CHAPTER I

THE SHAPE AND SIZE OF THE EARTH

If we stand on a hill top on a clear day, and look over the lowlands stretching away from below, there is nothing in what we see to suggest that we are on the surface of a globe. There is no appearance that the surface bends down from us as it recedes. Rather does it seem as if the Earth slopes up towards the horizon and as if the hill rises up in the middle of a shallow cup.

When men first began to think about such observations as this, and to consider the shape of the Earth, there was no obvious suggestion that they were on a globe, and, naturally perhaps, the first idea was that the Earth is a flat plain on which the mountains are creases, a flat 'firmament in the midst of the waters.'

Gradually, however, observations accumulated which could not be reconciled with the flatness of the Earth. A traveller, journeying from a mountain range, found on looking back that the mountains not only grew smaller and smaller but that they

sank and at last dropped down altogether out of sight.

When men began to go down to the sea in ships and ventured far out on the waters, the new land to which they sailed appeared first as one little peak, then as a range, and at last the whole land stood above the water. These observations were difficult to reconcile with the idea of a flat Earth, but easy to explain if it was round.

The doctrine of the roundness of the Earth, then, gradually replaced the doctrine of its flatness. But there was a long fight of nearly 2000 years between the doctrines. When Columbus at the end of the 15th century proposed to reach India by sailing to the west instead of to the east, arguing that as the Earth was round, the other side might be reached either way, his opponents, holding that the Earth was flat, regarded him as a fool and a heretic. It was urged that if the Earth were round, men on the opposite side would be walking with their heels upwards, that the trees would be growing with their branches downwards, and that it would rain, hail and snow upwards. All this appeared to them absurd, for they did not realise that the tendency to fall is a tendency to fall towards the centre of the Earth. They thought of 'falling' as a motion in the same direction everywhere, and anything loose on the other side of the Earth, if that other side could be

conceived as existing, should fall away from the surface. They argued that, in order to travel from that other side to this, a ship would have to climb up the sea as if it were climbing up a mountain slope, and that no wind would suffice to drive it up. It was even urged that the roundness of the Earth was inconsistent with the resurrection of the body. For the dead on the other side of the globe would rise on this side with their heels uppermost.

Columbus fought the last fight against a flat Earth, and won. He sailed to the west and found, not indeed the India which he had hoped for, but the West Indies. Soon after, the journey round the world was made, and the Earth was henceforth a globe for all who could study the evidence. Let us consider this evidence in its most conclusive form.

If we watch the stars, by night, at a place in this part of the world, we see that one star, the pole star, does not noticeably change its position, and that all the other stars circle round it. When we make careful measurements we find that the pole star is not quite fixed but goes in a small circle round a centre, which we may conveniently call the sky pole, and it is this sky pole round which all the other stars circle.

If we travel northwards, the stars still circle round the same pole, but the pole itself rises higher

in the sky. The fundamental fact is, that for the same distance of travel due north, the pole rises the same number of degrees, wherever our starting-point may be.

If we are at sea where the horizon is definite we may measure the height in degrees above that horizon. If we are on land where the horizon is conditioned by the elevation of the land and is therefore not a definite line, we may measure the distance in degrees from the zenith, the point directly overhead; and the zenith distance is 90° *minus* the distance from the true horizon, where, by the true horizon, we mean that which the sea-line would give if we had sea in place of land. Thus at a point near Nottingham the sky pole is 53° above the true horizon or 37° below the zenith. If we travel due north 69 miles, to a point near York, the sky pole is 54° above the true horizon or 36° from the zenith. Or if we go across to Ireland, at Cavan it stands 54° above the true horizon, while 69 miles due north at Londonderry it stands 55° above the horizon. Or taking a longer distance, at Coventry it stands about $52\frac{1}{2}^\circ$ above the horizon, while at Sandwick in the Shetlands 552 miles due north it stands about $60\frac{1}{2}^\circ$ above the horizon, having risen 8° for a travel 8×69 miles northward. Everywhere the rise is very nearly at the same rate of 1° for 69 miles' travel northwards, not exactly the same, as we shall see later, for the distance increases

slightly as we go from the equator towards the pole, but the increase is very slight.

Postponing for the present the description of the way in which pole height and distances are measured we may see at once that the relation we have stated is quite inconsistent with a flat Earth. Let us take the last case of Coventry and Sandwick and for simplicity of statement let us think of the pole star as actually at the sky pole. It need not affect the conclusion, for at one point in its circle the pole star will be at the same height above the horizon as the sky pole, and we may choose that point for consideration.

Let C (fig. 1) represent Coventry on a flat Earth, and S Sandwick 552 miles due north. At C make the angle $PCN = 52\frac{1}{2}°$ and at S make the angle $PSN = 60\frac{1}{2}°$, the two lines CP and SP meeting in P the pole star. It is easy to calculate by trigonometry, or to find by direct measurement of a carefully drawn figure in which CS represents 552, that to the same scale PN is about 2740 and CP is about 3450. That is, a flat Earth requires that the pole star is less than 3500 miles from Coventry, an utterly

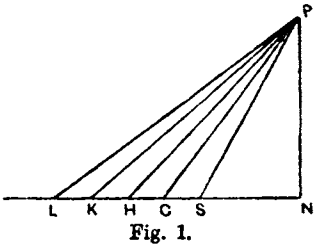

Fig. 1.

absurd result as we shall presently see. But passing this by, let us mark points H, K, L, distant 552 miles, 2×552 miles, and 3×552 miles respectively from C. On a flat Earth the angles PCN, PHN, PKN, PLN do not decrease successively by equal amounts. Careful measurements on a large figure suffice to show this. On the real Earth they decrease successively by 8°, so that the Earth cannot possibly be flat.

