INTRODUCTION.

It is impossible for us now to know what were the earliest beginnings of astronomical knowledge. Many of the remarkable discoveries, such, for instance, as the recognition of the principal planets, were made in prehistoric times. The very earliest allusion which historians have been able to discover refers to them as objects which were already well known. It is, however, reasonable to suppose that the first of all celestial problems which occupied intelligent man must have been the rising and the setting of the Sun. So long as the Earth was believed to consist of an indefinitely extended plane, it was hard to realise that the Sun which disappeared in the West one evening was indeed the self-same object as that which rose in the East on the following morning. Probably this fact alone led the earliest philosophers to the conclusion that however the apparent evidence of the senses might lead to an opposite conclusion, it was nevertheless certain that the Earth could not be an indefinitely extended plane, but that it must be a detached and isolated body so that the Sun was able to dip down under it, as it were, in the course of its nightly journey. Once this step had been taken arguments were easily forthcoming to shew that the Earth was of globular form. The symmetry of the spherical surface would naturally appeal to the taste of the early geometers, and when they saw that the Sun and the Moon were also spherical, then the doctrine that the Earth is indeed a mighty sphere became an accepted contribution to knowledge.

The earliest observation also associates the changes of the Seasons with certain alterations in the apparent position of the Sun. It was obvious that the Sun remained low down in the heavens during the winter, even at noon. In summer, on the other hand, the Sun ascended high in the heavens. Thus it was clear that the Sun was not a fixed point on the celestial sphere, so that even if the phenomenon of rising and setting was produced by the revolution of the celestial sphere, still some independent movement had to be attributed to the Sun. The acuteness of the early observers led them to distinguish the different stars in the sky. They saw that these stars were arranged in certain definite groups, and they noticed the remarkable fact that the stars belonging to these groups retained their celestial positions as permanently as the Alps or other mountains on the earth remained fixed in their terrestrial places. It was natural to watch how these constellations came into visibility as soon as the twilight of evening had subsided. And then a little attention revealed to the early astronomers the interesting fact that the constellations which came into view at the sunsets in the West were not the same throughout the year. They saw that these constellations changed with the seasons. At last it was noticed that when a year had elapsed, the same constellations returned to their original positions. Take, for instance, one of the most remarkable groups, the constellation of Taurus. At certain seasons the stars of this famous group were found to be situated in the West as soon as the light of the departing Sun had sufficiently faded to allow them to become visible. But after a few weeks these stars ceased to be seen, they had passed nearer and nearer to the West until at last by the time the sunlight had declined the stars in Taurus had passed below the horizon. Not for another year was this constellation to be seen in the same position, but then all the phenomena were precisely repeated. A little further consideration pointed out what the cause of these changes must be. It was no movement of the stars themselves. It was obvious that the changes must be attributed to the movements of the Sun. As the Sun advanced in its course it came near Taurus, and then the stars of that constellation set with the Sun. The same was true of many other constellations and hence it became manifest that the stars were strewn all round the celestial sphere, and that the Sun apparently performed an annual revolution in a track amongst the stars. This track was carefully marked out, and the route which it follows, laid down by the sagacity of these early observers, is the circle which we now call the ecliptic.

So long as the Earth appeared to be a body of vast magnitude with regard to the stars, and at a time when the stars and other celestial bodies were believed to be at no very great distance from the Earth, it seemed natural to suppose that the fundamental phenomena of rising and setting were caused by the rotation of the whole celestial sphere, bearing with it the stars, the sun and the moon, and all the other celestial bodies. But when it began to be realised that the dimensions of the Earth were after all but small in comparison with the distances at which the heavenly bodies were placed, then suspicions arose that possibly this apparent movement of rising and setting must be accounted for in another way. Once it had been shewn by geometers that all the phenomena which were actually observed could be explained either by the rotation of the celestial sphere in one direction, or by the rotation of the Earth itself in the opposite direction, there could no longer be much doubt as to the true explanation. It was obviously more rational to suppose that the Earth turned round once every twenty-four hours than that the stupendous fabric of the celestial sphere with the heavenly bodies upon it could accomplish a rotation in the opposite direction in the same time.

As the Sun performed its annual movements along the ecliptic which runs through the signs of the Zodiac, it was for ages supposed that the great luminary did therefore actually make an annual revolution around the Earth. Here again, however, it was shewn that the apparent movement was really quite different from the real one. Copernicus (1473—1543) pointed out how the phenomena as to the seasonal change of the Sun's altitude in the heavens, and as to the passage of the Sun through the various constellations which mark out the signs of the Zodiac, could all be accounted for in a much simpler manner. He made the bold supposition that the Earth, besides its rotation around its axis, also performs a movement of revolution around the Sun, acccmplishing this revolution in the course of a year.

