CHAPTER I

THE VAULT OF HEAVEN

We inhabitants of the earth enjoy a piece of good fortune to which we give very little thought, which, indeed, we take almost as much for granted as the air we breathe—I mean the fact that we have a transparent atmosphere. Some of the other planets, for instance Venus and Jupiter, have atmospheres which are so thick with clouds as to be totally opaque. If we had been born on Venus or Jupiter, we should have lived our lives without ever seeing through the clouds, and so should have known nothing of the beauty and poetry of the night sky, and nothing of the intellectual excitement and joy of trying to decipher the meaning of the vast panorama of lights which are scattered round us in all directions in space.

It will not form a bad approach to our subject, if we imagine that until to-night our earth had also been covered in by an opaque blanket of clouds. Suddenly this is rolled back, and we see the glory, and the tantalising puzzle, of the night-sky for the first time.

Our first impression would probably be that the stars were some sort of illumination of lamps or lanterns suspended above our heads, perhaps at only a few miles, or even yards, distance—rather like the lights in the roof of a vast tent or hall. This is what

our remote ancestors thought when human intelligence began to dawn, and men first let their thoughts travel outside the earth on which they lived their daily lives.

Very soon after the cloudy curtain had been rolled back, we should notice that this array of lights was not standing still above our heads. The best way of discovering how they move is to expose a photographic plate to the sky, and let each light record its own motion. That reproduced in Plate I was exposed for 2¼ hours. Each curved line represents the path of a single star, and we see at once that the stars are going round in circles. A little observation discloses that the whole array of lights appears to turn round solid once every twenty-four hours. It is as though the lights were attached to a great hollow shell which rotated above our heads, as a telescope-dome does above the telescope. This again is what primitive man thought, and indeed civilised man also, with a few exceptions, until 300 years ago, when the discoveries of Galileo first began to reveal the true structure of the universe.

The Rotating Earth

Yet, even if we had never seen the sky before to-night, we of to-day would know that the stars do not really move in this way. Experiments which can be made on earth, without looking at the sky at all, prove conclusively that the earth turns round in space once every twenty-four hours, and so shew that it is the earth and not the sky which is rotating.

The motion of the stars over our heads is as much an illusion as that of the cows, trees and churches that flash past the windows of our train.

These experiments are of two kinds. Let us discuss them in turn.

Most ships are steered by the help of an instrument known as the "magnetic compass." In this a small magnet is pivoted so that it can turn in any direction. The earth's magnetism pulls it round until it points to the north, and the navigator, knowing in this way which direction is north, steers his ship accordingly. But submarines and certain other modern ships are steered by an instrument known as the "gyroscopic compass," which works on quite a different principle. In this, a good-sized spinning-top has the ends of the axis round which it spins embedded in a frame. This again is pivoted so that it can turn in any direction. While the ship is still in port, the axis of the top is pointed north. The top is then set spinning, and is kept spinning by electrical machinery of the same kind as we use to keep an ordinary electric fan turning. No matter how much the ship turns about, the axis of the spinning-top remains always pointing to the north. The reason for this is the very simple one that there is nothing pulling on the top to change its direction of spin. Again the navigator can steer his ship by reference to this fixed direction. If his ship turns a complete circle in a fog, the compass will appear to be turning round inside the ship, and this will at once disclose that the ship has turned. When a submarine turns in a circle under the sea, its turning is shewn in the same way. And,

again in the same way, a gyroscopic compass on land will shew the daily turning of the earth in space.

