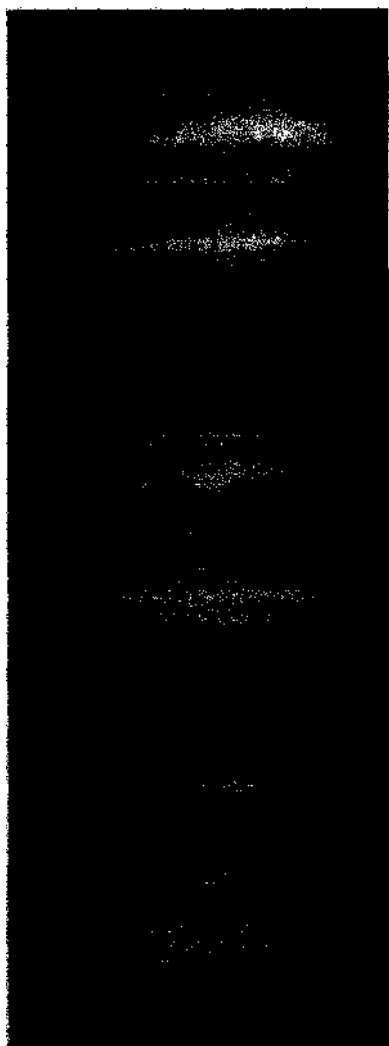
FIG. 81. JUPITER, SHOWING CLOUD BELTS AND FLATTENING OF THE POLES

By courtesy of

Lowell Observatory

FIG. 82. TWO PHOTOGRAPHS OF JUPITER AND FOUR OF ITS MOONS IN DIFFERENT POSITIONS IN THEIR ORBITS

journey round the sun are nine moons. Galileo discovered four of the biggest of these moons, which are all about the same size, but at different distances from Jupiter. Their



By courtesy of E. C. Slipher Lowell Observatory

FIG. 83. JUPITER

Three photographs of the same face of Jupiter. In the top two notice the great red spot shown in the photo as a black oval patch. Also notice other marked changes in the belts

times of revolution round the planet vary from 2 to $16\frac{3}{4}$ days. The other satellites were discovered much later by the use of big telescopes. The last moon discovered was found by means of the camera at Greenwich Observatory. It has never been seen even through a large telescope.

To an observer on Jupiter the moons of Jupiter would pass through phases just as our moon does, and they would produce eclipses of the sun or be eclipsed themselves when they passed into the shadow of Jupiter.

Observing the moons from the earth, we do not see them in their different phases, but we can see them as they revolve round Jupiter. Sometimes they appear on one side of the planet and sometimes on the other. They are fascin-



FIG. 84. SKETCH OF JUPITER AS SEEN BY MISS M. TINDALL THROUGH THE SIX-INCH TELESCOPE AT HAMPSTEAD OBSERVATORY

Note the cloud belts, the bright satellite in transit and its black shadow to the right of it

ating to study, for there are several things we may notice—

1. When a satellite or moon passes between us and Jupiter, it is so small compared with the planet that we speak of its transit across the face of Jupiter and not of the eclipse of Jupiter. This is similar to the transit of Venus across the sun.

2. As the satellite is seen crossing the face of Jupiter, we may often see the shadow crossing the disc as well. The satellite appears much brighter than its shadow, and sometimes it is rather difficult to distinguish. Fig. 84 shows a satellite and its shadow upon the disc of Jupiter.

3. Sometimes, as one watches, one of the satellites seems to vanish suddenly as though it had been "put out." This is because it has entered into the shadow of Jupiter, and therefore receives no light from the sun which it can

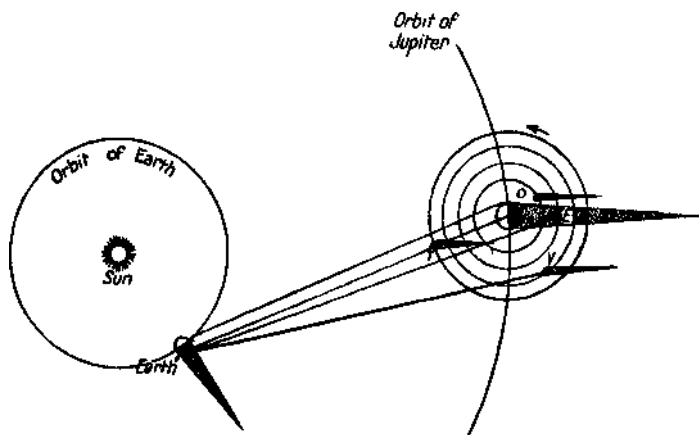


FIG. 85. SHOWING JUPITER WITH HIS FOUR CHIEF SATELLITES AND SHADOWS

V is visible some distance from Jupiter

T is visible in transit across the disc of Jupiter

E is eclipsed by shadow of Jupiter

O is occulted by the planet after having been eclipsed by the shadow

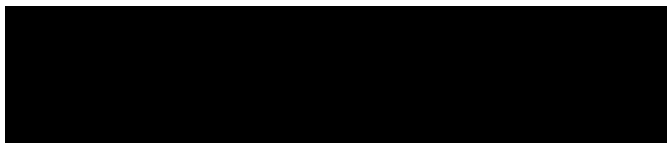
reflect to us. In other words, the satellite has been eclipsed by Jupiter.

4. At other times we may see the satellite pass behind Jupiter and thus vanish from our sight. Although we cannot see it, it is still shining on Jupiter, for it is still receiving light from the sun. This satellite is said to be *occulted* (concealed). In cases of occultation, the satellite is concealed by the planet and not by its shadow.

Interesting as these moons are to us, they would be much more interesting to an observer on Jupiter. It is

fascinating to see our own satellite sailing majestically among the stars. How much more interesting it would be to watch several moons in the evening sky—some rising, some setting, some in one phase, some in another, and perhaps one being eclipsed.

Before proceeding to read about the next planet, study



By courtesy of E. C. Slipher

Lowell Observatory

FIG. 86. SATURN

n th Feb., 1916

24th May, 1922

10th Sept, 1929

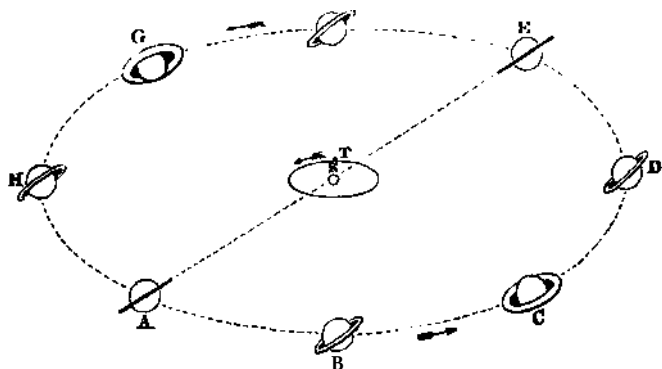
Photographs show three aspects of Saturn and its rings. In the central picture the dark band is the shadow of the rings. The shadow of the planet upon the rings is seen in the left and right pictures

carefully the diagram showing *transit*, eclipse, and occupation of Jupiter's moons.

The Ringed Planet. We now come to the most remarkable of planets, which provides, at times, a most strange and beautiful telescopic sight. Saturn is famous for its three rings, and many pictures of this planet show them. As a consequence, Saturn is sometimes a great disappointment to a casual observer; for it is only possible to see the third ring plainly through the biggest of telescopes, and sometimes none of the rings can be seen at all. When Galileo first saw the planet, he noticed what appeared to be two bright globes, one on each side of the planet. Later these globes dwindled in size and finally disappeared, much to his surprise and dismay. He wondered if he had been deceived. His eyes had not deceived him for he had

observed the planet when the rings were nearly "edge on" towards the earth. As they became quite "edge on," the rings became invisible. It was some years after Galileo's observation that astronomers discovered the rings.

These rings appear different at different times. To understand this, walk round a lamp on a table and *get*



THE PHASES OF SATURN'S RING

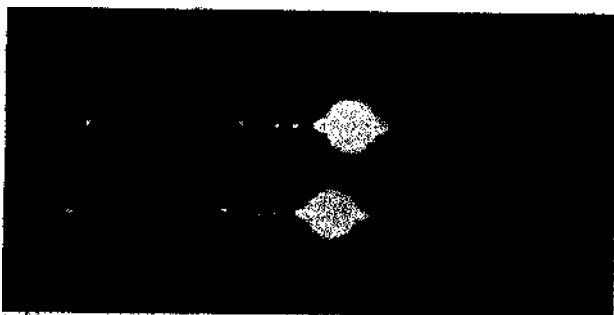
a friend to walk round it in a bigger circle while holding in his hand a plate which is inclined to the table. If you observe this plate from different positions, you will notice that sometimes you can see only the edge of it and at other times more or less of the surface. The plate, of course, represents the rings of Saturn. Fig. 86 shows photographs of Saturn and its rings taken in different years.

The rings may be considered to be an immense number of tiny moons all revolving round Saturn, or as a swarm of meteorites so close together that we do not notice the spaces between them as they revolve round the planet.

They are about 170,000 miles in diameter but under

100 miles thick, and are about 6,000 miles from the planet. The division between the two outer rings is about as wide as the Atlantic Ocean.

Besides these three rings, Saturn has nine moons. What a wonderful night sky there must be on Saturn, with three luminous rings partly hidden by the planets' shadow and several moons in the sky. The division between the outer



By courtesy of E. C. Slipher

Lowell Observatory

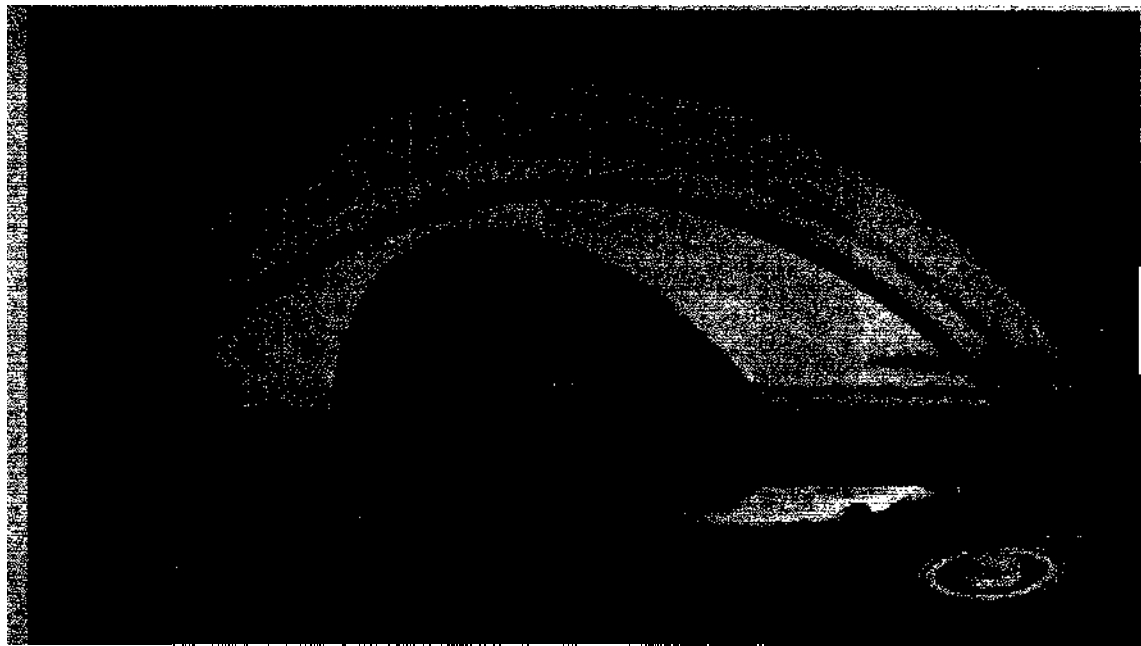
FIG. 88. SATELLITES OF SATURN, 1921

The photograph shows five of Saturn's moons. The ring is edgewise on, and therefore appears as two protuberances on the planet.

Remember Galileo saw the planet like this

and inner ring is caused by one of these moons attracting some of the small particles which form the rings.

Saturn itself is 886 million miles distant, or nearly twice as far as Jupiter, from the sun. It, therefore, has a very long journey round it which takes 29 of our years. It is so far from us that its moons are not so easily observed as those of Jupiter. The diameter of Saturn is nine times that of the earth and its time of rotation is about $10\frac{1}{2}$ hours. Saturn, like Jupiter, is very flattened at the poles, and its surface has belts of cloud very similar to those of Jupiter. As the axis of Saturn is inclined $26\frac{1}{2}^\circ$ to its orbit, it will have seasons, but very long ones.



By courtesy of

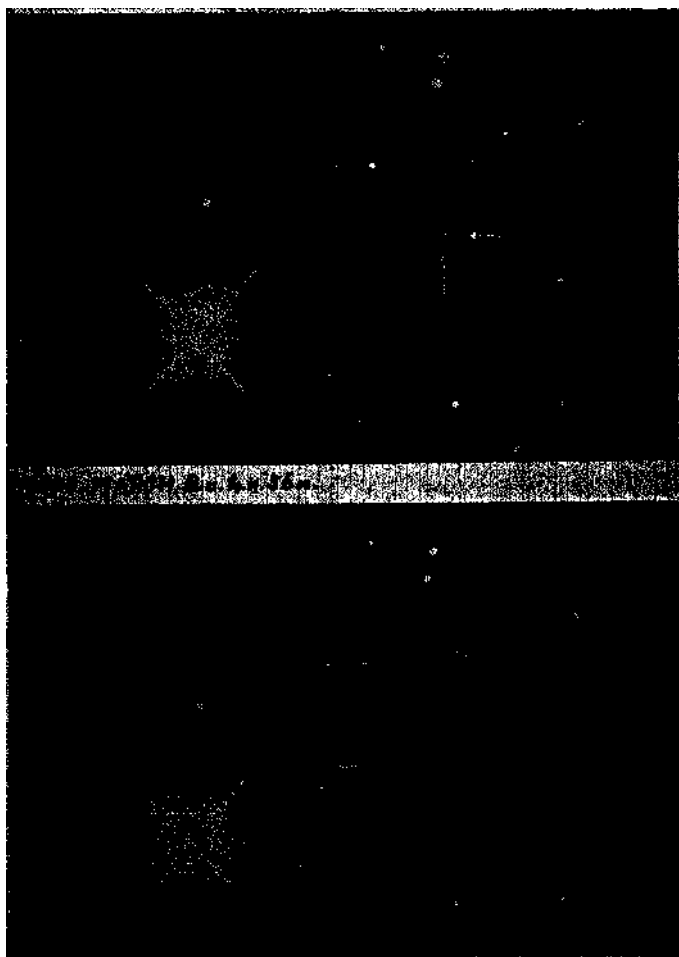
FIG, 89. IF LONDON WERE ON SATURN
A drawing showing the rings of Saturn and some of its satellite in different phases

With Saturn we have reached the last of the planets which were known to the ancient astrologers and astronomers.

Uranus. In 1781, Herschel, when examining the stars, noticed an object which appeared as a small disc. Upon using a higher power, the disc became clearer. A star does not do this. Later, he noticed that it had moved, and he wondered whether it might be a comet. Further observations, however, proved it to be a planet and it was given the name of Uranus. This planet is at a distance of 1,781 million miles from the sun, and so far from us that it is hardly visible. It is smaller than Jupiter and Saturn, but four times as big as the earth. It has four moons. The length of its year is equal to about 84 of our years.

After Uranus was discovered calculations were made, and it was expected to obey the ordinary laws of planets. The planet, however, did not behave properly. It did not appear in its right place in the sky at the right time. This annoyed astronomers, because they pride themselves upon the exactness of their predictions. At last they decided that there must be another planet which was preventing Uranus from behaving as it should do. Two men, one a French mathematician and the other an English astronomer and mathematician, set to work to calculate the position of another planet which would explain the motions of Uranus. When these calculations were finished, astronomers looked in the sky where they were told to, and in less than half an hour discovered the planet which was disturbing Uranus.

Neptune. The new planet was given the name of Neptune. It is nearly thirty times as far from the sun as the earth, and so far from us that it is quite invisible except through a good telescope. Neptune has only one



1930.MARCH.5D.3H.44M.

By courtesy of

Lowell Observatory

FIG. 90. PLUTO, THE NEW PLANET, IS INDICATED BY THE
ARROWS

From these two photos it may be seen that Pluto has altered its
position among the stars, thus showing that it is a planet.

satellite. Recently, Professor Lowell noticed irregularities in the movements of Neptune, and began to think there must be still another planet beyond it.

Pluto. After a year spent in careful searching, a new planet was discovered in 1930 by the aid of the camera. This planet has been given the name of Pluto. It was distinguished from a star by the fact of its change of position with regard to the other stars (see photographs). Pluto appears only as a point of light in any but the largest of telescopes. Its diameter is about 4,000 miles, or about equal to that of Mars. Its orbit has been calculated to be so large that the planet takes 248 years to complete one revolution. Perhaps, as this planet is so small, it should have been included among the dwarfs, but its position in the plan of the solar system makes it more convenient to mention it here. Astronomers are now talking of the possibility of another planet still more remote from the sun than Pluto!

Are the Planets Inhabited ? This is a question which is always being asked and never definitely answered. No one can say, definitely, whether life is present or not, but one can feel fairly certain that in all cases except Mars it is very improbable that life, such as we know it, could exist.

Mercury and Venus are suspected of turning only one side to the sun. If this is so they must be scorched on that side and intensely cold on the other. All the giant planets are now thought to be very cold, with no water vapour in the atmosphere, but all frozen to solid ice.

Mars appears to have little atmosphere and most of the land seems to be parched. If life be present on Mars it must be adapted to very different conditions and probably quite unlike anything that we know.

EXERCISES ON CHAPTERS V AND VI

- i. Experiment with balls and a light to see why Mercury and Venus show phases like the moon, while the outer planets, Mars, Jupiter, Saturn, etc., do not.
2. Make a sketch of the solar system, placing the planets in their right order.
3. Explain why it is really wrong to call Venus the "Evening Star."
4. When is Venus best seen? Give diagram and explain.
5. Give reasons why Mercury and Venus are well named.
6. What everyday phenomena depend upon the dust in our atmosphere?
7. What is the difference between a *transit* and an eclipse?
8. Venus is bigger than the moon. Why does it not hide the sun?
9. How may we recognize a planet?
10. The circumference of Jupiter is 266,000 miles. It rotates in 10 hours. How fast does a spot on the equator of Jupiter move in miles per second?
11. Work a similar sum for the earth with circumference 25,000 miles, and time of rotation 24 hours.
12. Why does Jupiter appear as an oval when seen in the telescope?
13. Which planets have been discovered since the invention of the telescope?
14. What is the difference between an eclipse and an occultation of one of Jupiter's satellites?
15. Name the dwarf planets in order of size.
16. Name the giant planets in order of size.
17. How was Neptune discovered?
18. Write a description of the evening sky as seen from Saturn.
19. Why do Saturn's rings show phases?