Thus was our knowledge of the celestial movements advanced to the stage from which modern Astronomy takes its departure.

CHAPTER I.

The Diurnal Motion.

§ 1. **Shape and Size of the Earth.** We learn in our geography books the well-known fact which demonstrates that the Earth is not the flat surface which a first glance would seem to indicate, but that it is of a more or less spherical form. More precisely we describe the figure of the Earth as produced by the revolution of an ellipse around its shorter axis. According to the best determinations the equatorial semi-diameter of the ellipse is 20926000 feet and the length of the polar semi-diameter is 20855000 feet, and from these figures we easily deduce that the ellipticity, by which we mean the ratio which the difference between the two axes of the ellipse bears to the larger, is 1/295.

§ 2. **Atmospheric Refraction.** The Earth is surrounded by an atmosphere with a density greatest at the surface of the Earth and steadily diminishing until the upper limit of the atmosphere is reached. The actual height to which the atmosphere extends cannot be stated precisely. It has been found that shooting-stars are sometimes seen at an altitude of more than two hundred miles, and since these bodies are only rendered visible by the resistance which our atmosphere offers to their motion we conclude that the atmosphere must be at least as high as that would indicate. From the astronomer's point of view the atmosphere has always to be reckoned with on account of the effects which it produces in distorting the apparent place of the heavenly bodies by refraction. Whenever a ray of light passes from one medium to another of different density its direction is deflected in accordance with well understood laws which are explained in any book on Optics. A ray of light from a star entering our atmosphere at *A* (Fig. 1) is in accordance with these laws bent down through a very small angle towards the centre of the Earth. We may suppose the atmosphere to be composed of a very large number of successive layers, or strata, lying one below the other and increasing in density towards the Earth's surface. When the ray passes at *B* from the upper layer to the next below it the ray is bent down again towards the centre by a very small amount. Passing thus from layer to layer it follows a curved path through the atmosphere. The observer is, however, immediately conscious only of the direction of the ray at the very end of its journey, where it enters his eye. Accordingly, the ray appears to him to come in the direction *S′E* and the angle between this line and the true direction of the star, namely *SMS′*, is called the *refraction*.

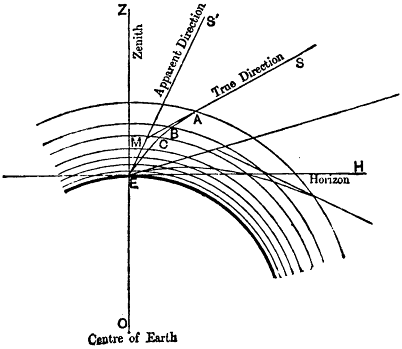

Fig. 1. Atmospheric Refraction.

A star vertically overhead is unaffected, since the ray of light from it to the eye of the observer is perpendicular to each of the successive strata through which it passes. But at any distance from the zenith, for so the point vertically overhead is termed, down to the horizon, the refraction gradually increases. Thus, for instance, at an apparent zenith distance of 45° the effect of refraction is to make a star appear 58″·2 higher than it ought to appear if the air were absent. Towards the horizon refraction increases, and becomes 34′ when a star is actually at the horizon, but, generally speaking, refraction may be taken as proportional to the tangent of the zenith distance for moderate distances from the zenith.

§ 3. **The Celestial Sphere.** The various celestial bodies are conventionally supposed by the astronomer to be on the surface of a sphere which we call the *celestial sphere.* Of course I need hardly say that the stars are at very varied distances from the Earth, but nevertheless the appearance of the heavens can be represented on a globe of which the observer is supposed to occupy the centre. With regard to the ordinary stars, their distances are so enormous as compared with the dimensions of the Earth, that the size of the latter may be absolutely neglected, and observers in all parts of the Earth may be considered equally as occupying the centre of the celestial sphere.

When dealing with the members of the solar system, whose distances though vast are not so enormous as to justify us in considering the Earth as a mere point at the centre, it is often necessary to take into account the position of the observer on the surface of the Earth.