The turning of the earth can also be proved by a still simpler device, known as Foucault's pendulum. Try hanging a heavy weight by a long string from a high roof, and set it swinging like the pendulum of a clock. This improvised pendulum will continue to swing in the same direction in space, again for the simple reason that there is nothing to change its direction. But you will find that it will not continue to swing in the same direction in the room in which it is hanging; its direction of swing will appear to turn round in the room. The reason is that the room itself is turning round all the time in space. A careful study of the motion will shew that the earth turns round once every twenty-four hours. In many science museums and laboratories, you will find a long pendulum swinging from the roof, and by watching it for long enough, you can see the floor of the building, and with it ourselves and the whole earth, turning round under the pendulum. Just in the same way, when we watch the apparent motion of the stars over our heads, what we actually see is ourselves and the whole earth turning round under the vaulted dome of the sky. We are like children on a "merry-go-round" in a village fair. The whole fair seems to be going round them, but actually it is they who are going round inside the fair.

If we were now seeing the stars for the first time, we might reasonably think they were only a few yards or perhaps a few miles overhead. Yet we should soon find that no journey we can take over

the earth would alter the directions of the stars in space, and neither would it, as a matter of fact, if the earth were hundreds of times bigger than it is, so that we could travel millions of miles from pole to pole, and we were armed with the most powerful telescope ever made. This shews how enormous the distances of the stars are in comparison with the size of the earth; our home in space, which seems so huge a globe when we travel over it, is only a tiny speck in the immensity of astronomical space.

Our nearest Neighbour—the Moon

When a journey taken over the earth's surface is found to produce a perceptible change in the direction of any object out in space, we may be sure that the object in question is nearer to us than the stars are. For instance, two observatories at different parts of the earth's surface, say Greenwich and Cape Town, cannot detect any differences in the directions of the stars, but do unmistakably see the moon in slightly different directions in space. This shews that the moon is nearer than the stars, and also makes it possible for us to estimate the distance of the moon from the earth, by a process similar to that of ordinary surveying, or of range-finding in war. We do not need to go to the top of a mountain to discover how high it is, nor need we go to the enemy's guns to find how far they are from our own. In the same way we need not go to the moon to find its distance from the earth. By this sort of surveyors' or "range-finding" method, we find that the moon is

about 239,000 miles away from the earth, and, to within a few thousand miles, its distance always remains the same. Yet a very little observation shews that the moon is not standing still; while its distance from the earth remains the same, its direction continually varies. We find that it is travelling in a circle—or very nearly a circle—round the earth, going completely round once a month, or, more precisely, once every $27\frac{1}{3}$ days. It is our nearest neighbour in space, and like ourselves, is kept tied to the earth by the earth's gravitational pull, to which we shall return later (p. 69).

Apart from the sun, the moon looks the biggest object in the sky. Actually it is one of the smallest, and only looks big because it is so near to us. Its diameter is only 2160 miles, or a little more than a quarter of the diameter of the earth. Once a month, or, more exactly, once every $29\frac{1}{2}$ days, at the time we call "full-moon," its whole disc looks bright. At other times only part of it appears bright, and we invariably find that this is the part which faces towards the sun, while the part facing away from the sun appears dark. Artists could often make their pictures more convincing if they kept this in mind —only those parts of the moon which are lighted up by the sun are bright. This shews that the moon emits no light of its own. It merely reflects the light of the sun, like a huge mirror suspended in the sky.

Yet the dark part of the moon's surface is not absolutely black; generally it is just light enough for us to be able to distinguish its outline, so that we speak of seeing "the old moon in the new moon's

arms." The light by which we see the old moon does not come from the sun, but from the earth. We know only too well how the surface of the sea or of snow, or even of a wet road, may reflect uncomfortably much of the sun's light on to our faces. In the same way the surface of the whole earth reflects enough of the sun's light on to the face of the moon for us to be able to see the parts of it which would otherwise be dark.

If there were any inhabitants of the moon, they would see our earth reflecting the light of the sun, again like a huge mirror suspended in the sky; they would speak of earthlight just as we speak of moonlight. "The old moon in the new moon's arms" is nothing but that part of the moon's surface on which it is night, lighted up by earthlight. In the same way, the lunar inhabitants would occasionally see part of our earth in full sunlight and the rest lighted only by moonlight; they might call this "the old earth in the new earth's arms."