CHAPTER VII

Minor Planets, Meteors, and Comets

ALTHOUGH members of the sun's family, the asteroids have been omitted from the two previous chapters,

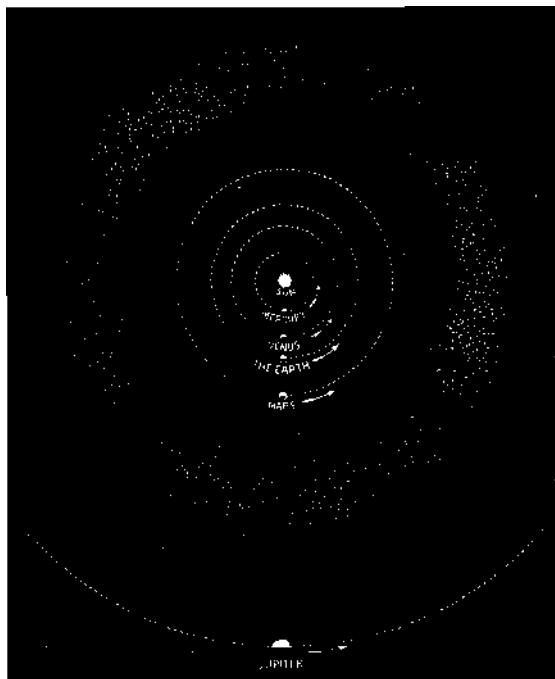


FIG. 91. THE REGION OF THE ASTEROIDS BETWEEN THE ORBITS OF MARS AND JUPITER

because they are more comparable in size with meteors and comets than with planets. The asteroids revolve round

the sun in elliptical orbits, which lie between the orbits of Mars and Jupiter. They appear to represent the material of a planet which failed to form into one spherical mass. The total number of the asteroids is not known, but over 800 have been recorded photographically. Ceres, the largest known, is about 400 miles in diameter,



By courtesy of

Dr. Max Wolf

FIG. 92

Two minor planets are shown as two short lines because they moved among the stars upon which the camera was turned

but the smallest known is only three miles across and is irregular in shape. Eros, 20 miles in diameter, has an orbit which crosses the orbit of Mars and thus, at times, becomes our nearest celestial neighbour after the moon. At its nearest, it is about 13 million miles from us. Although so small, Eros has been useful to astronomers, for they have used it to help them to determine the distance of the sun more accurately than could be done by using either Mars or Venus.

Falling Stars. Doubtless you have gasped with astonishment when you have seen a shooting star, and have wondered just what has taken place. The Babylonians used to think that shooting stars were *real* stars, which



FIG. 93. A SHOWER OF SHOOTING STARS OR METEORS SEEN AT SEA

had broken loose from the starry ceiling and were falling to the lower regions. The Arabs considered them to be fiery torches flung by angels at wicked jinn who were trying to sneak into heaven during the hours of darkness.

We now know them to be masses of stony or metallic



By courtesy of

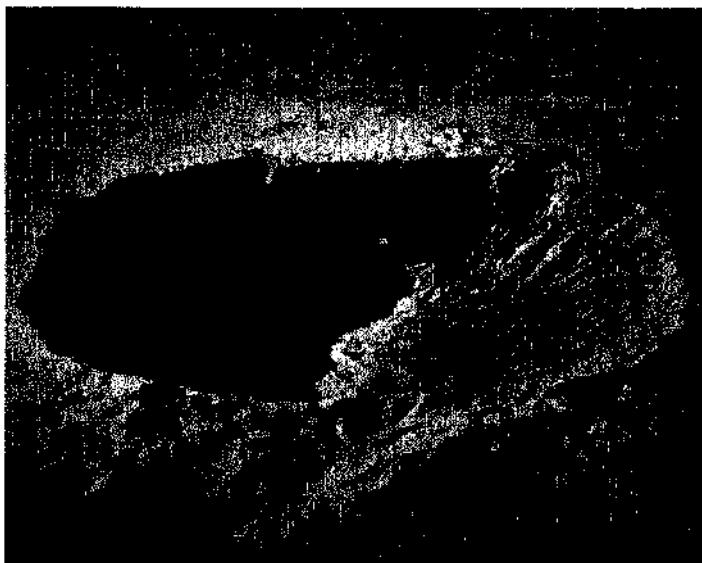
C. P. Butler, Esq.

FIG. 94. AN EXPLODING METEOR

material which, while flying through space, have come so close to the earth as to be attracted towards it. They enter the upper regions of our atmosphere while travelling at a speed of from 20-30 miles per second. Friction with the atmosphere, at this great speed, is so great that they become incandescent and, if small, are burnt up or changed to vapour. Sometimes shooting stars

appear to move very slowly across the sky and at other times very swiftly. In the first case, the meteors are overtaking the moving earth, and in the second case, they and the earth are moving towards each other.

Meteorites, As these incandescent bodies pass through the air we see their bright trails, perhaps 20 miles in length, stretched across the sky. Most of the meteors or "falling stars" are consumed before they reach the surface of the earth, but the larger ones do, occasionally, fall on the earth's crust. They have been picked up and studied by chemists who wished to discover their composition. Some of those examined are very metallic and others are stony. The metallic ones often consist of 90 per cent of iron



By courtesy of

H. J. Shepard

FIG. 100. AN AERIAL VIEW OF A GREAT METEOR CRATER
IN ARIZONA

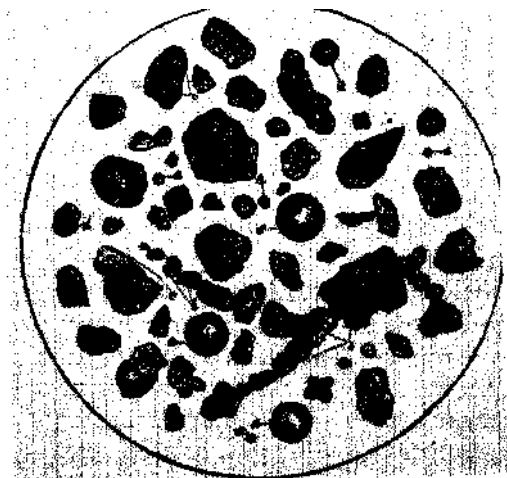


FIG. 101. METEORIC DUST (MAGNIFIED)

the pellets are sometimes found in mud dredged from deep seas.

The atmosphere may be looked upon as a screen which protects us from the meteors, which would otherwise reach us in great numbers. It is estimated that millions of



H.E.T.

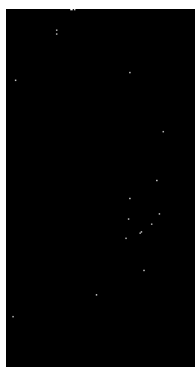
FIG. 102. NODULES OF MARCASITE WHICH ARE OFTEN
WRONGLY CALLED METEORITES OR THUNDERBOLTS

They are nodules of iron sulphide which are commonly found in the
lower layers of the chalk

meteors, weighing anything from an ounce to a ton, enter our atmosphere every day.

Thunderbolts and Fulgurites. Fire-balls, such as the one that fell in Normandy, make a noise similar to thunder when they explode. They have been mistakenly called thunderbolts.

The thunderbolt, of which we hear so much, is unknown to science. All the reputed thunderbolts are easily recognized as common, earthly substances which have been



By courtesy of

E. C. Slipher, Lowell Observatory

FIG. 103. MOREHOUSE COMET, 1908

17th Nov.

28th Nov.

Notice the difference in the tails

picked up after an exceptionally heavy thunderstorm. Minerals, fossils, and even cinders dropped from a passing fire engine have often been claimed to be thunderbolts.

The nearest thing to a thunderbolt that can be found is a fulgurite. A fulgurite is simply a tube of earth—generally sand—which has been fused by the intense heat of the lightning spark passing through it. Specimens of fulgurites may be seen in a corner of the meteorite gallery at the Natural History Museum.

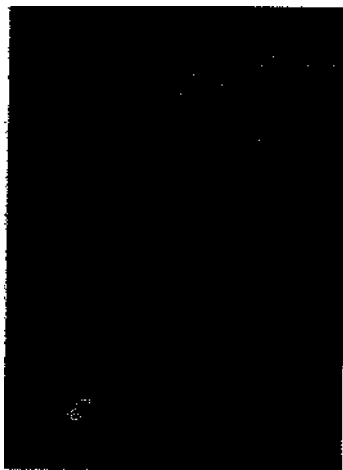


Photo by E. E. Barnard

FIG. 104. COMET SWIFT, 1892

Comets.

Comets importing change
of times and states
Brandish your crystal
tresses in the sky,
And with them scourge the
bad revolting stars
That have consented unto
Henry's death.

Henry VI, Act i, Scene I.

We are told by historians of all ages and all countries, of the terror caused by the sight of flaming stars or comets.

An old poet writes—

"... A blazing star
Threatens the World with Famine, Plague and War;
To Princes, death; to Kingdoms, many crosses;
To all Estates, many losses;
To Herdsmen, rot; to Ploughmen, hapless seasons.
To Sailors, storms; to Cities, treasons."

A comet seen in 43 B.C. was thought to be the chariot sent by God to take the soul of Julius Caesar to heaven. In 1066 a wonderful flaming star terrified the people. After the battle of Hastings was won, it was commonly believed that the comet was the herald of William's victory and Harold's death. The Bayeux tapestry, which

tells the story of the conquest of England, has a picture of this comet woven into it.

The Chinese astrologers thought that comets told of ambassadors moving from place to place. As the movements of ambassadors were important political events, they recorded all comets seen. These old records of comets

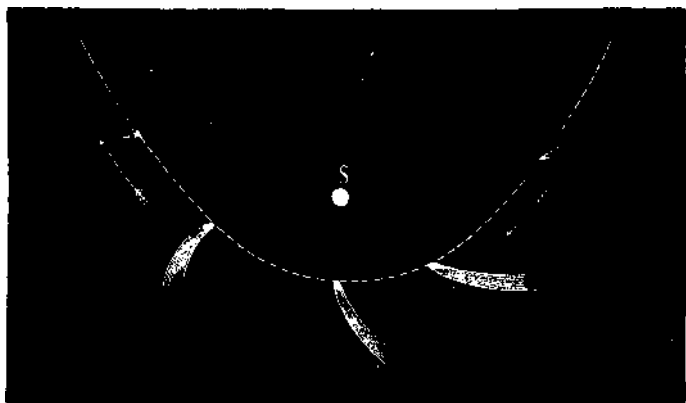


FIG. 105. PART OF THE ORBIT OF A COMET

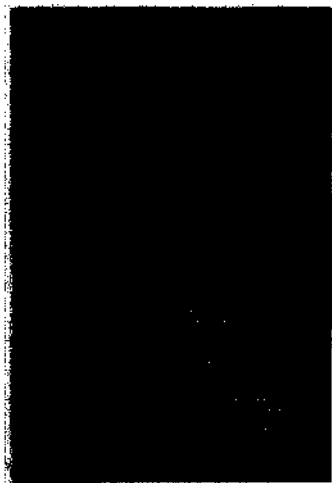
Note the tail does not show the direction of the comet's movement

have been useful to astronomers when studying the comets as heavenly bodies belonging to our solar system.

The word "comet" comes from a Greek word meaning "hair." It was given to these bodies because of the long, hairy tails which some comets have. (See Fig. 103.)

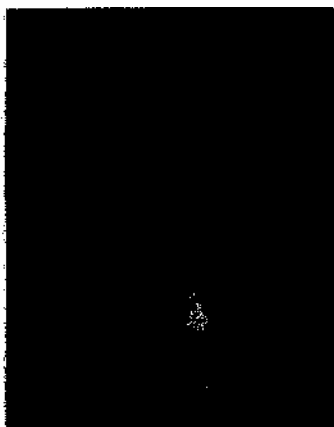
The brilliant head of a comet (nucleus) is now considered to be a mass of meteors—perhaps 1,000 miles wide—which is swinging along a very elliptical orbit extending from near the sun to far beyond the outermost planet known. As the nucleus approaches the sun, its speed increases, and a tail, or perhaps more than one, develops. The tails of comets are an incandescent mist, perhaps

50-200 million miles long. They appear to be formed in front of the head, and are then almost immediately pushed backward by the pressure of sunlight. The tail consequently always points away from the sun and gives no



By courtesy of Dr. H. Knox Shaw, Radcliffe Observatory, Oxford

FIG. 106. COMET BROOKS, 1911



By courtesy of Greenwich Observatory

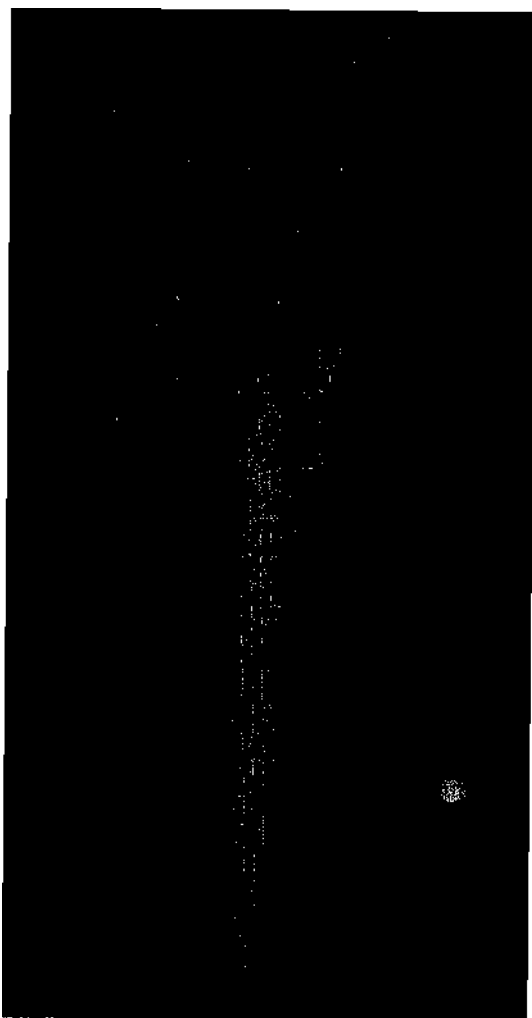
FIG. 107. A COMET WITH SEVERAL TAILS

Stars appear as trails because the camera was made to follow the motion of the comet

indication of the direction in which the comet is moving. (See Fig. 105.)

Although we do not now fear comets in the same way as people used to, yet there are still some who fear them in another way. When a great comet is seen approaching the sun, they wonder if it will strike the earth and thus bring about the end of the world. Others fear that the tail, which is so very long, will sweep across the earth and, perhaps, poison us all,

If a comet's head did strike the earth, we should probably see a great shower of meteors and probably some



By courtesy of Mr. Lampland and Mr. E. C. Slipher, Lowell Observatory

FIG. 108. HALLEY'S COMET, 13TH MAY, 1910

This photograph of Halley's Comet also shows—

- ∴ The planet Venus on the right
- ∴ A meteor passed across the comet during the exposure
- ∴ Stars drawn out into short lines because the camera was made to follow the comet

damage would be done. This is so unlikely to occur that we need not worry. The tail of a comet may very likely envelop the earth. Indeed, the earth has several times passed through the tails of comets and people have known nothing of it.

Halley's Comet. In the year 1910, the earth passed through the tail of the most famous of all comets, known as Halley's Comet. This comet has an orbit so large that it takes 75 or 76 years to complete one revolution.

Halley's Comet last approached near enough to the sun for us to see it in 1910. Its next appearance will be in 1986 when perhaps you may see it. If you do, you will certainly read in the newspapers about the astronomer Halley after whom it has been named. Halley saw it in 1682, and Kepler saw it in 1607. Halley worked out its orbit and predicted that it would be seen again in 1758 or 1759. He died before its return, but astronomers watched for it and found that it returned at the proper time, and in the proper place. The dates of the appearances of this comet have been worked out for many years back. In 1456, about the time of the fall of Constantinople, it was common for people to pray: "God save us from the Devil, the Turk, and the Comet."

Encke's Comet is a much more regular visitor but not nearly so big. It returns every $3\frac{1}{2}$ years.

Sometimes comets pass too near Jupiter and become deflected from their paths or even broken up. In 1846, a comet, known as Biela's Comet, broke into two, and finally became broken up altogether. Portions of this comet became strewn out along its orbit. When the earth passes across this track in November, many meteors are seen. Meteors usually seem to be travelling in swarms, and as the earth meets these swarms it gathers many of the individual meteors to itself. We thus see that some

meteors or shooting stars are merely fragments of comets which have broken up and left their remains strewn along their orbits, to be picked up by any passing planet.

EXERCISES

1. When do meteors become visible? In what month particularly are showers of meteors seen?

2. What is the connection between meteors and comets?

3. What have you learnt about meteors which might possibly explain some things seen on the moon?

4. Distinguish between the use of the words meteor and meteorite.

5. How did meteorites affect the construction of battleships?

6. Explain this quotation—

"When beggars die there are no comets seen

The heavens themselves blaze forth the death of Princes."

7. Which of the minor planets has been useful to astronomers? In what way?

8. Where are the minor planets situated and what do they possibly represent?

9. Name two famous comets. Who calculated the orbit of one of them?

10. What is a fulgurite?

11. Why do we often get showers of meteors in November?

12. What is a "falling star," a "fire-ball," the tail of a comet?

CHAPTER VIII

The Founders of Modern Astronomy

THE founder of modern astronomy was Nicholas Copernicus (1473-1543), who wrote a book to prove that the earth and the planets revolved round the sun, and that the old idea of the earth's being at the centre of all things should be given up. For that *geocentric* idea, he substituted the *heliocentric* idea. Copernicus, however, did not know, as we do now, that the earth and the planets revolve in elliptical orbits. He still believed that they moved in circular orbits, and, therefore, he still had to use some epicycles to explain the observed motions of the planets. Although his book was published in 1543, it was many years before the heliocentric idea was generally accepted. The Pope and the Church still believed in the older idea and thought it wicked to believe otherwise. Copernicus' book was, therefore, put on the list of books which should not be read, and people were forbidden to believe or to teach this new idea of the plan of the solar system.

A Great Observer. Tycho Brahe (1546-1601) was a Dane of noble birth. At an early age he became interested in the science of astronomy, because he observed an eclipse of the sun which took place at the exact time which had been foretold. This seemed so remarkable to him that he made up his mind to learn more of a science which could so accurately foretell what was going to happen to the heavenly bodies. He eventually established an observatory at Uraniburg, and there spent many years in making exact records of the movements of celestial bodies.

Tycho Brahe had no telescope, for such had not been invented, yet his observations and records were remark-



FIG. 109. COPERNICUS

ably accurate. He used a quadrant and sights in order to get exact measurements. Kepler, who followed him, stated that all theories of the movements of planets must fit in with the recorded movements made by Tycho. If they did not, then the theories were wrong not the records.

In the time of Tycho, sailors were crossing and recrossing the Atlantic to the newly-discovered lands of America.