Another set of measurements would show equally well that the Earth is not flat, and they are worthy of description inasmuch as they give us conclusive evidence of the true form.

If the Earth were flat and the pole star were vertically above a point O (fig. 2 (a)) on the flat sur-

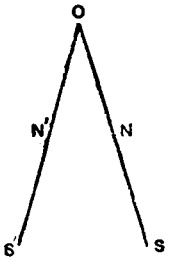

Fig. 2 (a).

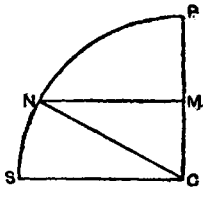

Fig. 2 (b).

face, two lines of travel SN, $S'N'$, each towards due north, would be straight lines and would meet at

O. The distances between the two lines at *SS'* or *NN'* would be proportional to the distance along either from *O*. Two travellers along these lines would approach each other by equal amounts for equal distances travelled northward. But the law of approach is quite different. If we start from two points on the equator, the line on the Earth's surface for which the sky pole is on the horizon, and travel due north from each, that is, always towards the point on the horizon immediately under the sky pole, the distance between the two lines of travel, measured along a line of equal pole height, is proportional to the cosine of the angle through which the pole has risen in the sky. Or if we draw a quarter circle (fig. 2(*b*)), and represent the distance travelled along each line by the length *SN* along this circle, the angle *SCN* being the rise of the sky pole, then the distance between the lines, if measured along a line of equal pole height, will be proportional to *NM*.

I have thought it worth while, even though the doctrine of a flat Earth has long been abandoned, to examine carefully the evidence which led to its abandonment. For that examination enables us to see that our ancestors were not so wrongheaded in holding the doctrine as, at first thought, they might seem to have been. They accepted the most obvious account of appearances, a flat Earth. They observed

that everything tended to fall straight down to the Earth; everywhere, as far as they could tell, in the same direction; or down-ness was universal. Having once taken this view, it was a real difficulty, rightly felt, that bodies could remain on the surface at the Antipodes. They should fall down into space there just as they fall down to the surface here. They had no measurements contradicting their view, nor had they means to make the measurements had they wished to do so.

Another piece of evidence, commonplace to us, was utterly closed to them. They had no difficulty in thinking of the Sun as rising up over the edge of the Earth and illuminating the whole surface at once. It was only with the invention of trustworthy portable clocks that it could be clearly proved that sunrise, noon, and sunset take place earlier and earlier the further we go eastward, later and later the further we go westward. Every traveller across the Atlantic knows that the clocks on board have to be altered each night to make them agree even fairly with the Sun, and every follower of cricket knows that the Australians may have finished a match before we breakfast.

We shall now examine the interpretation which we are obliged to give to the two sets of measurements which we have described, viz.:

1. That the sky pole rises through equal angles

towards the zenith for equal distances travelled due northwards.

2. That two lines on the Earth's surface, each drawn due northwards, are a distance apart, if measured along a line of equal pole height, proportional to the cosine of the pole height or proportional to the length NM in fig. 2 (*b*).

It is first necessary to show that we can fix a definite direction in space, wherever we may be on the Earth's surface, by drawing a line to one of the fixed stars.

Wherever we may be on the Earth, if we see the same groups of stars those groups form the same patterns in the sky. This shows at once that they are vast distances away. For if we look at any arrangement of objects, the less does the arrangement appear to change with a change in our position the further the objects are from us. As we walk along a road, the view of a house by the roadside changes almost with every step. A wood further back alters more slowly. Still, as we move the trees do appear to change places, a nearer tree being now in front of one, now in front of another of those further back. But a range of distant hills may show just the same appearance even though we move hundreds of yards along the road. No measurements which have been made, even with the most powerful telescopes, from different parts of the Earth's surface

at the same time have ever shown the least difference in pattern of the stars in any constellation, and we are forced to conclude that the stars are immensely distant in comparison with any distance we can set out on the Earth. Indeed, the pattern only changes very minutely if we use the vastly greater distance afforded by the motion of the Earth round the Sun from one side of its orbit to the other.

It follows that the direction of any one fixed star is, as nearly as we can measure, the same as seen from all parts of the Earth, or that straight lines drawn from all points to the star are parallel. This will hold good if, instead of any particular star, we take the point about which the stars in their patterns appear to circle; that is to say, the sky pole.

Let S (fig. 3) be a point from which the sky pole is seen along the line SP, and let N be a point due north of S from which the pole is seen along the line NP' parallel to SP. If SZ and NZ' are the verticals at S and N, that is, the lines directed towards their respective zeniths, the angle ZSP is greater than the angle $Z'NP'$, and, as we have seen, if SN is 69 miles it is greater by 1°. The surface therefore bends away from a fixed direction, that of the sky pole, by equal amounts in equal distances. This shows at once that in going northwards we are travelling in a circle, for that is the only curve which bends through equal angles in equal distances. If we produce the