The Sun

It is easy to measure the moon's distance, because it is so near the earth. It is much less easy to measure the distance of the sun, because this is much further away; the methods we use to find the moon's distance do not work very well for the sun. Somewhat, but not entirely, similar methods shew that the sun's distance is a little less than 93 million miles—probably about 92,900,000 miles. Thus the sun is about 400 times as distant as the moon, which explains why its distance is more difficult to measure.

Yet the sun and moon look about equally big in the sky. Every now and then, what is known as an "eclipse" of the sun takes place; the moon comes right in front of the sun, and is found to cover it up almost exactly. The explanation is of course that the sun is not only about 400 times as distant as the moon, but is also 400 times as big. Its diameter is about 400 times the moon's diameter, or 109 times the earth's diameter, or 864,000 miles. This of course means that the sun is 109 times as big in each direction as the earth—in length, and breadth, and height. As a consequence no fewer than 1,300,000 earths could be packed inside the sun.

The Distances of the Stars

The method I have just described will tell us the distances of the sun and moon, but it fails hopelessly if we try it on the stars. We soon find that we must take a far longer journey than from Greenwich to Cape Town before we can detect any change in the directions of the stars. Fortunately Nature herself provides such a journey and gives us free transport. The earth carries us right round the sun once a year, so that at any instant we are at the exact opposite side of the sun from our position of six months previously, and so are 186 million miles away from that position.

This journey of 186 million miles is so long that, after taking it, we do at last see the stars in slightly different directions in space, although, even so, we need extremely refined instruments to measure the

change of direction. By again using the surveyors' method, this time on an incomparably larger scale, we can calculate the distance of a star from the amount by which its direction changes as we ourselves move through 186 million miles.

The distances of the nearest stars can be measured with some accuracy in this way. A very dim star far down in the Southern Hemisphere, known as Proxima Centauri[1], proves to be nearest of all. It is about 25,000,000 million miles away, so that even the nearest of the stars is about 270,000 times as distant as the sun. Although this is the nearest of all known stars, it gives out so little light that it was not discovered until quite recently. Thus it is quite possible that even nearer, but still fainter, stars may be discovered at any time. Except for the sun, moon and some of the planets (pp. 53, 55), the brightest object in the whole sky is Sirius, and this is found to be 51,000,000 million miles distant. Although it is more than twice as far away as Proxima Centauri, we receive 70,000 times as much light from it. Five other stars, besides Proxima Centauri, are known to be nearer to the earth than Sirius; as they appear fainter than Sirius, notwithstanding their nearness, they must of course be intrinsically fainter than Sirius.

[1] The significance of the names of stars is explained on p. 13, the way to identify the stars in the sky on p. 154.

The Picture-book of the Sky

Even if we were seeing the stars for the first time to-night, we should notice that they are something more than a mere random collection of points of light. There is more law and order in their arrangement than we should expect to find if bright and faint spots of light had simply been scattered at random over the face of the sky from some sort of huge pepper-pot. After we had seen the sky for a few nights, we should discover that this same ordered arrangement persisted night after night. The same groups of bright stars seen night after night would soon begin to suggest the outlines of familiar objects, which would help us to remember their arrangement on the face of the sky. It is easy to discover lines of stars, triangles, squares and letters of the alphabet, such as U, V, W, in the sky. Our ancestors, helped by vivid imaginations, saw such objects as a plough, a bear, a chair, and a serpent. In this way the stars were divided up into "constellations," or groups of associated stars.

Some of these still bear the names of common objects, but a far greater number bear the names of mythical Greek heroes and of objects occurring in Greek legends. In some cases a group of several constellations near together gives a sort of pictorial representation of a legend; the sky seems to have been utilised as a sort of permanent picture-book, and made to illustrate story after story of ancient mythology as the earth turned round under it.