Then, more than ever before, it was necessary to have some means of telling the correct time in order that sailors might find their position when out of sight of land. Tycho's great object was to make a table which would

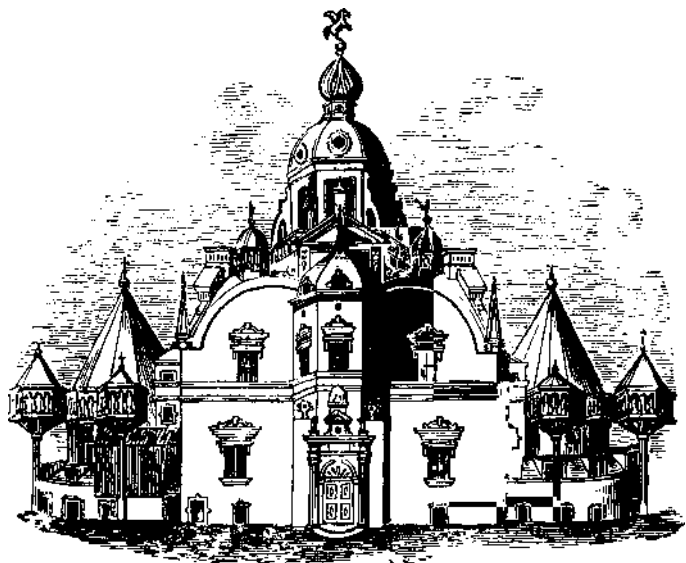


FIG. 110. TYCHO BRAHE'S HOUSE AND OBSERVATORY

help sailors by showing the times and positions of the heavenly bodies. From his numerous observations Kepler, after Tycho's death, drew up a set of tables and published them. They were known as the Rudolphine tables. The first Nautical Almanac, sometimes known as "the sailors' Bible," was drawn up on something the same lines and was based upon Tycho's tables.

Although Tycho lived after Copernicus and knew of his teaching, he still retained his belief that the earth was at the centre and that the sun revolved round it.

Kepler (1571-1630). When Tycho Brahe died Kepler,

The careful work of Tycho in observing and recording facts helped Kepler, the thinker, to find out the laws which became the foundation of the real science of astronomy. It is important to remember that the laws of science must agree with the facts observed or they cease to be laws. The laws of science are not laws which must be

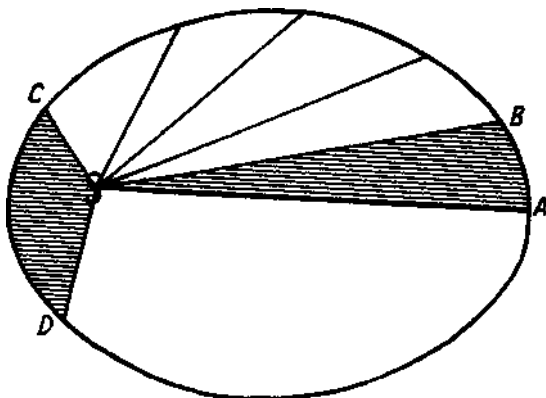


FIG. 113.

The radius vector or line joining the sun to the planet sweeps out equal areas in equal times. Note: Planet takes the same time to travel from C to D as from A to B

obeyed, but statements which seem to explain all or most of the observed facts and enable us to forecast what will happen under given conditions.

Galileo (1564-1621). Kepler had a friend in Italy with whom he corresponded about astronomical matters. This friend was Galileo Galilei, a professor of mathematics and science at Pisa, Padua, and Florence. Galileo believed that facts observed were more important than the statements of even such learned men as Aristotle. He challenged some of that great master's statements, and by experiments proved them to be wrong. Aristotle had said that heavy weights fell faster than lighter ones. Galileo

said they did not. The Church and the Schools condemned him for disagreeing with such a great authority. He did

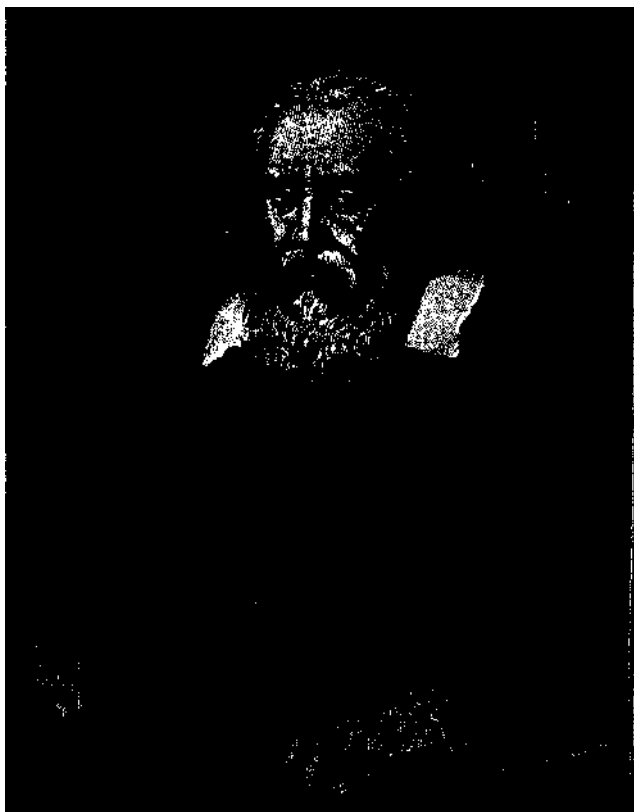


FIG. 114. GALILEO

not give in, but, before them all, he dropped two weights, one of 100 lb. and one of 1 lb., from the top of the Leaning Tower of Pisa. They reached the ground at the same time, thus proving Galileo right, and Aristotle wrong.

After this experiment, Galileo was so disliked that he

went to Padua, where he became professor of mathematics. By this time, he was a thorough believer in the teachings of Copernicus, and taught his students that the earth was just a speck in the universe, which revolved round the sun; and that men were very unimportant creatures crawling about on its surface.

Discovery of the Telescope. In 1608 a spectacle maker in Holland arranged two lenses in such a way that he could see distant objects more clearly. When Galileo heard about this, he thought over the news for some time, and then made a better instrument than the Dutchman had made. The telescope had now been invented, and it was not long before Galileo turned it towards the celestial bodies. By its means he was able to see the mountains on the moon and watch their shadows grow longer and shorter. He looked at the sun and saw spots on it which passed across from one side of the disc to the other, and thus proved that the sun rotated on its axis. He observed that Venus had phases like those of the moon; that Jupiter had four moons which revolved round it, and that Saturn had a most remarkable and puzzling appearance. As a result of his observations he was more than ever convinced of the truth of the Copernican idea, and therefore continued to teach it in spite of the opposition of the Church. At last he was brought before the Inquisition, and forced to promise not to teach it any more. After Galileo's death, the theory of Copernicus gradually became more widely known, and at last became accepted by all astronomers in spite of the wishes of the Church. The discovery of the telescope led to the discovery of an immense number of new facts about celestial bodies, their appearance, nature, and motions, so let us turn to the next chapter and study its construction.

CHAPTER IX

Three Important Instruments

THREE of the most important instruments to the modern astronomer are: the telescope, the camera, and the spectroscope.

The Telescope. There are two important kinds of telescopes, known as *refractors* and *reflectors*. The first made

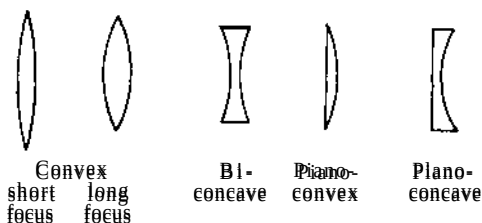


FIG. 115. FORMS OF LENSES

and best known is the refractor. It is so called because the light, which enters it, is bent or refracted by curved pieces of glass known as lenses. Lenses may be of many different shapes (Fig. 115). When rays of sunlight fall upon a convex lens they are bent or refracted so that they cross at a point called the focus (Fig. 116). The focus is an important part of the lens, although it is outside the glass of which the lens is made. The distance from the lens to the focus is called the focal length of the lens.

The telescope is an instrument designed to enable us to see at a distance. In order to see a thing clearly, two things are necessary: The object must be of a good size, and it must send sufficient light to the eye. There are

two parts in a telescope—the object glass and the eyepiece—which have quite different kinds of work to do. The object glass—or lens nearest to the object—forms a

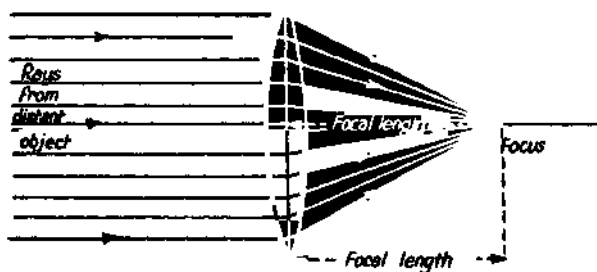


FIG. 116

brilliantly-lighted but small image near to the eye. The eyepiece is simply a means of magnifying this small bright image.

A simple telescope can be made from two convex lenses.

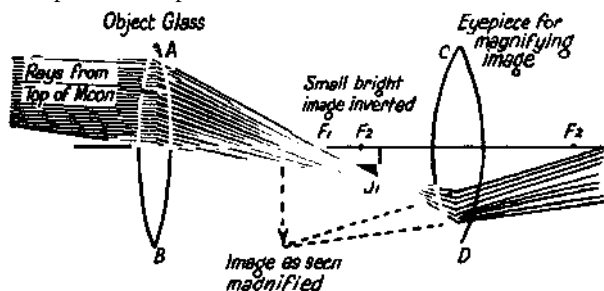


FIG. 117. TWO LENSES FORMING A SIMPLE ASTRONOMICAL TELESCOPE

The object glass should have a long focal length and a large diameter. The eyepiece should be smaller, with a shorter focal length. The bigger the object glass, the more rays of light will be bent to form the image, which will therefore be bright.

In Fig. 117, rays falling on lens AB form a small bright inverted image at I_v . The position of this image may be found by using a screen of ground glass or greaseproof paper. The eyepiece—lens CD —is placed nearer to this image than its focal length. An eye placed near the eyepiece will see a magnified image which is still inverted.

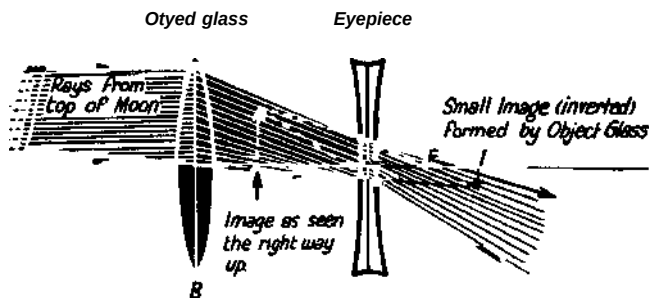


FIG. 118. TWO LENSES ARRANGED AS IN FIELD GLASSES OR GALILEO'S TELESCOPE

When using an astronomical telescope or looking at photographs of celestial bodies, it is important to remember that the image is inverted, so that the north of the moon or planets will appear at the bottom and the south at the top. In order to make the image appear the right way up, another lens would have to be used. This would cause some light to be lost and is therefore not done.

The image formed by the object glass may be magnified to different extents by using eyepieces of various magnifying powers. Too big a power must not be used with a small object glass or the image seen will not be distinct, because the first image is not bright enough to stand the magnification.

Galileo's Telescope. The telescope known as Galileo's telescope is not quite the same as the one described above.

A similar object glass is used to form an image at I

in Fig. 118, but a concave lens is placed nearer to the object glass than the image. The rays of light which would have formed an image at f , are now refracted by the concave lens as shown in the figure, and an eye placed near the eyepiece now sees an image the right way up. Field glasses and opera glasses are made in this way, but

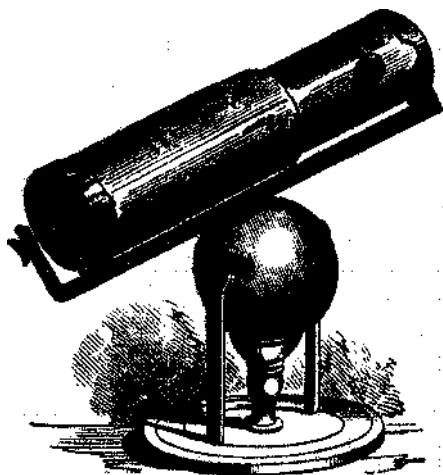


FIG. 119. A SMALL REFLECTING TELESCOPE

Note eyepiece near the open end

they are not used much for astronomical observations. However, if you have a pair of such glasses, use them, for many interesting things can be seen by their aid.

The Reflecting Telescope. When rays of light are bent by a lens, they are also dispersed as they are when they pass through a prism. As a consequence of this, the image may be seen with a coloured fringe. Sir Isaac Newton knew of no way of preventing this and, therefore, used a concave mirror instead of a lens to form an image. In reflecting telescopes, light from a distant object is allowed to fall on a concave mirror placed at the lower end of

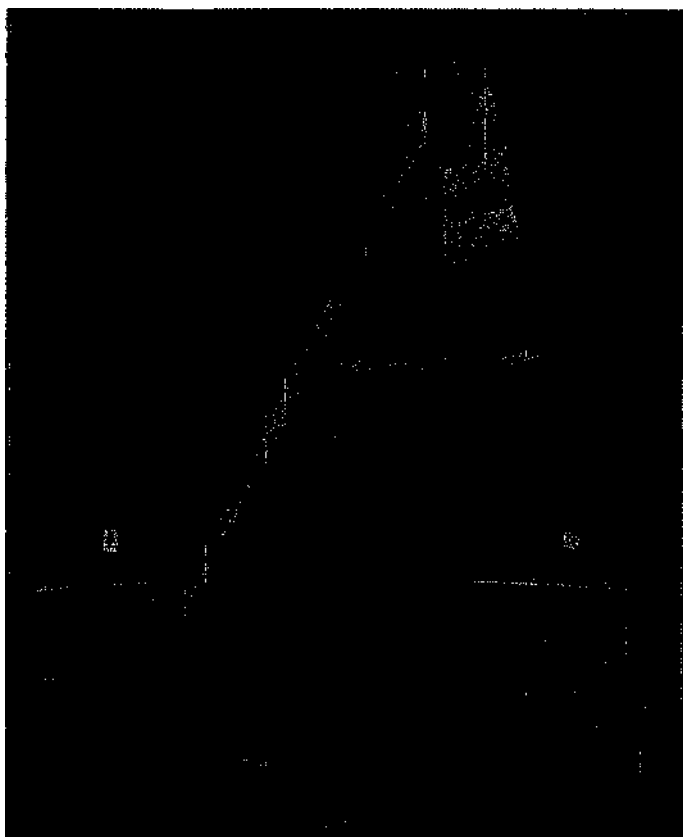
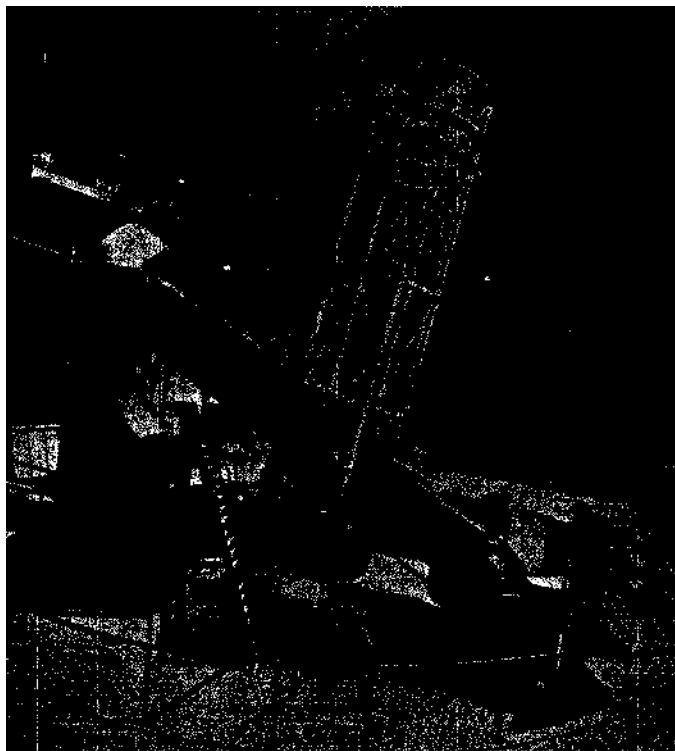


FIG. 120. THE LARGE REFRACTING TELESCOPE AT YERKES OBSERVATORY

the telescope tube. The light is reflected in such a way that an image would be formed near the open end of the tube. In order to see this image, the observer would have to look down the tube and his head would, therefore,

cut off the light from the object. To prevent this, a small mirror or prism is placed in the tube at *P* (Fig. 123). This

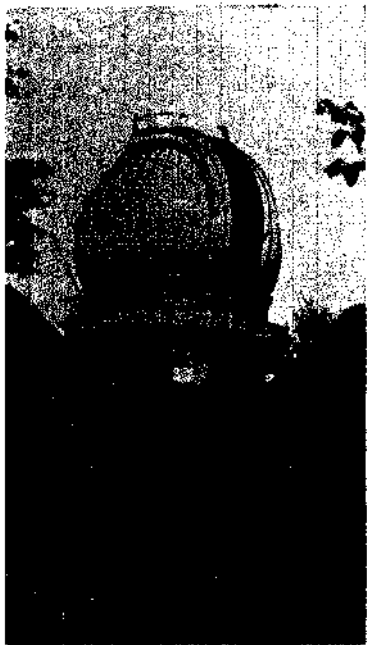


By courtesy of

Mt. Wilson Observatory

FIG. 121. THE GREAT 100-INCH REFLECTOR TELESCOPE AT
MT. WILSON OBSERVATORY, CALIFORNIA

reflects the rays which were going to form the image and makes them form an image near the side of the tube. A hole is made in the side of the tube, and the eyepiece is inserted to magnify the image. If you study Fig. 123



By permission of The Astronomer Royal

FIG. 122. THE DOME HOUSING ONE
OF THE GREAT TELESCOPES AT
GREENWICH OBSERVATORY

Notice the end of the 28 in. refractor
protruding through the aperture

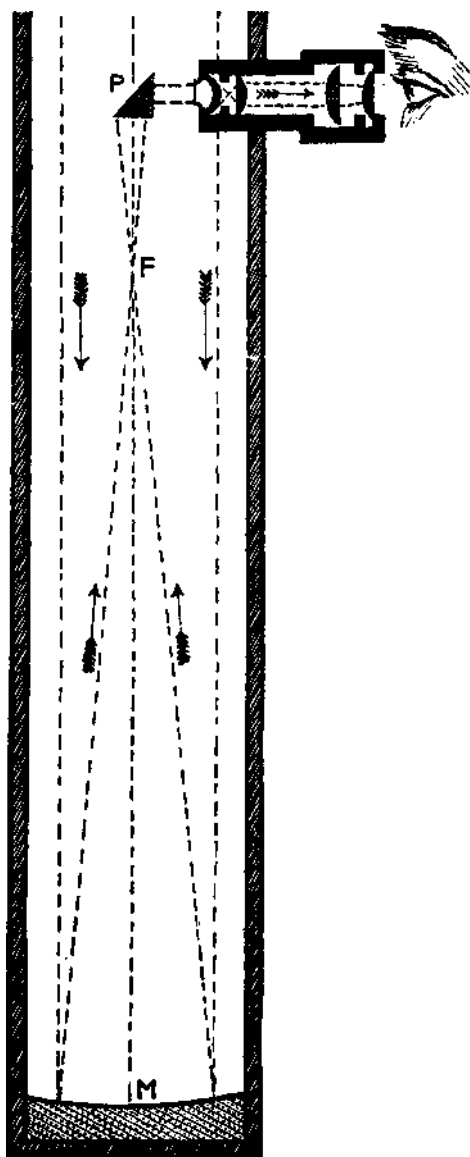


FIG. 123. SECTION OF A REFLECTING TELESCOPE

this book are from photographs taken at these observatories.