§ 4. **The Constellations.** The majority of the objects visible in the sky are known as the fixed stars; there are only five planets which are conspicuously visible to the unaided eye, namely, Mercury, Venus, Mars, Jupiter and Saturn. The fixed stars have been classified according to their degrees of brightness. The brightest stars are those of the first magnitude, such as Sirius, Arcturus, Vega, and Capella. The next order of magnitude may be illustrated by the stars which form the well-known constellation of the Great Bear. The stars below those again would be the third magnitude, and so down to the very faintest stars which could be seen with the most powerful telescope. Of the first magnitude stars the number is nineteen, of the sixth there are nearly five thousand, while of the ninth there are about a quarter of a million. A star of the first magnitude is about a hundred times as bright as one of the sixth. Stars of the fifth magnitude are faint to the unaided eye, while those of the seventh can but rarely be perceived without a telescope. The numbers of the stars increase enormously as we include the fainter objects. Argelander's famous chart of the northern hemisphere contains 324,188 stars. All stars of the first nine magnitudes were included in this list, and a considerable number also between the ninth and tenth magnitudes. The total number of stars now known must be reckoned by scores of millions.

The prodigious multitude of minute stars is well shewn in the Milky Way, that broad band of light across the heavens. One of the earliest results of the application of the telescope to celestial spaces was to prove that the Milky Way was composed of myriads of stars, generally speaking too minute to be discernible with the unaided eye, but producing by their clustering myriads the luminous effect which is so well known. A photographic plate exposed in a properly mounted camera for a few hours will record the impression of uncounted thousands of stars in almost any part of the Milky Way. In certain places these stars accumulate in such abundance that it seems almost impossible to discriminate, in the coruscating mass, the individual stellar points which contribute to it. Sometimes, on the other hand, we are astonished to see vacant tracts in which few stars are to be found. From the earliest times it was found necessary for convenience in studying the heavens to divide the stellar regions into groups, which are known as constellations. This early method, which has survived to the present day, supposes the surface of the celestial sphere to be covered with imaginary representations of human figures and other objects. By some grotesque associations the bright stars in the sky are made to indicate the forms of the objects. Whatever may be said as to the art or the science of this scheme it, at all events, provides us with the convenience of a special name for each part of the sky, the stars in each region being termed a constellation. We must refer to an atlas of the stars for a description of these constellations, and it will be necessary for the student by the aid of such an atlas to make himself familiar with the positions of the leading groups.

§ 5. **The Diurnal Motion of the Sphere.** The diurnal motion of the stars, in which of course the Sun, the Moon and planets also participate, has now to be considered. Take some particular constellation, and for this purpose the constellation known to astronomers as Ursa Major and to many people in this country as The Plough is very convenient (Fig. 2). It is convenient because whenever the sky is clear this particular group will be found above the horizon. The first observation to be made is to note the position of Ursa Major with reference to the surrounding objects. The observation is to be repeated a few hours later. A very remarkable change will have taken place. It will be seen that the whole constellation has shifted

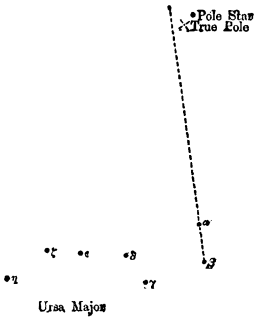

Fig. 2. The Pole and the Pole Star.

bodily. The apparent angular distances of the stars in the constellation from each other have not indeed altered, but the whole constellation has been displaced relatively to the terrestrial objects. A like observation may be made with any other constellation that is visible and in an hour or two the changes in its position will be obvious.

The learner must specially make himself acquainted with that most important star in the northern hemisphere which is known as 'the Pole Star.' It is easily indicated by the two leading stars in the Great Bear which are called 'the Pointers,' because the straight line joining them points very nearly to the Pole. At different hours of the night, or even at different seasons of the year, the Pole Star will always be seen in the northern sky at what is nearly the same elevation above the horizon. The fixity of the Pole Star appears in marked contrast to the never-ending changes in the position of the constellations. We do not indeed say that the Pole Star is absolutely fixed, but the amount of its movement is quite insensible in comparison with the movements of the other constellations.

It would seem indeed as if the celestial sphere containing all the constellations was actually revolving about an axis which passed through the Earth's centre and which also passed, I cannot say through the Pole Star but quite near to it, piercing the celestial sphere in points which are called the North and South Poles. This movement of the constellations, by which each of them appears to complete a circuit of the celestial sphere once a day, is called the diurnal motion. In this motion the relative positions of the stars are unaltered and each star maintains its distance from the pole unchanged except for the small disturbance caused by the atmospheric refraction, as explained above, the amount of which varies as the star changes its position.

§ 6. Circles of the Sphere. It can easily be shewn that if a point on a sphere rotates so as to be always at the