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# CHAPTER I

# THE EARTH

These are restless days in which everyone travels who can. The more fortunate of us may have travelled outside Europe to other continents—perhaps even round the world—and seen strange sights and scenery on our travels. And now we are starting out to take the longest journey in the whole universe. We shall travel—or pretend to travel—so far through space that our earth will look like less than the tiniest of motes in a sunbeam, and so far through time that the whole of human history will shrink to a tick of the clock, and a man's whole life to something less than the twinkling of an eye.

As we travel through space, we shall try to draw a picture of the universe as it now is—vast spaces of unthinkable extent and terrifying desolation, redeemed from utter emptiness only at rare intervals by small particles of cold lifeless matter, and at still rarer intervals by those vivid balls of flaming gas we call stars. Most of these stars are solitary wanderers through space, although here and there we may perhaps find a star giving warmth and light to a family of encircling planets. Yet few of these are at all likely to resemble our own earth; the majority will be so different that we shall hardly be able to describe their scenery, or imagine their physical condition.

As we travel through time, we shall try to extend this momentary picture into a sort of cinematograph film that will shew us not only the present, but also the past and the future, of the universe. We shall see the sky as it was a million years ago, a thousand million, and possibly even a million million years ago; we shall watch vast colonies of stars, each like the sands of the seashore in number, being born, living their lives, and finally dying. As one tiny incident in the great drama, we shall watch one inconspicuous grain of sand—our sun—being broken up in great turmoil and finally producing a family of planets. We shall watch one of the smaller of these planets—our earth—coming into being as a globe of hot gas which gradually cools, and ultimately becomes a suitable abode for life. In due course we shall see life appearing, and finally man arriving, taking possession of his tiny speck of dust in space, surveying with astonishment the strange universe in which his life is cast, and looking wonderingly and perhaps anxiously and fearfully into the future.

Before we start on our long journey, let us pause to examine our own home in space—the earth. We shall learn a lot from it that will be useful in our travels. We know that it is globular in shape; we discover this by travelling over it and mapping it out, by watching ships coming over the horizon, or by examining the shape of its shadow when this passes over the face of the moon at an eclipse. It may sound a simple matter to do all this, but the human race had inhabited the earth for hundreds of thousands of years before doing it. For until the last few hundreds of years most people thought the earth was flat, and a few misguided people still think it is. The ancient Greeks, including Homer, thought the earth was a flat circular disc, with Oceanus, the ocean—which they regarded as a river—flowing all around it. The dome of heaven covered this much as a dish-cover covers a dish. Probably the Greek Pythagoras, who was born about 570 B.C., was the first to maintain that the earth had a globular shape.

We also know that the earth is rotating. Day after day and night after night, we see sun, moon and stars rising in the east, moving in stately procession across the sky, and sinking in the west; and ever since the dawn of human intelligence men must have noticed the same thing. But so long as they thought of the earth as a flat plain, it was easier to picture the dome of heaven as turning over the earth than to imagine that the earth might be turning under the dome of heaven. Even Pythagoras, who believed that the earth was a globe floating in space, did not suspect that it turned round under the stars. He imagined that it stood at rest at the centre of the universe, and that the stars were attached to a sphere which turned around it from east to west. So far as we know, Heraclides of Pontus (about 388–315 B.C.) was the first to state perfectly clearly that it was the earth itself which turned round, and that this was why the heavenly bodies appeared to move across the sky.

It is not difficult to prove for ourselves that it is we who are moving round under the stars, and not the stars that are moving round above our heads. Now that we all drive cars, we are all familiar with the property of matter that we describe as "inertia". About a century after Christ, Plutarch explained it in the words "Everything is carried along by the motion natural to it, if it is

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not deflected by something else". Fifteen hundred years later, Isaac Newton described the same property of matter by saying that every body perseveres in its state of rest, or of uniform motion in a straight line, unless it is compelled to change by forces impressed on it. When our car is running freely, stopping the engine does not stop the car; the momentum of the car still carries it forward, and to stop it we must either put on the brakes, or wait until friction and air-resistance brake the motion in a more leisurely manner. Not only every object, but every part of an object, seems to want to continue its present motion, and will only make a change if something pulls on it and compels it to do so. If we turn the steering-wheel of our car, we can make the lower part of the car follow the front wheels, but the upper part will seem to want to continue on its old course; if we turn the wheel too abruptly, there is a danger, as we know, that the car will overturn. Or, if the road is icy or muddy, so that the wheels get no grip on the road, the whole back part of the car will tend to follow its old course, so that the car may skid. We shall encounter this property of inertia very often on our journey through time and space.