Mounting of Telescopes. Owing to the revolution of the earth, all the celestial bodies appear to move. If a telescope be pointed to a star, that star will gradually move across the field of view and soon go out of sight. To prevent this, many telescopes are mounted in such a way that they can be moved by clockwork at the same rate as the star is moving, and thus the star is kept in the centre of the field. Students living in London may see a telescope so mounted at the observatory of the Hampstead Scientific Society on the reservoir at Hampstead, where visitors are encouraged to look at the moon and stars.

The Camera, If we visited an observatory we should notice that most of the work done was not at the eyepiece of a telescope, but in a photographic dark room or at a desk. The camera has been a help to the astronomer in many ways.

- i. The photographic plate placed at the eyepiece of the telescope will give a perfect record of the position of all objects seen there. This record can be examined at leisure and kept for comparison with other photographs taken at other times or in other places.

2. The camera can be left in position for hours, if necessary. It does not get tired like the human eye. In this way, the camera saves the astronomer many tedious hours at the eyepiece, and provides him with more accurate, permanent records than he could possibly make by the most careful drawings and notes.

3. Celestial bodies which cannot be seen by the most powerful telescope have been made known to us by the use of the camera. However long we gaze at a faint distant star, it will never appear any brighter, but rather

it will become less distinct as our eyes get tired. The longer a photographic plate is exposed to the action of light, the more action the light will have upon the chemicals in the plate, and therefore the more distinct will be the image formed. The camera thus builds up a number of small impressions to form one large impression.

4. Some of the rays given off by luminous bodies are invisible to the eye, but they affect the photographic plate. It has, therefore, been possible to photograph distant stars and nebulae which do not send us sufficient light to enable us to see them.

The camera easily distinguishes a planet, asteroid, comet, or satellite from a star. Because of their own motion among the stars, such bodies do not appear to move across the field of the telescope at the same rate as the stars do. By clockwork, the camera may be made to move at the same rate as the stars, which will then appear as dots, while the other bodies will appear as short lines or trails (see photograph of minor planets at Fig. 92). On the other hand, the camera may be made to move with the planet, comet, etc., and then the stars will produce trails (see photographs of comets).

On page 106 is a photograph of the planet Pluto near to a great star. Perhaps, you have already wondered that a star should appear so big in a photograph, although it never appears to be more than a point of light in even the biggest telescopes. If you remember that the camera builds up impressions you will realize that the longer a plate is exposed the bigger will be the impression. To photograph a faint object such as Pluto, long exposures are necessary. During the long exposure, the effect of the bright light from the star is continually and gradually spreading over the surface of the plate, thus forming a

large impression quite unlike the image of a star seen in a telescope.

The Spectroscope. Perhaps the most useful instrument which has recently come into the hands of the modern astronomer is the spectroscope. We have already seen

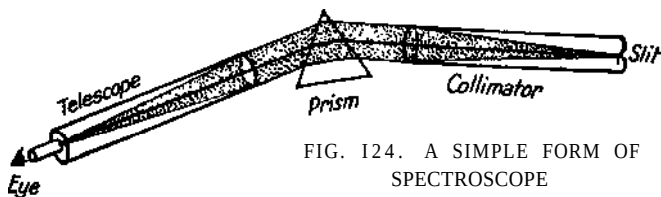


FIG. 124. A SIMPLE FORM OF SPECTROSCOPE

that a triangular glass prism breaks up sunlight into a spectrum. The simplest spectroscope uses a prism of this kind with a small telescope to view the spectrum formed by light falling from a narrow slit upon the prism. When the spectrum of sunlight is carefully examined, a number of dark lines are seen among the colours. These are known as Fraunhofer's lines, after the discoverer of the first ones.

The light from a spirit lamp with a little salt upon the wick does not show an ordinary spectrum, but two bright



FIG. 125

Top: Bright line spectrum of sodium flame

Bottom: Dark lines of Sodium seen when light is viewed through sodium flame

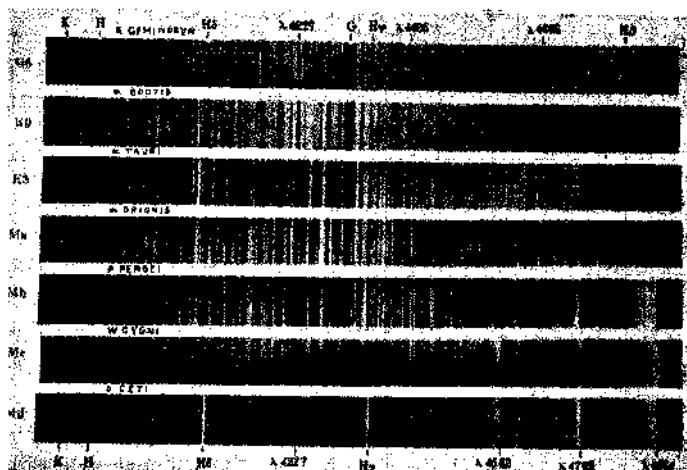
yellow lines are seen, just where two dark lines appear in the yellow portion of the sun's spectrum.

If a bright light from a limelight lantern is allowed to pass through such a flame before falling on the prism, the bright yellow lines become dark lines, and are known as absorption lines.

Other incandescent elements give other lines

situated in different parts of the spectrum, but no two elements give the same lines. It is therefore possible to identify elements by their spectra.

Light from incandescent solids and liquids produces a continuous spectrum; light from incandescent gases



By courtesy of

University of Michigan Observatory

FIG. 126. SPECTRA OF VARIOUS STARS

gives a bright line spectrum; and light from incandescent gas which is illuminated from behind gives a dark line spectrum.

What are the Sun and Stars Made of ? From a study of the spectra formed by sunlight, astronomers have been able to tell that most of the elements found on the earth occur in the sun. As the spectrum of the sun has dark lines, the astronomer knows that the light passes through hot vapours, and therefore that the sun is hotter than the vapours which surround it. He also knows that the temperature of the sun is so high that iron and platinum exist there in the form of vapours.

By the study of their spectra, stars have been shown to be suns which are composed of elements similar to those in the sun. Some stars show chiefly helium lines; some chiefly hydrogen lines; others lines of many elements; and still others show that compounds are present.

Some nebulae give bright-line spectra; therefore we know that they must be made of gases.

The Temperature of Stars. The spectra of substances alter slightly at certain high temperatures. Up to 2,600° C. we get one set of lines. At 4,000° C.—the temperature of the electric arc—these lines become less prominent and new ones appear. At higher temperatures, still other lines appear. Thus, by means of spectra, the astronomer can tell something of the temperature of the sun and even of the distant stars.

The Speed at which Stars Travel. If a star is approaching the earth, the lines appear to be displaced very slightly towards the violet end of the spectrum. If it is going away from the earth they are displaced towards the red end of the spectrum. When the amount of displacement is measured, then the rate of movement towards, or away from, us can be calculated.

. Thus we see that the spectroscope has made the verse at the beginning of Chapter I out of date. Read now this verse quoted by Sir Robert Ball in *Starland*—

Twinkletwinkle little star
Now we find out what you are
When into the midnight sky
We the spectroscope apply.

EXERCISES ON CHAPTERS VIII AND IX

1. Did Copernicus really invent the Copernican theory? What is the difference between the present idea and the ideas of Copernicus?
2. It is sometimes stated that weather science is in a similar

state now to that in which astronomy was in Tycho Brahe's time. Can you explain why ?

3. What was the great work of Tycho Brahe and Kepler?

4. What are the three laws of Kepler ?

5. From Law 2 find in which part of its orbit a planet will move most quickly.

6. What was the difference between Galileo and other professors of his time ?

7. What astronomical discoveries did Galileo make?

8. Take several convex lenses and find their focal lengths. Focus the sun or a bright distant object as sharply as possible.

9. Form an image of a distant candle upon a ground glass or grease-proof paper screen. Magnify the image by another lens. Remove the screen and look through the lenses at the candle. Does the candle appear the right way up or not? You now have a small astronomical telescope.

10. Draw the rays by which the image in Question 9 was formed.

11. Form Galileo's telescope as follows. With a convex lens form an image on a screen. Now place a concave lens between the convex lens and the screen. Remove the screen. Look through the lenses and focus until the image is quite distinct. Is the image the right way up or not ?

12. Draw the rays by which the moon is seen in the reflecting telescope.

13. Explain why the camera is such an important astronomical instrument.

14. How is it that the camera can show us stars that we cannot see?

15. In some photographs in this book stars appear as dots, in others as lines. Why is this ?

16. What do we learn by the aid of the spectroscope ?

CHAPTER X

The Stars

A "Close Up" of a Star. We have already read many details of one star. The sun, although so unlike a star to the naked eye, is really only a star seen "close up." Yes, I know it has been stated to be 93,000,000 miles away, yet, as we shall learn later, that is close up compared with the nearest of the other stars. Look at Fig. 79, page 95, and notice how small the sun would appear to an observer on Neptune. Compare it with the size of the sun as it appears to an observer on earth. From the nearest star our sun would appear as a point of light just like the rest of the stars. The planets would be quite invisible. Our star—the sun—is only an average one. There are many stars bigger, and hotter, and brighter, than our star. Betelgeuse, a large red star in the shoulder of the giant Orion (see Fig. 127) is 300 times as big as the sun. If it were placed where our sun is, it would extend so far out from its centre that it would envelop the earth and reach to the orbit of Mars. Its diameter has been measured and found to be not less than 200,000,000 miles.

Fixed or Movable. The casual observer of the stars often thinks that, although the sun, moon, and planets rise and set, yet the stars remain fixed in the same position in the sky all the time. If you take the trouble to observe a particular star carefully for some hours, you will easily see how false that idea is. To see that the stars do appear to move, take up your position so that a bright star appears to be near a tall chimney or steeple. Make observations of the same star from the same spot several

times during an evening. You will see that the star has moved, and you may come to the conclusion that the star is rising, or setting, just as the sun and moon do. Ancient observers noticed the rising and setting of stars, and thought that the celestial sphere, with the stars fixed in it

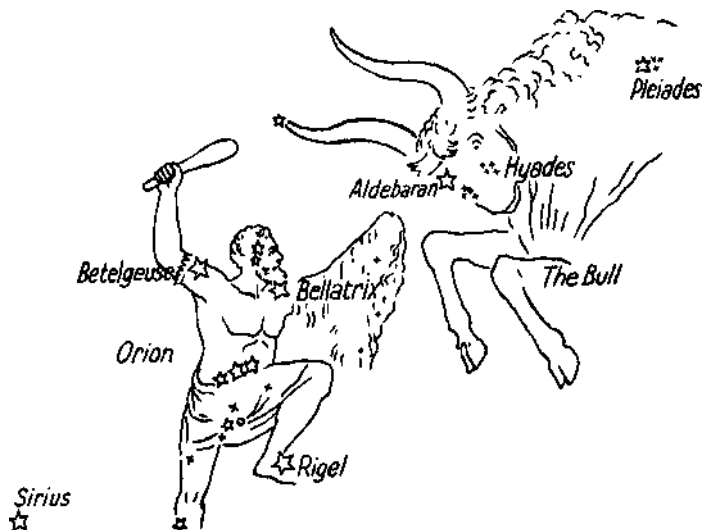


FIG. 127. ORION AND THE BULL

From an old star map

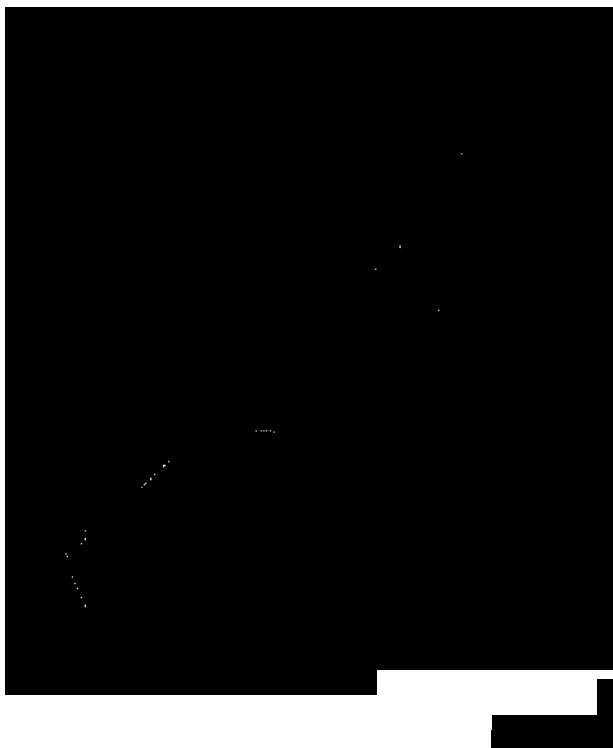
revolved as a whole round the earth. You, however, should realize that it is only an apparent motion caused by the rotation of the earth.

The Pole Star, Polaris, and Circumpolar Stars.

But I am constant as the Northern Star
Of whose true fixed, and resting quality
There is no fellow in the firmament.

Julius Caesar.

There is one star, as Shakespeare says above, which does not appear to move, although you watch it carefully all through the night. This star is called the North Star,



By courtesy of

Dr. W. J. S. Lockyer

FIG. 128. A PHOTOGRAPH OF CIRCUMPOLAR STARS AND
A METEOR TRAIL

Each arc of the circle represents the path of a star during the exposure. The long diagonal line was produced by a meteor which happened to pass by while the photograph was being taken
Exposure 2 hr. 14 min.

the Pole Star, or Polaris. It is situated in that part of the heavens which is almost directly over the North Pole of the earth.

While standing in the middle of the room, look at a point of the ceiling immediately overhead. Turn round on your axis and notice that the point does not appear to move. Now, while continuing to rotate, look at the pictures on the walls. The pictures seem to move round you in circles in the opposite direction to that in which you are moving.

This simple experiment explains why the Pole Star does

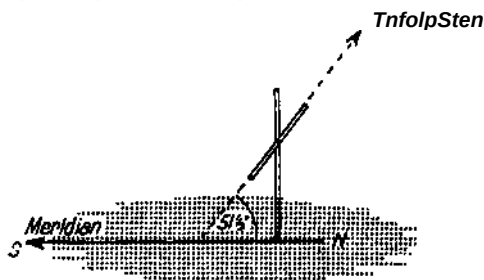


FIG. 129. TWO STICKS ARRANGED TO POINT TO THE
NORTH STAR
(Latitude of London)

not appear to move, but all other stars near it seem to move in circles round *it* as a centre. Stars which appear to revolve round the Pole Star in circles, without rising and setting, are known as *circumpolar* stars. Fig. 128 shows a photograph of the circumpolar stars. The camera was pointed towards the Pole Star and exposed for some hours. As the earth carried the camera round with it, the stars formed images on different parts of the plate, and thus produced arcs of circles.

The Importance of the North Star. As the Pole Star does not appear to move, it is quite a useful star to travellers, for by means of it they can find the "north," and therefore any other required direction. Sailors can use the star at night, just as they use the sun during the

day, to help them guide their ships across the trackless ocean. In this case, however, they do not have to think of the time when getting their direction from the star.

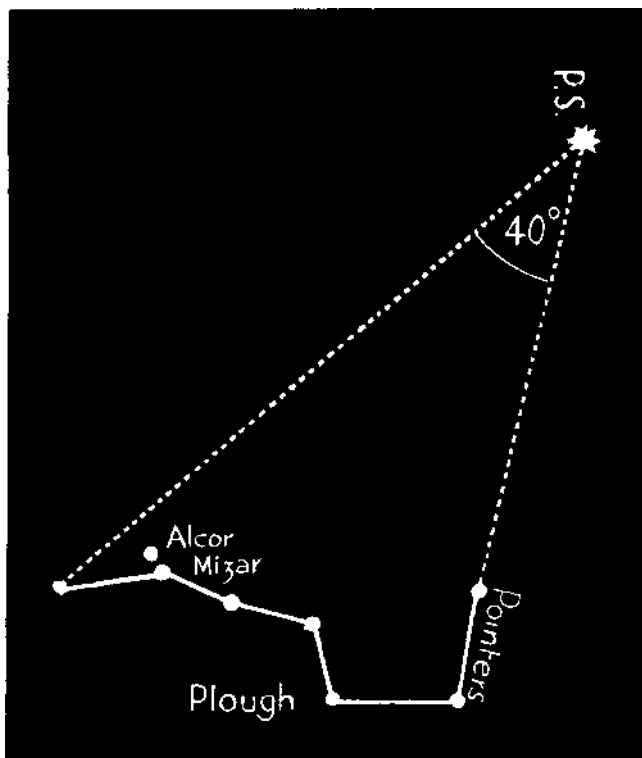


FIG. 130. THE PLOUGH AND THE POLE STAR

How to Find the North Star. METHOD I. Find the meridian (north and south line) by means of the sun at midday. Take a pole and fix it upright in the garden. Securely fix on the pole a stick arranged so that the angle between it and the horizontal is equal to the latitude of your home (for London this is $51\frac{1}{2}^\circ$), and so that the upper

end of it is pointing to the north. In the evening, when the stars are out, you will find that this stick is pointing to the North Star. Warning: Do not use the magnetic needle to

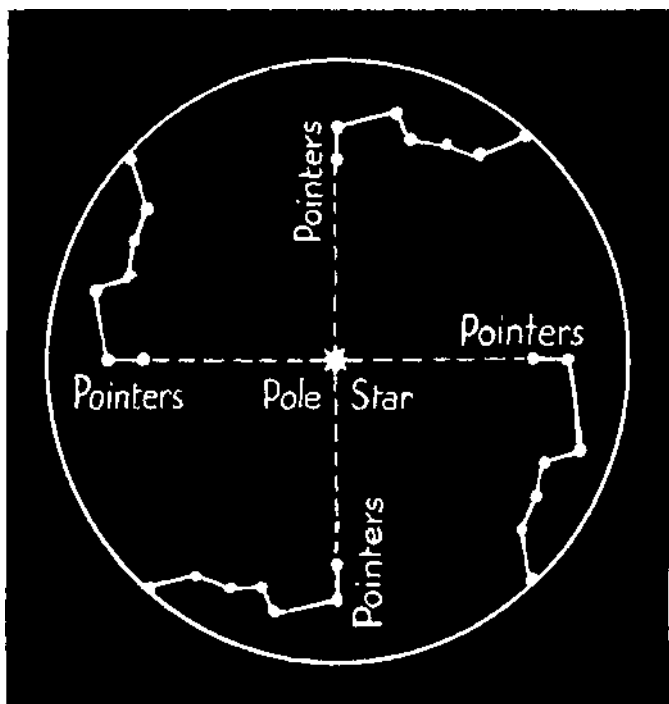


FIG. 131. THE PLOUGH IN FOUR DIFFERENT POSITIONS

get your north and south line because the magnetic poles of the earth are not true north or south.

METHOD 2. A better and easier way of finding the North Star is by using the seven bright stars shown in Fig. 130. This group of stars is known by many names: the Plough, Charles' Wain, the Wagon and Horses, the Dipper, the Great Bear, and Ursa Major (Latin for Great Bear).

In Fig. 131 this group of stars is shown in several positions because the stars in it are circumpolar ones, and therefore appear in different places at different times of the night, and in different seasons of the year.

To make sure that you can recognize this group of stars make a copy of Fig. 131 on a post card and place a pin through the point marked P.S. Hold the card at

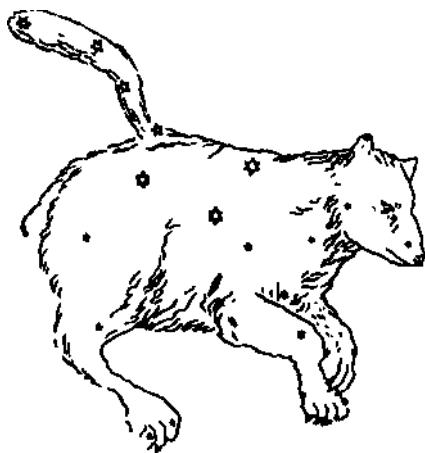


FIG. 132. THE GREAT BEAR
(From an old star map)

arm's length above the level of your head and slowly rotate the card on the pin. In this way you may become familiar with the appearance of the group in any of its positions. When you are familiar with its appearance, go out on a starry night and try to find the group in the sky. Upon finding it, imagine a line joining the two stars forming the front of the Plough to be produced about four times the distance between the two stars. This line will pass very near to a bright star which is the required Pole Star. The point P.S. on your card represents the Pole Star.

This method of finding the North Star is better than the stick method, for it may be used anywhere in the Northern Hemisphere without any previous preparation. Any trouble taken to recognize and find the Great Bear and Pole Star will be amply repaid, for it is the best starting place from which to seek many other stars.

Real Motion of Stars. We have seen that the apparent

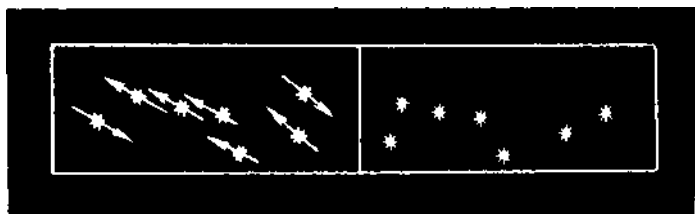


FIG. 133

Left: The Plough with arrows showing direction of movement of the stars

Right: The Plough as it will appear in 100,000 years

motion of rising and setting stars, and circumpolar stars, is due to a real motion of the earth. Are all the stars really immovably fixed? Astronomers have shown that they are not, but their real motions can only be noticed after very prolonged observations. Hipparchus, 129 B.C., made a catalogue of the stars visible to him, and marked their relative positions. From a comparison between the present position of stars and drawings in old catalogues, it is apparent that the stars do alter their positions. Fig. 133 gives some idea of the directions in which the stars of the Plough are moving.

By means of the spectroscope one star has been shown to be coming towards us at the remarkable rate of 500 miles per minute. If it continues to move in the same direction it will take hundreds of thousands of years to get here, and by that time the sun will have moved and

taken the earth and the other planets somewhere else. The sun has been shown to be moving towards a point of the sky in the constellation of Lyra (the Harp).

Let us pause a moment to think of the movements of the earth. 1. It rotates on its axis. 2. It revolves round the sun. 3. It is journeying with the sun and other planets towards the constellation Lyra.

How Many Stars are There? How many stars do you think you saw on that bright starry night when you last gazed at them? Was it hundreds, thousands, hundreds of thousands, or millions? Probably you think they were numberless. They were not. They have been counted. The number of stars visible depends upon whether the moon is shining and whether the sky is observed in the town or country. Faint stars, which are just visible on a dark night, are not visible when there is a bright moon or when the streets are well lighted. There are between 3,000 and 4,000 stars visible to the unaided eye, of which about 2,500 only are visible to us in the Northern Hemisphere. Although this number appears surprisingly small, yet the number of stars known by the aid of the telescope and camera is just as surprisingly big. We know of the presence of 30,000,000,000 stars, although some of them have been discovered only by aid of the camera.

Distance of the Stars. Hold a pencil in front of you at a distance of one foot from your eyes. Look past it with your right eye, at the objects in the room. Close the right eye and, without moving head or pencil, look again with the left eye. The pencil seems to move against the background of more distant objects. Now hold the pencil at arm's length and repeat the experiment. The amount of movement is less. Knowing the distance between the eyes, and the amount of shift it is possible to calculate the distance of the pencil from the eye.

To measure the distance of the nearer stars a method similar to this is adopted. The pencil represents the star whose distance is to be found. The distance between the left and right eye is enlarged by viewing the star from opposite sides of the earth's orbit. By this and other methods it has been found that thirty of the nearest

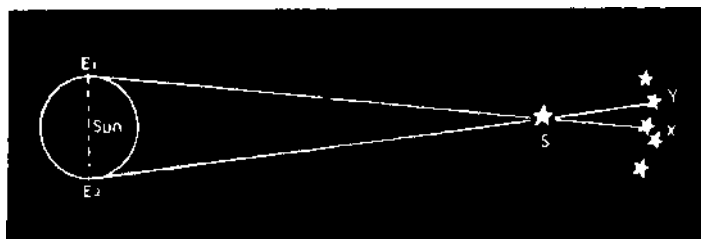


FIG. 134. METHOD OF MEASURING THE DISTANCE OF STARS BY PARALLAX -

Star S is viewed from opposite sides of the earth's orbit E_1 and E_2 . It appears to be near x when viewed from E_1 , but near y when viewed from E_2

stars are within a hundred billion miles, a few hundreds within five hundred billion miles, but most of them are a hundred thousand billion miles away. The nearest stars, known as *α Centauri* and *approxima Centauri*, are twenty five billion miles away. *Approxima Centauri* is slightly the nearer. Such figures are beyond understanding. Possibly you cannot even write such numbers in figures. It may perhaps help if you remember that 1,000,000 seconds is about eleven days, but a billion seconds is more than 30,000 years. If we try to make a model on a small scale and represent the 93,000,000 miles between the earth and the sun by *one inch*, then the nearest star must be placed four miles away from the sun. The distances between the stars are reckoned to be of the same order as the distances between the sun and other near stars.

In order to overcome the difficulty of using such large figures, astronomers have used a new unit of measurement called the *light-year*.

Speed of Light and Light-years, Light has a speed of 186,000 miles per second, or, put in another way, light travels so fast that it could go round the world seven and a half times in one second.

The unit of distance called the light-year is the distance light travels in one year. Work it out for yourself in miles and keep the result.

Using this unit *α Centauri*, the nearest star is found to be $4\frac{1}{3}$ light-years away, and some of the more distant stars are thousands of light-years off. If *α Centauri* could suddenly cease to shine to-night, we should still continue to see it for over 4 years. We see most of the stars by light which left them before we were born, and many of them by light which left them hundreds or thousands of years ago. It is interesting to think that we cannot really be certain that the stars are still there. Although such a thing is highly improbable, the stars may have ceased to shine by now.

Some Star Distances—

	<i>Light-years</i>
<i>α Centauri</i>	4 $\frac{1}{3}$
Sirius	8 $\frac{1}{2}$
Ursa Major	18.5
Vega	26 $\frac{1}{2}$
Pole Star	76
Betelgeuse	200
Rigel	466

Some of the star clusters are from 22,000 to 220,000 light-years distant, and the most remote nebulae many millions of light-years away. Work it out in miles from your last result.

Brightness and Distance. Quite reasonably you might suppose that the nearest stars would be the brightest, and

that we might get some idea of the relative distances of the stars by measuring their brightness. This is not so, for you see in the above table that the brightest star in the heavens—Sirius—is twice as far away as the nearest star, and that the brilliant star, Rigel in Orion, is 466 light-



Procyon -White

Sirius - White

The Sun -Yellow

Faint red stars

Van Maanen's Star- White dwarf

Larger star of the Binary

known as Alpha Centauri - Yellow

FIG. 135. SHOWING THE GREAT VARIETY IN SIZE OF SOME OF THE STARS

(NOTE. Betelgeuse is 300 times as big as the sun)

years distant. The brightness of a star does depend upon its distance, but also upon its size, temperature, and colour.

Astronomers classify stars by their brightness. The brightest are said to be of the first magnitude. There are twenty such stars. The stars of the Plough are mostly of the second magnitude, and the faintest seen by the unaided eye on a moonless night are of the sixth magnitude. By the aid of the telescope we may see stars of the twenty-first magnitude. A star of the fifth magnitude is two and a half times as bright as one of the sixth magnitude, and so on. If the sun were at a distance of only $32\frac{1}{2}$ light-years from us we should call it a star of the fifth magnitude. (Warning: Magnitude does not mean size, but refers to the brightness only.)

There is about the same amount of difference between

the brightness of the Sun and Sirius—the brightest star—as there is between Sirius and the faintest star.

Colour, as you know, gives some idea of temperature. When we speak of dull red heat or of white heat we understand white hot to be much the hotter.

Some stars are red, some blue, some yellow, and some white. Betelgeuse is red, Rigel blue, the sun yellow, and Vega white. The hotter a star is, the more luminous it will appear. Capella gives out light of the same nature as sunlight; therefore its temperature is the same. It is, however, 130 times as luminous as the sun would be if placed the same distance away. By such an argument we can see that Capella must be much bigger than the sun.

The sun is a star of medium weight and luminosity, but as there are so many small ones it is rather above the average.

EXERCISES ON CHAPTER X

I.

New stars all night above the brim
Of waters lighten'd into view;
They climbed as quickly, for the rim
Changed every moment as we flew.

"*The Voyage.*" Tennyson.

. Explain the above verse.

2.

"There stay, until the twelve celestial signs
Have brought about their annual reckoning."

Write a few lines about the above quotation from *Love's Labour's Lost*, Act v, Sc. 2.

3-

The sun flies forward to his brother sun
The dark earth follows wheeled in her ellipse."

"*The Golden Year.*" Tennyson.

Explain these two lines.

4. How do we know of the presence of stars which we cannot see?

5. Make a sketch to show where the Pole Star may be seen: (1) on the horizon; (2) overhead; (3) at altitude $51\frac{1}{2}^{\circ}$

6. What do you understand by circumpolar stars? **Where** would all the visible stars be circumpolar?

7. How may a bright star be distinguished from a planet: (1) by telescope; (2) by camera; (3) by eye?

8. Describe two ways of finding the North or Pole Star.

9. Make a sketch of the Plough and the North Star.

10. What is the speed at which light travels? How far will it travel: (1) in a minute; (2) in a year?

11. The star α Centauri is $4\frac{1}{3}$ light-years away. How far is this in miles?

12. What do you understand by a star of the sixth magnitude?

13. How can we tell that Capella is much bigger than the Sun?

14. On what things does the brightness of a star depend?

CHAPTER XI

Some Constellations and Bright Stars

Constellations. When we look at a star-spangled sky there seems to be very little order or arrangement there. The stars seem to be bright points of light scattered about anyhow in the celestial sphere. Peoples



of the older civilizations, who lived more in the open than we do, grouped the brighter stars together and imagined many fanciful objects could be seen in the heavens. The Greeks gave names to these groups or constellations. Many of them were named after gods and heroes well-known in Greek myths, e.g. Perseus, Andro-

FIG. 136. CASSIOPEIA MEta, Cassiopeia, and Hercules. (From an old star map) Other groups were named after animals such as Bull, Ram, Swan, and Bear. Ptolemy made a list of forty-eight constellations. The names given to the constellations by the Greeks are still used by astronomers. There are, however, now eighty constellations. The Greeks knew nothing of some of the stars of the Southern Hemisphere, for they never saw them in their part of the world.

The Signs of the Zodiac. It has already been noticed that the sun, moon, and planets appear to move across the sky from east to west. They always appear in a belt of the celestial sphere about 16 degrees wide. This belt is divided into twelve equal portions of 30 degrees each. The bright stars in each portion form a constellation, and

the twelve constellations—mostly named after animals—are known as the signs of the zodiac.

The Ram, the Bull, the Heavenly Twins
And next the Crab, the Lion shines,
The Virgin and the Scales,
The Scorpion, Archer, and the Goat,
The man that bears the Watering Pot
And Fish with glittering tails.

The signs are usually known by their Latin names—

- | | |
|--------------------|------------------------------|
| 1. Aries (Ram). | 7. Libra (scales). |
| 2. Taurus (Bull). | 8. Scorpio (Scorpion). |
| 3. Gemini (Twins). | 9. Sagittarius (Archer). |
| 4. Cancer (Crab). | 10. Capricornus (Goat). |
| 5. Leo (Lion). | 11. Aquarius (Water bearer). |
| 6. Virgo (Virgin). | 12. Pisces (Fish). |

The sun passes through these constellations in the order given above.

In the course of a year we revolve round the sun, which therefore appears to be situated in different constellations or signs each month. We face different portions of the celestial sphere in turn, and so different signs appear in the south—or on the meridian—each month. The constellations appear to move westward 30 degrees per month. As the constellations also appear to move round the earth each day they must also move through 15 degrees every hour. These two movements make it difficult for the beginner to spot any particular constellation or star for they are not always in the same place.

When about to explore the heavens, as suggested later in this chapter, it would be a good plan to make copies of Figs. 137, 138, 139, and use them as rough guides. Use a pocket torch to examine the sketches you make. First of all find the Plough, or Great Bear, and from that, the North Star. Then hold your sketch so that the Plough is in a similar position, and proceed to trace out the other constellations.

First Excursion Among the Stars. On the first occasion try Fig. 137, which is the easiest. From the Pole Star find

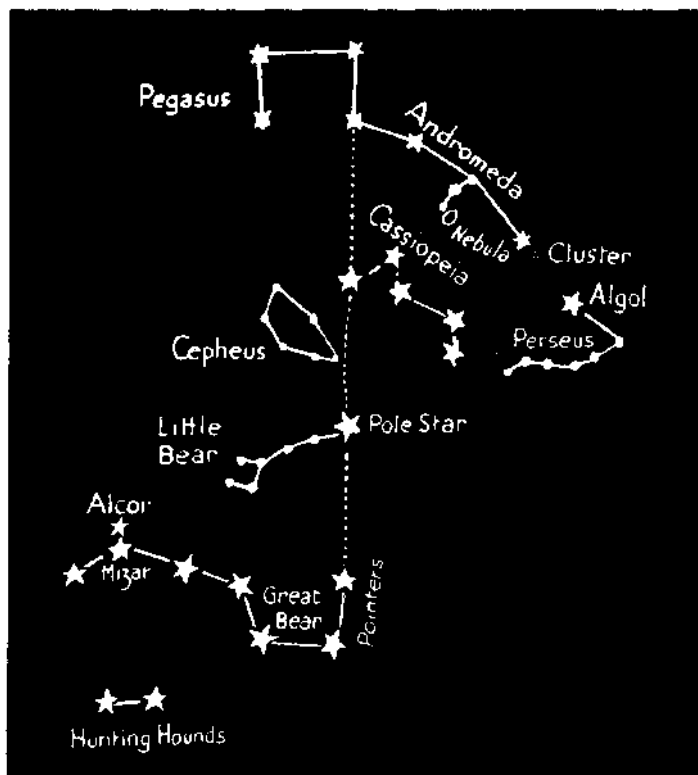


FIG. 137. FIRST EXCURSION

the Little Bear. It is much the same shape as the Great Bear, but smaller and fainter. The North Star is the last star in its tail

On the opposite side of the Pole Star from the Plough and about the same distance from it, you will find a badly-formed W or M, which is known as Cassiopeia's Chair.

Cassiopeia was the wife of King Cepheus and the mother of Andromeda. Andromeda offended the god Neptune by boasting that she was more beautiful than the sea-nymphs who attended him. As a punishment, she was condemned by Neptune to be chained to a rock on the seashore until devoured by a sea-monster. Perseus, the slayer of the Gorgon, saw her, rescued her, and later married her. The whole story is told in *Kingsley's Heroes*.

Between Cassiopeia and the Little Bear may be seen the King Cepheus. Behind her is Andromeda, which is most easily found by a line of stars ending in the very bright star Algol in the constellation of Perseus. Algol is a double or binary star, which is famous because it was the first binary star to be recognized as such by the use of the spectroscope. At the other end of the line of stars representing Andromeda, is the great square of Pegasus. Pegasus may be found by carrying the line of the pointers of the Plough past the Pole Star and Cassiopeia, as shown in Fig. 137. The position of the Great Nebula in Andromeda is shown by a small circle in Fig. 137. Two star clusters are also shown near Andromeda and Perseus.

Now return to the Plough. Over the middle star (Mizar) of its handle is a small star called Alcor. These two stars are known as the Horse and the Rider, when the Plough is known as the Wagon and Horses. Alcor, although so faint as to be hardly visible, is shown by the telescope to be a double star.

Below the handle of the Plough find the two stars of the **Hunting Hounds**. The nebula shown on page 182 is **found in** this constellation.

Now, if you have found all these constellations, make certain **of** them by looking for them at every opportunity,

Second Excursion. On this occasion start as before **from the Plough**. Arrange your diagram of Fig. 138, so that the

Plough on it appears in the same position as it does in the sky. From the pointers move backwards from the Pole to find the constellation of Leo, which is more like its name than most constellations. Regulus, a bright star, forms the handle of a portion of the constellation, some-

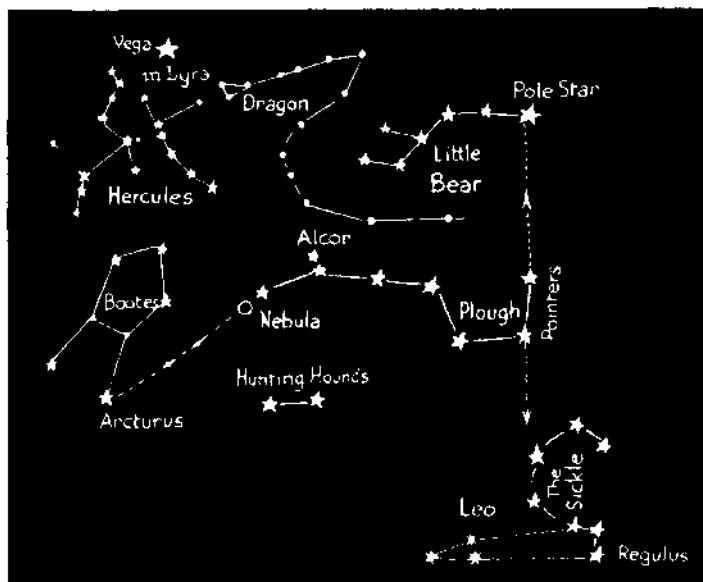


FIG. 138. SECOND EXCURSION

times known as the sickle. Now trace a line from the handle of the Plough to the bright star Arcturus in the constellation of Bootes. Bootes may be recognized by its pentagon. Arcturus is a first magnitude star, and one of our nearest neighbours. It is believed to be moving at the immense speed of 200 miles per second.