It is important to us at the moment because it provides us with the simplest and most convincing proof that the earth actually is rotating. If we swing a heavy ball or weight, pendulum-wise, at the end of a string, we shall find that it keeps on swinging in the same direction in space, no matter how much the top of the string is twisted or turned about; we can no more steer the swing of the pendulum in space by turning the top of

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the string than we can steer a car on ice by turning the steering-wheel.

Now let us set our pendulum swinging in such a direction that it swings towards and away from some clearly defined land-mark, such as a church tower. As we want the motion to continue for a long time, we had better take a really heavy weight and suspend it from a high roof; if we try the experiment on a less massive scale, the pendulum will be stopped too soon by air resistance.

If the earth were standing still in space, our pendulum would naturally continue swinging towards and away from the tower, until the resistance of the air brought it to rest. Instead of this, we shall find the direction of its swing moving gradually farther and farther away from the church tower. The true direction of the swing of the pendulum cannot have changed, so we can only conclude that the church tower must have moved. And this, indeed, is what has happened; the rotation of the earth has carried it round.

Now let us start on our travels by going to the North Pole, and let us take our pendulum with us and perform our experiment there. If we disregard the earth, and keep our eyes fixed on the sky, we shall see that the swinging pendulum moves towards and away from the same stars throughout its whole motion; if, for instance, we start it swinging towards Arcturus, it will keep on swinging towards and away from Arcturus. This proves that Arcturus stays always in the same direction in space. If we now look down to the earth, we shall be able to watch the earth's surface turning round under our non-turning pendulum at the rate of a revolution once every 24 hours—or, to be more precise, every 23 hours 56 minutes and 4·1 seconds. In other latitudes the result of the experiment is less easy both to describe and to explain.

This experiment is generally known as Foucault's experiment. The French physicist Foucault performed it in public in 1852, suspending his pendulum from the dome of the Panthéon in Paris. Thousands of people watched, and, as they saw the pendulum change its direction relative to the walls of the Panthéon, many averred that they could feel the earth turning under their feet.

The same principle of inertia provides a second, but rather less direct, proof of the earth's rotation. We who live in England are so accustomed to the incessant and rapid changes in our own weather that we almost forget that there are large stretches of the earth over which the weather hardly varies at all. It is always hot in the vicinity of the equator, and as winds drag air over these hot regions, the air itself becomes heated and tends to rise upwards, like the hot air in a stuffy room or the hot gases in a chimney. In the same way, when the winds drag air across the Arctic and Antarctic regions, this air becomes cooled and so tends to fall earthwards.

If the earth were not rotating at all, this local heating and cooling of air would set the whole atmosphere into a state of steady circulation in a north-south direction. Air would descend at both poles; the pressure of other air descending behind it would then push it along the earth's surface towards the equator, where it would rise upwards and move back to the poles through the upper reaches of the atmosphere. Such a circulation actually occurs, but is almost concealed by other and more complicated motions produced by the rotation of the earth.

The rotating earth drags the whole circulating system of air round with it, but the latter can never quite keep pace with the solid earth which is forcing its motion. A mountain or other point on the earth's surface in Norway is moving round the axis of the earth at about 500 miles an hour, while one near the equator is moving at about 1000 miles an hour. Now the frictional drag of the earth is never quite forcible enough to speed the air up from 500 to 1000 miles an hour in the course of its southerly journey from Norway to the equator. The earth's mountains and surface are not rough and spiky enough to get a perfectly firm grip on the air, so that this is always slipping backwards a bit—as a motor-car does when the clutch is not holding perfectly. When we feel the air slipping back in this way, we say there is a wind blowing from the east to the west.

This is the origin of the trade-winds which blow steadily westward on both sides of the equator. If the earth were not rotating there would be nothing to cause the trade-winds, so that we can think of these winds as providing a proof of the earth's rotation. It is easier to sail westward than eastward, because in sailing westward the inertia of the air around us keeps us from participating in the full motion of the earth. In sailing eastward, we have the more serious task of overtaking the earth in its motion.