Now seek the long, straggling constellation of the Dragon—an irregular line of faint stars ending in a small triangle. It lies between the Great and Little Bears and

almost encloses the latter. The head of the Dragon is near to the head of Hercules, in which constellation is the

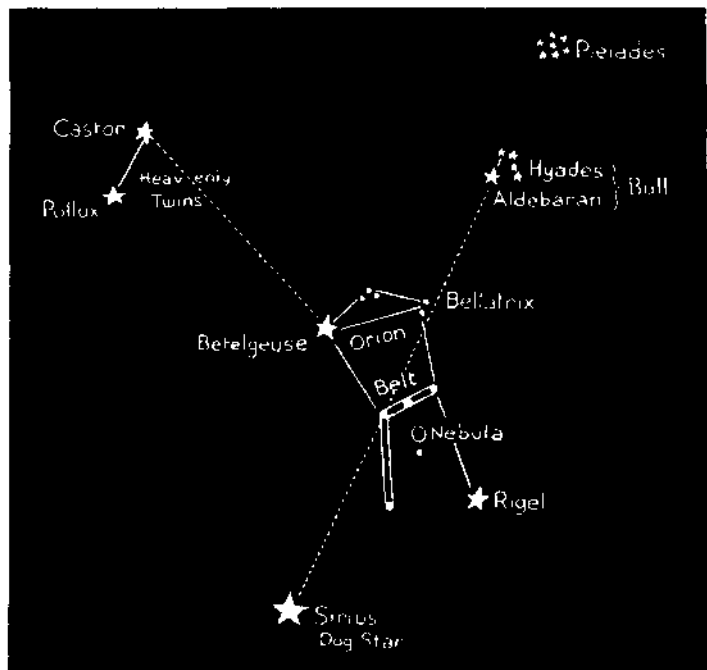
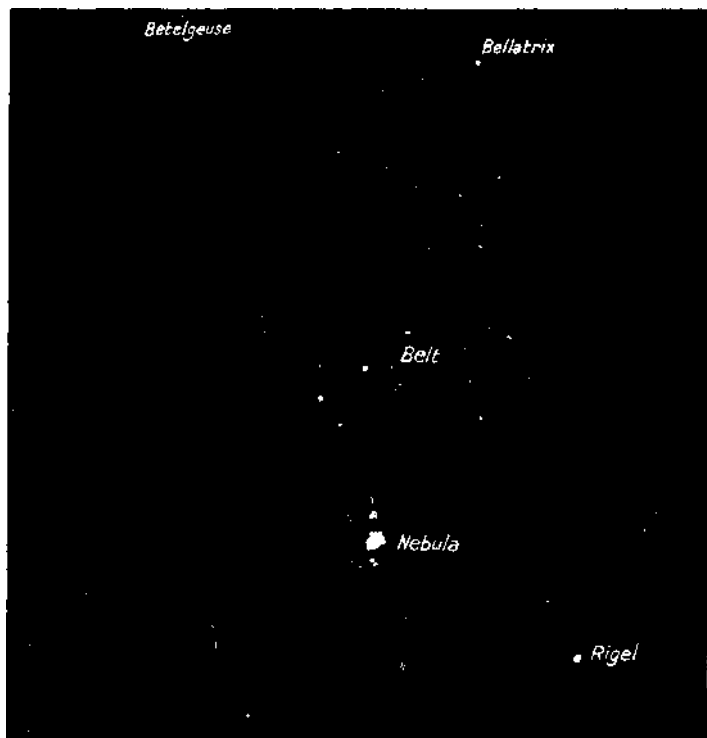


FIG. 139. THIRD EXCURSION

star cluster shown on page 175. Not far from Hercules is the bright star Vega in the constellation of Lyra. In Lyra, which is a small, badly-made W quite close to Vega, is the Annular Nebula shown on page 177. It is towards the constellation Lyra that the solar system is moving at the rate of 12 miles per second.

Third Excursion. For this excursion we must wait for a winter evening, for some of the stars to be found do not rise above the horizon on summer evenings.

Find the Pole Star and turn to face the south. In the southern sky search for the constellation of Orion. This constellation is a very fine one, and should be easily fourfcj.



By courtesy of

The Royal Observatory, Greenwich

FIG. 140. THE CONSTELLATION OF ORION

The bright red star Betelgeuse appears very small because red light does not act on the photographic plate so well as white or yellow light. Notice the luminous nebula in the sword of Orion. Compare with Fig. 149

There is a photograph of it on this page. It is best detected by the three stars in the Belt of Orion and by the two brilliant stars Betelgeuse and Rigel, one on either

side of the belt. (Sec Page 149.) In the sword which hangs from the belt is the famous nebula shown on page 179, and seen as a small misty patch in the photograph of the constellation.

Betelgeuse, above the belt, is a reddish star of special

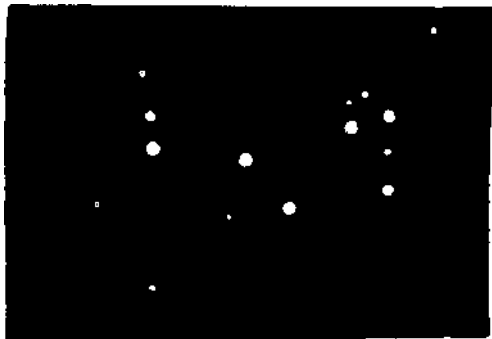


FIG. 141. THE PLEIADES AS SEEN WITH SLIGHT OPTICAL AID

interest, because it was the first star to have its diameter measured.

Sirius, the brilliant star in the Dog, may be found by tracing an oblique line from Bellatrix through the belt. If this line is produced in the opposite direction we find Aldebaran, one of the clock stars which is in Taurus—the Bull. Near Aldebaran is the cluster of the Hyades. Continuing the same line we find the faint, but easily recognized, cluster of the Pleiades. Only six or seven stars can be seen by the naked eye, but a small telescope shows a hundred, many of which are shown by the camera to be surrounded by nebulous clouds.

Another line drawn through Rigel and Betelgeuse and then produced brings us to the two bright stars of Castor **and** Pollux. These are the brightest stars in the sign of the Heavenly Twins. Castor is especially interesting, as it is

seen by a telescope to be two stars, one of which in a large telescope is also seen to be a pair of stars. Recently each of these has been shown by the spectroscope to be a double

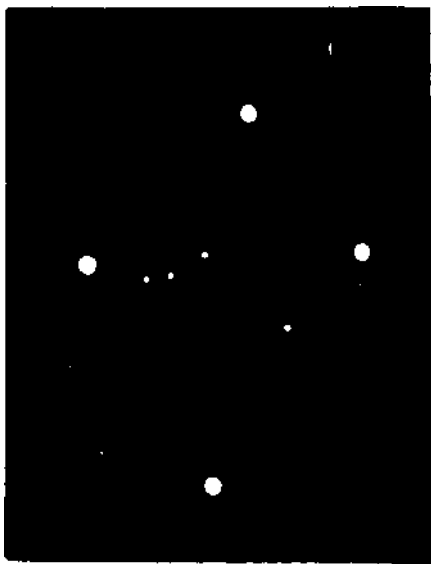


FIG. 142. THE SOUTHERN CROSS

The most beautiful constellation of the Southern Hemisphere
(Invisible in England)

star. Thus Castor is really six stars which appear to the naked eye as only one.

You may care to visualize this excursion in this way: The warrior Orion with his Dog is defending the Heavenly Twins from the Bull, which is now charging down upon him instead of the Twins.

It is well to remember on these excursions that the planets Venus, Mars, Jupiter, and Saturn appear like bright stars, and may be found among the constellations, thus spoiling them from the amateur observer's point of view.

Many more excursions might be taken, but I must **leave** you now to plan them for yourself from a star atlas, or some more detailed book on astronomy.

When you have learnt the shape of the constellations in the sky they should stand out in your mind like the different countries on a map of Europe.

EXERCISES ON CHAPTER XI

1. Make sure of the Plough, Cassiopeia, and the North Star.
2. Copy Fig. 137 and search the heavens for the constellations.
3. Copy Fig. 138 and trace the stars in the sky.
4. Copy Fig. 139 and trace the stars in the sky.
5. Look at all the pictures referred to in the chapter.
6. Sketch the arrangement of stars in Orion, Cassiopeia, Plough, Leo.

CHAPTER XII

The Milky Way and Nebulae

Showed the broad white road in heaven
Pathway of the ghosts, and shadows,
Running straight across the heavens,
Crowded with the ghosts, and shadows.
To the Kingdom of Ponemah.
To the land of the hereafter.

Hiawatha.

ON a clear, moonless night the most striking part of the sky is that narrow belt known as the Milky Way. This glowing band has interested peoples of all times and all nations. The Norse spoke of it as the path to Valhalla—the land of the departed spirits. The Welsh called it "the Silver Street leading to *Caer Groydon*." The Peruvians called it "The Dust of the Stars."

Democritus (460-370 B.C.) suggested that it might be formed by numerous faint stars so crowded together that we could not distinguish them. Other and later Greek astronomers disagreed with Democritus; but, when Galileo turned his telescope upon the Milky Way, Democritus was proved to be right. The Milky Way is a vast number of stars. Look at Figs. 143 and 144, which are photographs of parts of the Milky Way. One can but gaze at them in astonishment.

Astronomers have studied this Milky Way and have noticed that there appear to be clusters of stars in it. They believe that our sun is a star in a large cluster situated about 30,000 light-years from the centre of the Milky Way. Our cluster of stars is 18,000 light-years across. Other clusters in the Milky Way system

(Galactic system) are the Pleiades and the Hyades. The Pleiades can be seen as a faint cluster of six stars by the naked eye, but a photograph shows over two thousand.

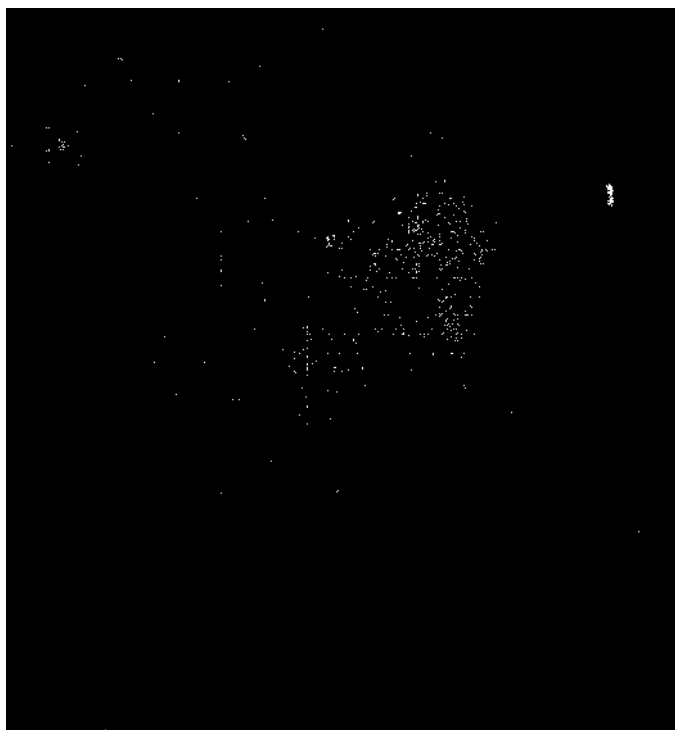


Photo by

E.

E.

Barnard

FIG. 143. A DENSE STAR CLOUD IN THE MILKY WAY

The Milky Way, or Galaxy, is thought to consist of thirty thousand million stars arranged in a disc or lens shape. The thickness of the lens or disc is about 5,000 light-years, and the long diameters about 300,000 light-years. When we gaze into the sky at the Milky Way, we

are looking along the great length of the disc and so see many stars apparently crowded together. On looking



Photo by

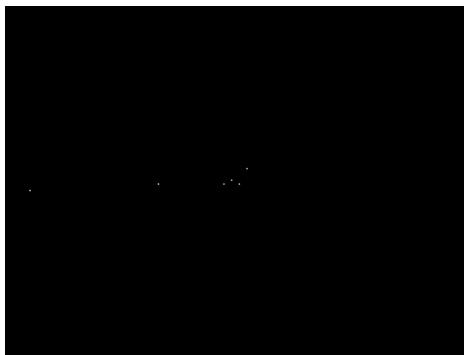
E. E. Barnard

FIG. 144. PART OF THE MILKY WAY NEAR THE DOUBLE CLUSTER IN THE CONSTELLATION OF PERSEUS

The double cluster is seen a little to the left of the centre of the photograph

towards the galactic poles we notice that the individual stars are much more scattered.

Imagine yourself in a long, narrow wood. If you look towards the sides of the wood you will see only a few trees some distance apart, but if you look along the length of the wood you will notice there are many more trees to be seen,



By courtesy of

Dr. J. S. Plaskett

FIG. 145. THE GREAT CLUSTER IN HERCULES

A good example of a cluster of stars arranged in a globe. **Such star** clusters are from 20,000 to 220,000 light-years away. The photograph was taken in British Columbia with an exposure of 1 hr. A model of this cluster can be seen in the Science Museum at South Kensington

and they appear so crowded that they prevent you seeing beyond the wood.

The stars and clusters which make up the Galaxy are thought to be moving round some central point situated in the star cloud of Sagittarius. The sun is moving towards the constellation Lyra.

Globular Clusters. Besides the clusters of stars in the Galaxy there are a number—possibly 100—of clusters of stars known as globular clusters which appear to be around the edge of this system. (See Fig. 152.) The globular clusters are from 22,000 to 220,000 light-years distant. Look at the picture of one of the best of these

clusters situated in the constellation of Hercules (Fig. 145). It consists of about 30,000 stars arranged in a globe. Although they appear so close together, neighbouring stars are probably a million million miles apart. In the Science Museum, at South Kensington, are models showing the arrangement of stars in a globular cluster.

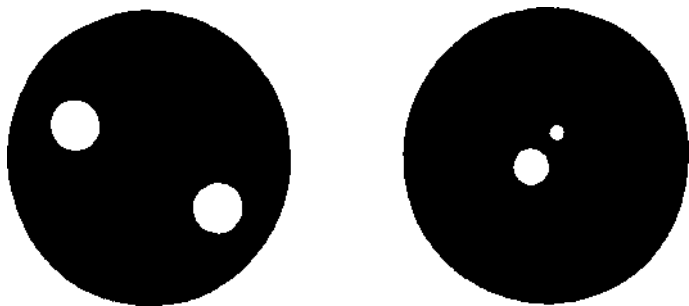


FIG. 146. TWO BINARY STARS

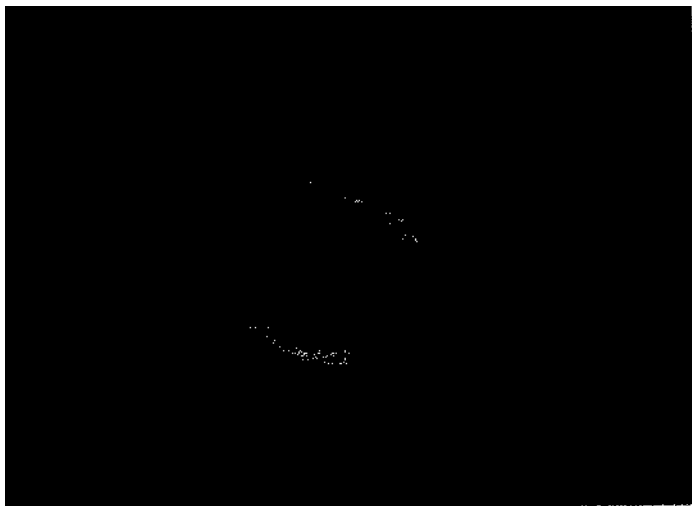
Double and Binary Stars. Some stars, when observed through a good telescope, appear as double ones. This may be due to their being in the same, or almost the same, line of sight. They therefore appear as one star to the naked eye, but the telescope enables us to separate them. Binary stars are double stars which are really fairly close together and are revolving round a common centre. Such binary stars are often of different colours and sizes; the larger being often red, or orange, and the smaller blue, or green. One way of testing the quality of small telescopes is to try to separate the double stars.

Variable Stars. Some stars are seen to vary in brightness. This may be due to two stars eclipsing one another. Algol is a well-known example which may be watched by the naked eye.

One type of variable star is known as a cepheid variable. Such stars do not owe their variation to any eclipsing

body, but are believed to be pulsating stars (i.e. stars which are alternately swelling and shrinking). Cepheid variables have been used to measure the distance of the more remote stars.

Novae. Occasionally a nova or temporary star is seen to blaze forth in the heavens and, after becoming very



By courtesy of

Ritchey

FIG. 147. THE RING NEBULA IN THE CONSTELLATION
LYRA

It is about 400 light-years distant, and covers an area greater than
that of the whole solar system

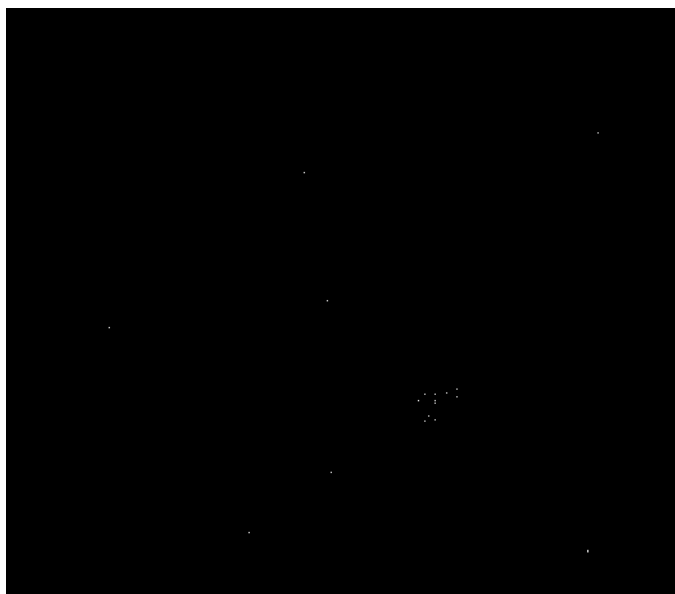
bright, gradually fade to an insignificant star invisible to the naked eye.

Tycho Brahe observed one in 1572 which rapidly became so bright that it could be seen in daylight. By 1574 it had become almost invisible. Only seventy such novae have been discovered since the time of Tycho Brahe.

Such temporary stars may be due to the collision of two

faint stars, but more probably they are caused by a faint star passing through a nebula.

Nebulae. The word nebula means a cloud. Unfortunately it has been used to name several types of things:



photoby

Roberts

FIG. 148. NEBULA IN PLEIADES

(1) Planetary or ring nebulae. (2) Irregular bright masses of luminous gases. (3) Irregular dark clouds of gas or possibly fine dust. (4) Spiral nebulae. Types (1) (2), and (3) are found within the Galaxy. The fourth type is found at great distances beyond the borders of the Milky Way, and such nebulae are therefore known as *Extra Galactic Nebulae*.

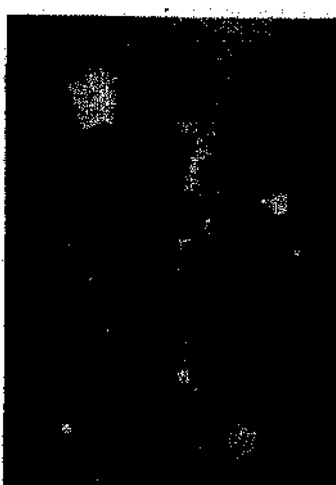
1. *Ring Nebulae*. Fig. 147 is a photograph of the best

known ring nebula, which is seen in the constellation of Lyra. A faint star in the centre is surrounded by a very extensive mass of glowing gas, probably large enough to



By courtesy of Yerkes Observatory
FIG. 149. THE GREAT NEBULA
IN ORION

This great mass of glowing gas is like a cloud with no regular shape. It is seen in the sword of Orion (see Fig. 140). It is believed to be 600 light-years distant. Note the dark cloud hiding a portion of the luminous nebula. Exposure 3 hr.



By courtesy of Mt. Wilson Observatory
FIG. 150. A DARK NEBULA

This dark cloud shaped like a horse's head in one part, hides all the distant faint stars. The few stars seen on the left are in front of the cloud. Note the streak of luminous nebula which divides the photograph into two. Photograph taken through the 100 in. reflector telescope at Mt. Wilson

cover the whole solar system. This type of nebula is not very well understood. It may possibly be a star forming from a cloud of gases.

2. *Luminous Cloud Type.* The best example of this kind of nebula is shown in Fig. 149. To the naked eye it appears as a faint star or smudge of light. In a small telescope it is seen as a hazy spot with no regular shape,



FIG. 151. A PORTION OF THE MILKY WAY

Showing the Great Rift of dark nebulous matter which hides many stars

but spreading in all directions in irregular masses. In Fig. 139 a small circle is seen in the sword of Orion. This represents the position of the nebula.

- The spectroscope shows that this nebula is chiefly composed of hydrogen and something else which is not properly understood. This great cloud of luminous gas is

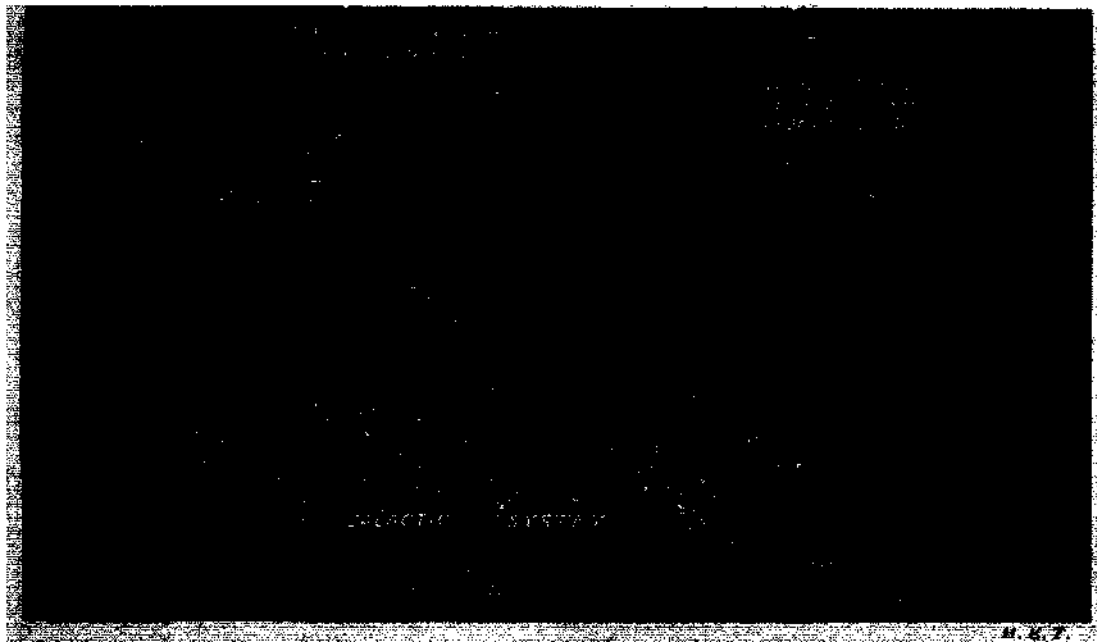
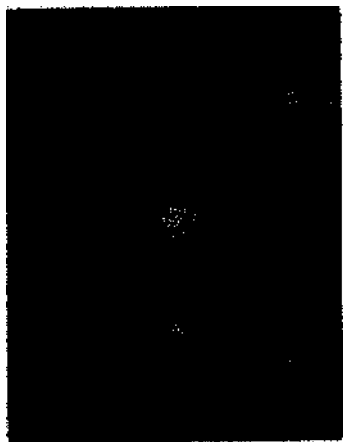


FIG. 152. A PICTORIAL SUMMARY OF THE UNIVERSE

Showing (1) The Galactic system with star clusters, dark and luminous nebulae, and globular clusters. (2) The Extra Galactic nebulae or Island Universes in various positions

about 600 light-years distant. There are several other bright nebulae of this type. A photograph of the Pleiades (page 178) shows that there is a large amount of this type



By courtesy of Yerkes Observatory

FIG. 153. THE GREAT NEBULA
IN ANDROMEDA

A nebula seen obliquely (c.f. Figs. 154 and 156). It can be seen by the naked eye. The stars seen in the photograph are much nearer to us than the nebula. In Fig. 98 it is seen as a much smaller object among the stars

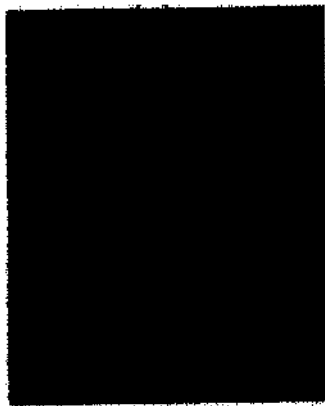


Photo by Ritchey

100 in. Telescope, Mt. Wilson

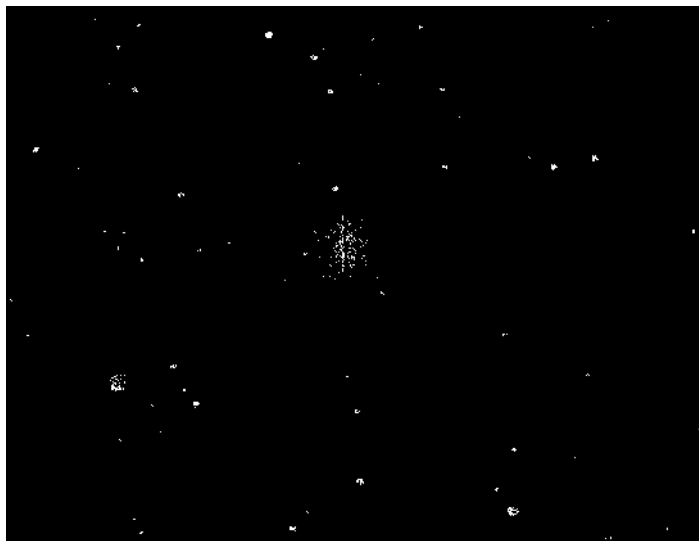
FIG. 154. THE SPIRAL NEBULA
IN HUNTING HOUNDS

A nebula looked straight in the face. (Compare Figs. 153 and 157.) Note the bright central nucleus and the two arms on opposite sides

of luminous cloud surrounding many of the stars in that cluster. Sometimes these nebulae are so extensive that they enclose almost the whole of a constellation, the stars of which appear as bright spots amongst the bright haze.

3. *Dark or Black Nebulae.* When we observe the Milky Way carefully, we notice dark patches and rifts where few or no stars can be seen. There are two possible explanations of such dark patches. The first—not thought to be probable—is that there are really no stars

there and that we are looking out into space. Most astronomers believe that these rifts and patches are due to dark clouds of non-luminous matter—probably gas—



By courtesy of

Mt. Wilson Observatory

FIG. 155. A NEBULA SEEN FULL FACE

which is hiding the stars situated behind it. This dark matter may be some of the stuff from which future stars may be made. It may be such clouds which cause novae to appear when faint stars pass through them.

Fig. 151 shows the Great Rift in the Milky Way. Fig. 150 is the famous Horse's Head Dark Nebula. This is found a little to the east of the left-hand star in the belt of Orion. You should notice that it is bordered by some luminous matter which appears like the silver lining of a cloud, and probably shows that the other side of this dark nebula is illuminated. The few stars seen on the left-hand

side of the picture are nearer to us than the cloud, and are therefore seen against the dark background.

4. *The Extra Galactic Nebulae.* Lying far outside the Galaxy, or Milky Way system of stars, are nebulae of quite a different type. These are the Spiral Nebulae or White Nebulae. There are probably about two million of them, the nearest ones being about 900,000 light-years distant. The more distant ones may be as far off as 140,000,000 light-years. Think over those numbers a little. Remember what a light-year is, and that light from the sun reaches us in about eight minutes. The distances are appalling. The best way to get some idea of the immensity of the universe is to study Fig. 152 very carefully and read the notes below and in it.

When looking at the sketch of Andromeda, Fig. 137, one of these great nebulae is seen on her girdle. This is called the nebula in Andromeda. You should remember that the stars are members of the Galaxy, but the nebula is far beyond it, and only appears to be in Andromeda because that constellation lies between the nebula and us. The stars which appear scattered over the nebula in Fig. 153 are between us and the nebula. This nebula is not only very distant, but also very large. It is like a small edition of the whole galactic system. Its diameter is 45,000 light-years. Compare this with the diameter of the Milky Way.

Fig. 154 shows another spiral nebula of this type, only this one is seen full-faced, whereas Andromeda is viewed obliquely. Notice the bright spots in the arms and the bright nucleus. This nebula may be found in the constellation of Hunting Hounds. It is about the same distance from us, namely 850,000 light-years.

One of these nebulae seen edge on is shown in Fig. 156. Again we see the bright globular nucleus. The dark band across it is obviously either the edge of the nebula or one

of its arms. It may appear dark because it is less bright than the nucleus, or there may be some dark matter there.

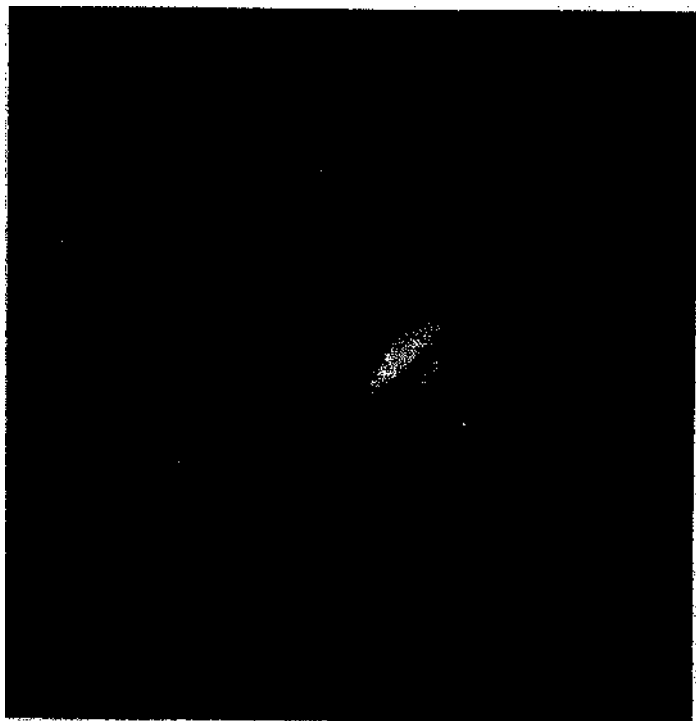


Photo by

Mr. Ritchey in 60 in. Reflector, Mt. Wilson Observatory

FIG. 156. A NEBULA SEEN EDGE ON

Notice the bright globular nucleus. The dark band across it is the edge of the nebula or one of its arms which appears dark against the brighter nucleus

The large and remarkable spiral nebulae are not believed to be masses of gas, but great systems of stars as large, or nearly as large, as the Milky Way. They are sometimes known as island universes. The bright patches in them represent star clusters, such as our star cluster. Sir James

Jeans says there is probably enough matter in these nebulae to form 2,000,000,000 stars, but some of it is not yet condensed into stars.

A Comparison—Past and Present. Before proceeding



Photo by

H. W. H. H.

FIG. 157. A SPIRAL NEBULA BREAKING UP INTO STARS

Possibly the Galactic system might look something like this from a distance

It would have to be magnified to the size of Europe to show the earth

Further, let us pause to notice how our present ideas differ from those of the early astronomers. They looked upon the earth as the centre of the universe about which the sun, moon, planets, and stars all revolved. We recognize the earth as a dwarf planet belonging to the

solar system and revolving, like the other planets, round the sun. We consider the sun to be one of many similar stars in a star cluster which is in one of the arms of a spiral nebula. Our nebula—the galactic system—is an

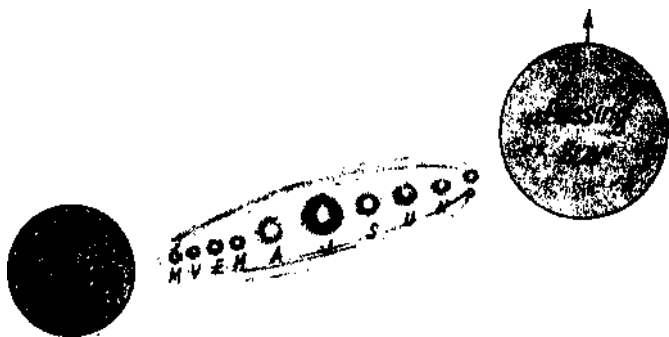


FIG. 158. FORMATION OF THE SOLAR SYSTEM
(After Jeans)

irregular conglomeration of star clusters and nebulous matter, part of which is dark and part luminous. On the borders of our nebula are the star clusters which belong to it. The galactic system is one of millions of spiral nebulae which make up the whole great universe.

When I consider thy heavens, the work of thy fingers,
The moon and the stars, which thou hast ordained;
What is man that thou art mindful of him!

Psalm viii, v. 3.

The Origin of the Solar System. Many attempts have been made to explain how the earth first came into being. Sir James Jeans has given us an account of how he thinks the whole system of planets was formed.

Many millions of years ago some large star may have come very near to the star which we now call the sun. The attraction between the two stars caused a large mass of

gases to leave the sun and shoot out towards the passing star. As the star passed away, this long cigar-shaped mass of gas gradually broke up into smaller masses, which commenced to revolve round the sun. Later these masses condensed, and so formed the whole system of planets.

Possibly the star, which produced our system of planets, may have a similar set of planets formed at the same time, which has accompanied it on its journey through space. We do not know that such planets were formed, for such small bodies as planets could not be seen when at such great distances from us as even the nearest of the stars.

Such near approaches of stars to one another are considered to be extremely rare occurrences; so it is not thought probable that many of the stars have planets.

Thus, we are to think of the earth and the planets as offspring of the sun, which itself was formed from nebulous matter in the great spiral nebula known as the Galaxy, Milky Way, or Galactic system.

EXERCISES ON CHAPTER XII

1. Give other names for the Milky Way.
2. What celestial bodies are present in the Galaxy?
3. Name three clusters in the Milky Way?
4. Why is it difficult to see the Milky Way in London?
5. What do you understand by a globular cluster?
6. Describe the difference between the nebula in Orion and the nebula in Andromeda?
7. Describe the different types of nebulae and mention which do not belong to the Galactic system.
8. What is meant by nebula, spiral nebula, dark nebula? Give examples of each.
9. Make a rough sketch of our nebula in section and show a possible position for the solar system.
10. What is the Great Rift in the Milky Way?
11. Give a short account of the formation of the planets.
12. Why is a quotation from Psalm viii put into this chapter?

CHAPTER XIII

The Uses of Astronomy

Forecasting the Future. Many people think astronomy is a very interesting subject, but consider its study to be rather a waste of time because it has such little practical value. The study of astronomy, by the ordinary person, is certainly chiefly a matter of interest and curiosity; but its practical value is seen to be by no means small or unimportant, when we consider the work of the great observatories.

Until the time of Tycho Brahe, many of the observations of celestial bodies were made in connection with astrology. Even Tycho had to predict the future, and cast horoscopes for his master, in order to earn the right to be his astronomer and to use the observatory.

Astrology began to go out of fashion when men began to realize the universe, and to see how small and unimportant the earth and man were in the whole scheme of things. In the old astrology the stars and planets were supposed to have some influence over the fortunes and lives of men. Most people, now, do not believe in the ability of astrologers to foretell the future and fortunes of men from celestial observations; and yet astronomers can undoubtedly foretell some things with very remarkable accuracy. They can forecast the movements of planets and foretell the reappearance of comets, the occurrence and duration of eclipses of the sun and moon, or the times of eclipses, transits, and occultations of the satellites of Jupiter. They can tell with certainty and accuracy the position of the moon and planets among the stars for long periods ahead, and

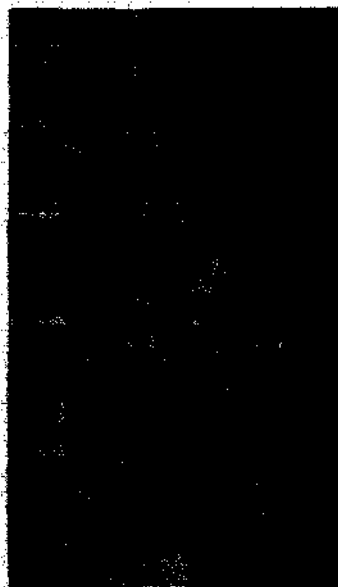


FIG. 159. THE TRANSIT
INSTRUMENT AT GREENWICH
The meridian 0° longitude passes
through the eyepiece of this
instrument

At sea the more usual method is to take observations of the sun when it is on the meridian. The zenith distance (i.e. the distance of the sun from the zenith) is found by using a sextant; and the nautical tables are consulted to find out at what latitude the sun is in the zenith on that day. You will remember that the sun appears to move across the equator from $23\frac{1}{2}^{\circ}$ S. to $23\frac{1}{2}^{\circ}$ N. in the first half of the year, and back again in the second half. At the equinoxes it is overhead (or in the zenith) at the equator, in June at the Tropic of Cancer $23\frac{1}{2}^{\circ}$ N., and in December at the Tropic of Capricorn $23\frac{1}{2}^{\circ}$ S. When the sun is overhead at the equator then the zenith distance is the same as the latitude. If zenith distance is 45° then latitude is 45° . When the sun is north of the equator it will appear higher in the heavens than when at the equator, so the zenith distance will be too small, and we must add to it the number of degrees the sun is north of the equator. Example: If we find, by the tables, that the sun is 15° N. of the equator and, by observation, that the zenith distance is 30° , then the latitude is $30^{\circ} + 15^{\circ} = 45^{\circ}$ N.

On the other hand, if the sun is south of the equator, it will appear too low in the heavens, and the zenith distance will be too great. We must therefore subtract from the zenith distance the number of degrees that the sun is south of the equator. EXAMPLE: If the sun is 15° S. of the equator and the zenith distance is 60° , then the latitude = $60^{\circ} - 15^{\circ} = 45^{\circ}$ N. (See Fig. 160.)

Similar calculations can be made in the Southern Hemisphere, but it will be necessary to remember that the sun is then in the north at mid-day.

It is possible to find the latitude of a place without the aid of the nautical tables. The sun's apparent journey of 47° from $23\frac{1}{2}^{\circ}$ S., across the equator to $23\frac{1}{2}^{\circ}$ N. takes 6 months. Consequently, the sun moves through $\frac{47}{6} = 8^{\circ}$

roughly in 1 month. If at a given place the zenith distance is 40° on 21st April, then the latitude is $40^{\circ} + 8^{\circ} = 48^{\circ}$ because the sun is 8° north of the equator.