Shortly after Heraclides had explained the rotation of the earth, Eratosthenes of Alexandria measured the earth's size with great skill and surprising success. He believed, with most people of his time, that the sun's distance was enormously great in comparison with the dimensions of the earth. If, then, the earth had been completely flat, the sun would have been directly overhead at all places at the same time. Actually he found that when it was overhead at Syene (the modern Assouan), it was not overhead at Alexandria, which lay 5000 stades to the north. As the sun's rays could not come from different directions at the two places, he argued that the "overhead" directions must be different. Actually he found they were different by a fiftieth of a circle, or 7⅕ degrees—when the sun was directly overhead at Syene, it was 7⅕ degrees from the zenith at Alexandria. Hence he concluded that the earth's surface curved through 7⅕ degrees between the two places, or, as we should say to-day, that the difference of latitude between the two places was 7⅕ degrees.* An easy calculation shewed that the circumference of the whole circle of the earth must be fifty times 5000 stades, or 250,000 stades. Eratosthenes subsequently amended this to 252,000 stades, which was probably equivalent to about 24,662 of our English miles. As the actual circumference of the earth measured in a north-south direction is 24,819 miles, while that around the equator is 24,902 miles, we see that Eratosthenes' measurement was in error by less than one per cent.

Let us take yet another illustration of the principle of inertia,

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* The true difference is about 7° 7′.

which tells us that objects continue moving in a straight line unless something pulls them away from it. We know that if we are swinging a weight round at the end of a string and the string suddenly breaks, the weight will immediately fly off at a tangent into space. Now that the string is broken, the inertia of the weight carries it on in a straight line; before the string broke something must have been pulling on the weight to keep it moving in a circle; this was of course the pull of the string.

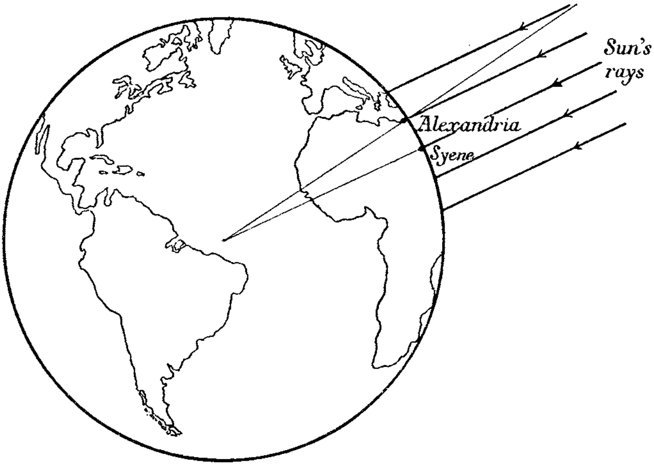

Fig. 1. Eratosthenes found that when the sun's rays fell vertically at Syene, they were a fiftieth of a whole circle away from the vertical at Alexandria. He concluded that the circumference of the earth was fifty times the distance from Alexandria to Syene.

Now objects at the earth's equator are in a similar position to the weight at the end of the string. The earth's rotation carries them round and round in a circle 24,902 miles in circumference once every 24 hours, so that their speed is rather more than

1000 miles an hour. The principle of inertia tells us that they would continue their motion in a straight line, and so fly off at a tangent into space, were it not that something is continually stopping them from doing so—pulling them out of the straight line in which they would otherwise move.

We describe this something as the "gravitational pull" of the earth. It pulls on our bodies with such force that we find ourselves unable to jump more than a few feet into the air, and of course it must exert a correspondingly powerful pull on other objects. Yet it is not all-powerful. The faster a body moves, the greater the pull needed to keep it to a circular path—as we discover if we return to our weight and swing it round faster and ever faster at the end of our string. The earth's pull can easily hold down objects moving at 1000 miles an hour, but with objects moving faster there is less margin to spare. The margin would disappear entirely if the earth were suddenly to start spinning at seventeen times its present speed, so that we had an 85-minute day. We should then see the surprising spectacle of all the objects at and near the earth's equator rising from the ground and flying off at tangents into space, the air and the sea of course accompanying them on their journey. Objects reposing on the earth's surface are rather like drops of rain on the surface of a bicycle wheel: so long as the wheel spins slowly, nothing happens, but when it spins fast they fly off and do not come back.

With things as they are, objects at the equator are very far from being thrown off into space, yet they shew a certain