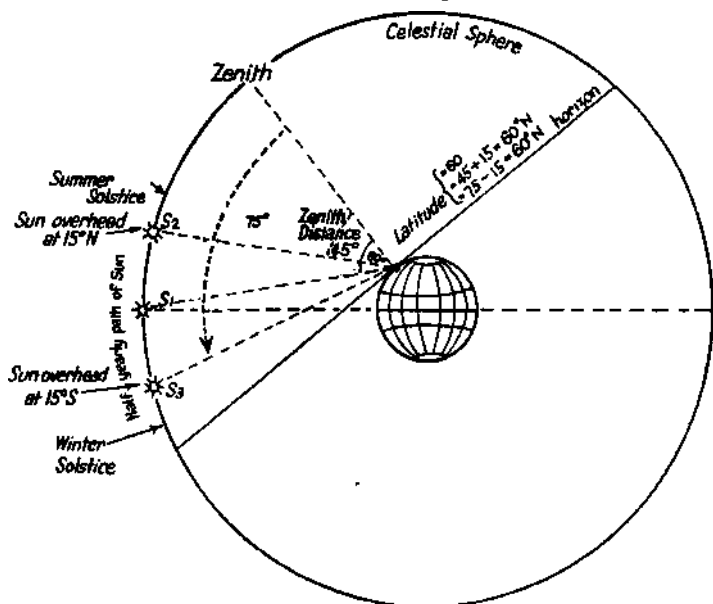


FIG. 160. HOW TO FIND LATITUDE OF THE SPOT

If sun is at S_1 latitude = 60°

If sun is at S_2 latitude = $45 + 15^{\circ} = 60^{\circ}$

If sun is at S_3 latitude = $75^{\circ} - 15^{\circ} = 60^{\circ}$

NOTE. Study Fig. 160 and see that you understand it before proceeding to the next paragraph.

Longitude. To find the longitude of a place is rather more difficult. Longitude is the number of degrees east or west of a line known as the Greenwich Meridian, or Line 0° . This meridian passes through the North and South Poles of the earth, and through the centre of the eyepiece of the telescope at Greenwich, known as the transit instrument, which is shown in Fig. 159.

Of course this line is not marked upon the surface of the earth, except at the one place shown in Fig. 161, which is just outside the walls of Greenwich Observatory.

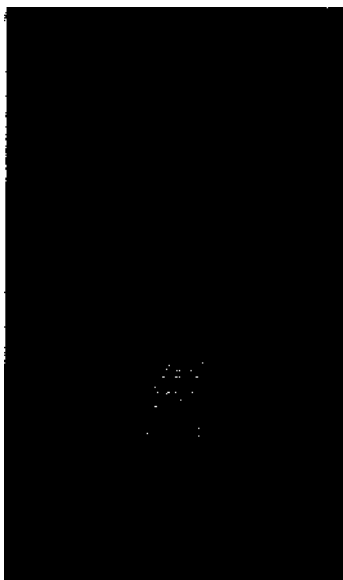
The sun on its apparent daily journey round the earth crosses the Greenwich Meridian at 12 o'clock noon. As it takes 24 hours to move through 360° , therefore it moves through $360^\circ/24 = 15^\circ$ in 1 hr. or 1° in 4 min.

We (the earth) move from west to east; therefore places 1° west of Greenwich will get the sun on their meridian 4 min. later than Greenwich does, and places 1° east of Greenwich will have noon four minutes earlier than Greenwich.

Remembering this, it is possible to obtain the longitude of a place by finding the time when the sun is due south and comparing it with the time when it was due south at Greenwich.

If local noon (sun due south) is at 2 o'clock by Greenwich time, then the earth has travelled eastward for 2 hours and the longitude must be $2 \times 15^\circ = 30^\circ$ W. of Greenwich.

A ship at sea must be able to know Greenwich time in order to find its longitude. It therefore usually keeps two kinds of time: local time and ship's time or Greenwich mean time.



H. E. T.

FIG. 161. THE LINE 0° LONGITUDE WHICH IS MARKED ON THE PATH OUTSIDE THE IVY-COVERED WALL OF THE OBSERVATORY AT GREENWICH

Greenwich mean time is carried by means of specially-made chronometers, which keep very accurate time for a long period, and are very little affected by differences of temperature. Even the best of chronometers require to

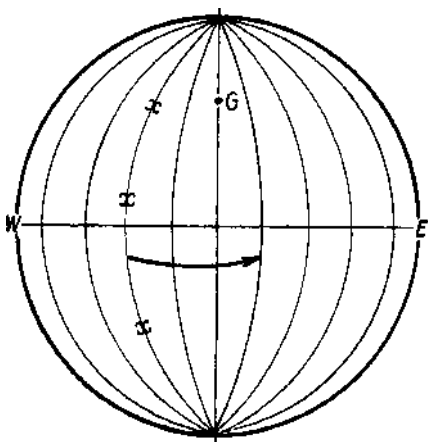


FIG. 162

If ships at x get noon at 2 p.m. by Greenwich time, then longitude of x is 30° W.

be checked and at times repaired. This is one of the duties of the observatory at Greenwich. Sailing ships, passing within signalling distances of each other, used to compare their chronometers. Ports used to be particular to keep Greenwich time, and made arrangements to let captains know the correct time by firing guns, or dropping time-balls, at stated times of the day. Fig. 163 shows the time-ball on the top of the oldest part of Greenwich Observatory. Everyday, at exactly 1 o'clock by the Greenwich clock, it is dropped from the top of the mast to the bottom. It is in such a position that it can be seen by captains on their ships when lying in the Port of London.

Ship's time can be checked at sea by astronomical observations. They used to measure the angular distance

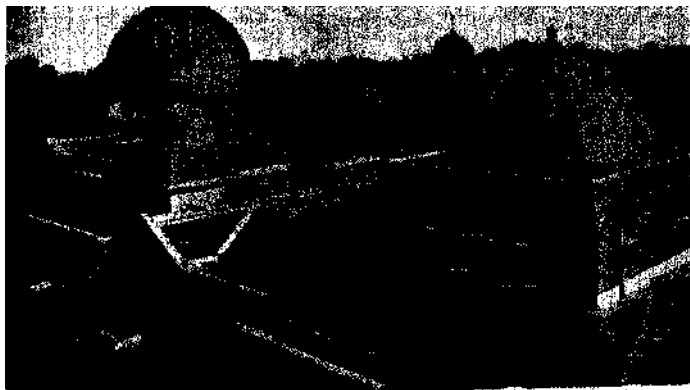
?



FIG. 163. THE TIME-BALL AT GREENWICH OBSERVATORY

between the moon and a bright star or planet by means of the sextant. After making difficult calculations and comparing the results with the distance between the celestial

bodies, as shown by the Nautical Almanac, Greenwich time could be calculated. This method, now gone out of



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FIG. 164. A GENERAL VIEW OF GREENWICH OBSERVATORY
TAKEN FROM THE TOP OF THE ORIGINAL OBSERVATORY
WHICH IS IN THE SAME GROUNDS

use, was known as the method of lunar distances. When It was first introduced it was found that the positions of the heavenly bodies were not sufficiently well known to make it reliable. In order to remedy this, Charles II founded the Royal Observatory, which was built at Greenwich in 1675.

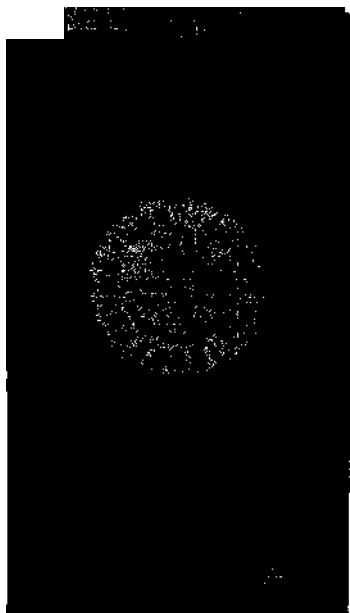
Greenwich Observatory. Fig. 164 is a general view of the present observatory buildings taken from the top of the original observatory, which is within the same grounds. Each dome houses one or more important telescopes, one of which is shown in Fig. 122, page 140.

Until the end of the eighteenth century the chief work of the observatory was to make observations of the sun, moon, planets, and bright stars, and so add to the know-

ledge of their positions and movements. Since then, the work has been greatly extended. The observatory—now a branch of the Admiralty—repairs and times naval chronometers, makes meteorological observations, and prepares charts showing how the magnetic north differs from true north. It also carries on observations of faint stars, and many important observations are made which are of more purely scientific interest.

The Nautical Almanac. Its chief work, however, is to keep correct time and to produce the Nautical Almanac or Sailor's Bible. This is a book of several hundred pages, which is published yearly. It gives advance knowledge of the position of the sun, moon, planets, and stars. It foretells eclipses of the sun and moon, and gives the times of eclipse, transit, or occultation of Jupiter's chief satellites. Without this book, or some similar publication produced by foreign observatories, ships would not dare to leave their port on any long sea journeys.

Time. When we realize how important the correct time



H.E.T.

FIG. 165. THE PUBLIC CLOCK
OUTSIDE GREENWICH OBSERVATORY

This clock is connected electrically with the Greenwich clock, which is kept in an underground room in the observatory

is to the mariner, we may wonder how many ships have been lost or damaged by striking reefs or submerged rocks, through either careless observations of celestial bodies or an incorrect chronometer. It is very important that the position of sunken wrecks, submerged reefs, and small islets, etc., should be exactly marked on charts. This can only be done by obtaining their correct latitude and longitude.

Before the invention of railways, correct time was of small importance to the dweller on land, but now it is essential for the safe and reliable running of our trains. Recently correct time has been regularly broadcast from wireless stations, so that there is no excuse for any one on land or sea keeping bad time.

Sun Time and Star Time. Greenwich time is often called G.M.T., or Greenwich mean time. A day is the *mean* or average time between two successive crossings of the Greenwich meridian by the sun. That is, from noon of one day to noon of the next.

As the earth moves at different rates round its orbit at the same time as it rotates, therefore the lengths of time between one crossing of the meridian and another will vary slightly throughout the year. Experiment with a globe and a lamp and you will see that this must be so. Because of this, we use the average, or mean, time instead of the actual time, such as would be shown by a sundial.

In practice, time is taken from the stars and not from the sun. It is easier to tell the exact moment when a star crosses the meridian than when the sun does, and moreover, the sidereal or star day does not vary like the solar day. It is, however, nearly 4 mm. shorter, so suitable corrections have to be made to give us solar time.

Checking the Clock. Whenever there is a clear night sky, certain bright stars, known as clock-stars, are observed

through the transit telescope situated on the meridian at Greenwich. In the eye-piece of the telescope are a number of fine lines made of cobweb, the centre one being the meridian. The observer watches the clock-star pass across the field of view, and immediately it crosses the meridian he touches a button. An electric current causes a fountain pen to make a mark on a line which it is drawing on a revolving chart. The instrument, called a chronograph, on which the chart and pen are fastened, is connected with the Greenwich clock, and is driven in such a



FIG. 166. THE LINE AS DRAWN BY A CHRONOGRAPH
A to B, B to C, and C to D are two second intervals. A star
passed the meridian one second after the time shown at A

way that the line drawn is automatically marked every two seconds. The dot, made by pressing the key on the telescope, therefore shows the exact time when the star crossed the meridian. (See Fig. 166.) The difference between this time and the calculated time is the error of the clock. In foggy weather observations may be impossible for several days; but so accurate is the clock that the error is seldom found to be more than a very small fraction of a second.

The Equation of Time. The difference between Greenwich mean time and the time shown by the sundial is known as the equation of time. Sometimes the sundial is behind Greenwich time and sometimes in front of it. Tables are constructed to show the amount of this difference for each day of the year. By adding or subtracting the number of minutes shown in the table it is possible to tell the correct Greenwich time by means of a sundial.

NOTE. The equation of time is given in *Whitakefs Almanack* for each day of the year.

Standard Time.

The sun that bids us rest, is waking
Our brethren 'neath the western sky.

When the sun is on the meridian (north and south line) of any place, it is noon there. This means that when it is noon at Greenwich, places east of Greenwich have already had their noon; and places farther west will have it later. These places should have different times. For the sake of convenience Europe has been divided into sections 15^0 wide. In these sections the same time is kept. This time is called standard time. Central Europe is 1 hour and Eastern Europe is 2 hours ahead of Greenwich. America is divided into five sections, with five different times, each differing from the next by 1 hour. 4 a.m. Pacific time is 5 a.m. mountain time, 6 a.m. central time, 7 a.m. eastern time, and 8 a.m. Atlantic time.

The time broadcast from foreign observatories differs from Greenwich time by a whole number of hours or half hours.

The Date Line or Where the Day Begins. The day must commence somewhere. It commences at the date line. Suppose we follow the zones of time round the globe. As we go west from Greenwich we find that the time is earlier and earlier. When Greenwich has noon, places farther west have not yet reached the meridian for the earth moves from west to east. On the west coast of America it will be only 4 a.m., and somewhere in the Pacific Ocean it will be the previous midnight. It will be exactly midnight on the line of longitude 180^0 . As this line lies almost wholly in the Pacific Ocean it causes little inconvenience by having the time on one side of it 11 p.m. on 31st December and on the other side 11 p.m.

Ist January. By agreement the date line does not follow the 180° of longitude exactly. In places it is drawn either east or west of that line, so that groups of islands, such as the Fijis and Samoan Islands may be wholly on one or the other side of it. Sunday a.m. in Samoa will be Monday a.m. in Fiji.

By aeroplane you could fly from an island in the Fiji group on Ist January and arrive in an island of the Samoan group on 31st December.

By wireless it is possible to hear in England things which are happening in Australia on Ist January while it is still 31st December with us. Clocks in Australia are about 9 hours faster than ours.

Direction. Sailors in wooden ships steered their ships by the magnetic compass. The magnetic needle does not point true north, and, moreover, it is affected by any iron work in the ship. It is impor-

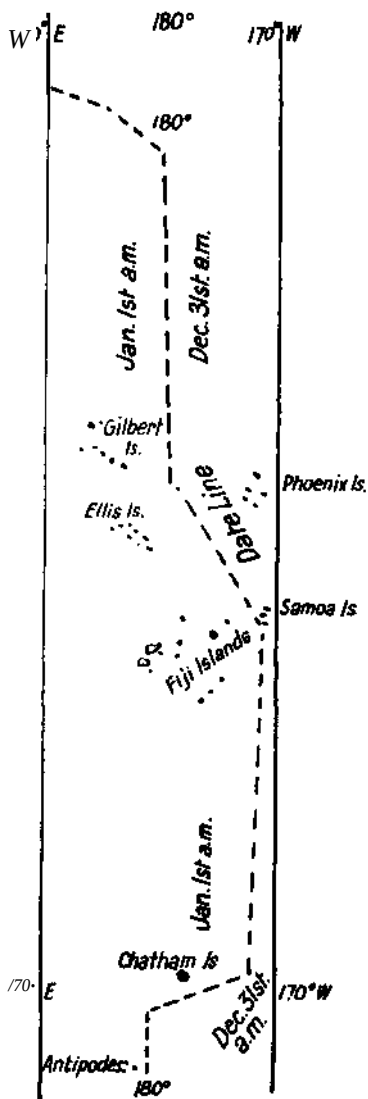


FIG. 167. A PORTION OF THE INTERNATIONAL DATE LINE

tant, therefore, to be able to tell how much the north, as shown by the compass, differs from true north, In a well-ordered ship daily observations of the sun are made in order to find due north, and thus determine the error of the compass by which the ship is steered. Surveyors in unexplored lands and travellers in deserts also use astronomical observations in order to find direction.

The highest branch of surveying is geodesy. The geodolist discovers the exact size of the earth or of a degree of latitude by making observations of celestial bodies. It is by the help of the geodolist that we know the earth is a globe with flattened poles and a bulge near the equator.

Leap Years. The earth is said to revolve round the sun in one year. The real time of revolution, however, is nearly $365\frac{1}{4}$ days, not 365 days exactly. For convenience we take 365 days for a year, and every fourth year we add an extra day in February in order to make up for the four quarters.

If the number of the year is not divisible by 400 we miss the leap year, which would occur at the beginning of each century, because the time of revolution is not quite $365\frac{1}{4}$ days. By this means we manage to keep our seasons in the same months of the year.

There is still another use for astronomy, of a different kind, which is by no means unimportant. The study of the universe has helped man to realize something of its wonderful nature and its immensity. He begins to realize his own position in both time and space, and he is led to think of the cause of all these things and of the power which may control them.

EXERCISES ON CHAPTER XIII

1. What events can astronomers foretell?
2. How do the celestial bodies affect the lives of men?

3. How do we locate a place on a map?
4. An observer in a big town on the west coast of Norway finds that the altitude of the Pole Star is just over 60° . Use your atlas and find out where he is.
5. From your atlas find the altitude of the Pole Star in the Cape Verde Islands.
6. Find the latitude of your own home by means of the Pole Star, two rulers, and a protractor. Point one ruler to the horizon, the other to the Pole Star, and measure the angle between them.
7. On 21st May the zenith distance of the sun is 50° . What is the latitude of the place?
8. The zenith distance of the sun is 25° . The nautical tables say that the sun is overhead at 10° N. What is the latitude?
9. The sun appears in the zenith at midday on 21st January. What is the latitude?
10. Find the zenith distance of the sun and calculate your latitude.
- II. How can you find the longitude of a place?
12. The sun passes the meridian at 3 p.m. by Greenwich time. What is the longitude? Is it east or west?
13. Valencia Island is longitude 10° W. What is the time there when it is noon at Greenwich?
14. What is the time in Ascension Island when it is noon at Greenwich? Use your atlas.
15. Cairo is in North Africa, Durban in South Africa. What is the time in Durban when it is 3 p.m. in Cairo?
16. What is the time in (a) Tokio, (b) Los Angeles, when noon in Greenwich?
17. Does the sun set earlier or later in Bristol than it does in London? By how much.
18. When and why was Greenwich Observatory built?
19. What is the chief work of the observatory at Greenwich?
20. Trace the date line in your atlas.
21. Why do we have leap years? Why was 1900 not a leap year?
22. Explain—

Longitude west, Greenwich time best
Longitude east, Greenwich time least.

APPENDIX

Planet	Satellite	Year. Time of Revolution	Diameters	Distance from the Sun	Day or Time of Rotation
Mercury .	0	88 days	3,030 miles	36,000,000 miles	88 days
Venus .	0	225 "	7,700 "	67,000,000 "	225 "
Earth .	1	365 "	8,000 "	93,000,000 "	24 hr.
Mars .	2	687 "	4,000 "	141,000,000 "	24½ "
Jupiter .	5	12 yr.	86,500 "	483,000,000 "	10 "
Saturn .	9	29 "	73,000 "	886,000,000 "	10 "
Uranus .	5	84 "	32,000 "	1,781,000,000 "	?
Neptune .	2	165 "	34,000 "	2,792,000,000 "	?
Pluto .	0	248 "	4,000? "	3,720,000,000 "	?

Moon: Diameter = 2,000 miles. Distance from earth 240,000 miles.

Light travels at a speed of 186,000 miles per second.

" " " 11,000,000 miles per minute.

Temperature of stars 2,000° to 23,000° C.

1 light-year = 6,000,000,000,000 miles.

Stars move through 1½ of sky in 1 month.

15° in 1 hr.

BRIGHT STARS

	Distance in Light-years.
Sirius (the Dog Star)	8.6
Aldebaran (in the Bull) .	57
Betelgeuse (in Orion)	200
Rigel (in Orion)	500
Vega (in Lyra)	26
Alpha Centauri (in Centauri)	4.3
Arcturus (in Bootes)	41
Capella (in Auriga)	52

SOME DISTANCES

Round the earth	25,000 miles
To the moon	240,000 "
To the sun	93,000,000 "
1 light-year	6,000,000,000,000 "
Nearest star (4 ¹ / ₃ light-years) .	26,000,000,000,000 "
Globular clusters (22,000 to 220,000 light-years)	?
Nearest nebula (about 850,000 light-years)	5,100,000,000,000,000,000
Farthest nebula (about 140,000,000 light-years)	840,000,000,000,000,000,000

