elevation. In like manner in defining the position of any one piece of ornamentation in the vertical series it will not be sufficient to say that it is at a certain angular distance from any one point, say a door, because all the pieces in the same row are at this angular distance from the door. But if these two methods of stating position be combined, if the height above the ground as well as the angular distance from the door be given, then a definite statement may be made both of the position of the pane of glass and the piece of ornamentation. Similarly with the stars. Imagine a horizontal circle passing from north to south, and thence to north again. A line from the zenith through any body will cut this circle at some one point, and the number of degrees included between that point and the north point will give the angular distance from the north point, or, as it is called, the azimuth. The whole of an imaginary line of bodies extending from the zenith to the horizon will have the same azimuth (see Fig. 3). In the same way we may imagine a whole ring of bodies

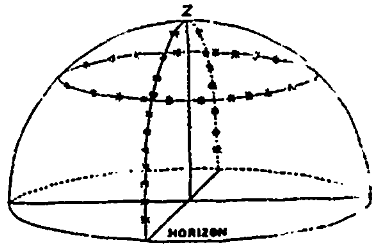

FIG. 3.—Stars with equal altitudes and stars with equal azimuths.

at the same height above the horizon, having the same altitude (see Fig. 3), but a particular altitude and a particular azimuth can be true of only one of those bodies. It is in this way, then, by a statement of the altitude and azimuth, that the position of a star or other celestial body can be indicated with reference to any one particular place of observation and any one particular instant of time.

It is by thus dealing with this angular measurement that the exact positions of the heavenly bodies have been determined.

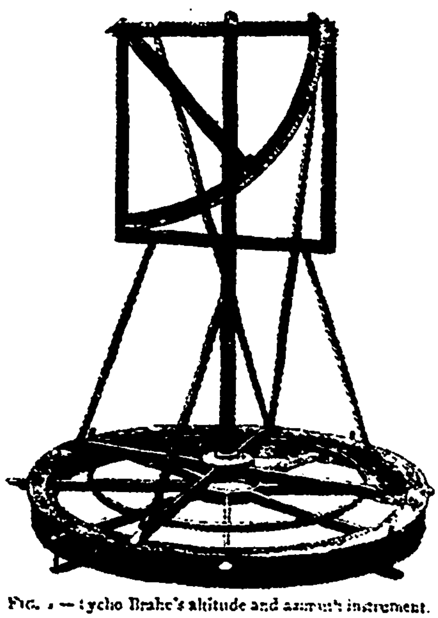

FIG. 4.—Tycho Brahe's altitude and azimuth instrument.

This point has been discussed at some length, because in making an historical survey it will be found that the growth of that particular knowledge of which we shall come to speak, has been the growth of man's capability of getting finer and finer in this angular measurement. To go back to the time of the old Greeks, Hipparchus, one of the most eminent of ancient observers, even in his day could define the position of a heavenly body to within one-third of a degree. Since these 360 degrees into which circles are divided are each subdivided, first into 60 minutes, and each of these again into 60 seconds, the one-third of a degree to which Hipparchus attained may be called 20 minutes of arc.

Passing from his time to the middle ages, a most interesting instrument then in use claims attention. Fig. 4 is a copy of a photograph of the instrument.

The model, from which the photograph has been taken, is an exact copy of an instrument made by one of the most industrious astronomers that ever lived, Tycho Brahe, and shows how, even in the very beginning of this observational science, men got at a very admirable way of making their observations, considering the means they had at their disposal. First there was in this instrument a quadrant of a circle (see Fig. 4), which served their purpose just as well as a whole circle. Combined with this was an arrangement somewhat resembling the "sights" on a modern rifle. Remember this was before the days of telescopes. So they started with these sights and a little pinhole, that they might take a shot, as it were, at a heavenly body, putting the eye near the pinhole, and seeing the heavenly body in a line with the front sight. Then the instrument was provided with a plumbline to show the vertical. This plumbline was so arranged that when the sight lay along it, a body in the zenith would be observed, and an angle of 90° altitude recorded. With the instrument thus set, any smaller altitude could be read along the quadrant, according to the position of the line of sight passing through the eye, the centre of the quadrant, and the place of the heavenly body.

To get azimuth they used a horizontal circle, shown at the base, also divided into degrees and provided with a pointer. By sweeping the instrument round until the azimuth was such that the body was seen through the pinhole, and the altitude was such that it was seen in a line with the front sight, they fixed its position, as well as that instrument enabled it to be done. Supposing that their circles were properly divided, it was quite easy to determine a division as small as the quarter of a degree. This would put Tycho Brahe in only a little better position than Hipparchus. That is to say, from the time of the Greeks until about the middle of the fifteenth century, the only advance made with this angular measurement, was that a reading of one-third was improved into a reading of one-fourth of a degree.

Another notable improvement and advance towards a finer and more accurate measurement was made by Digges. He introduced the diagonal scale, the principle of which is shown in Fig. 5. The arrangement consists of a number of concentric

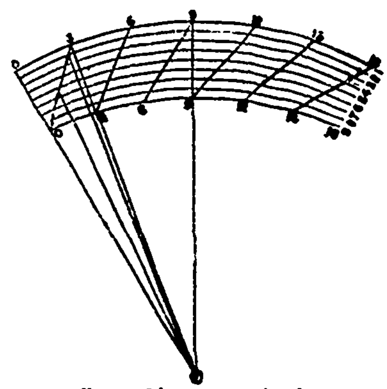

FIG. 5.—Digges' diagonal scale.

circles, in this case nine. The distance between the divisions of the inner circle is 3°. From each of these divisions diagonal lines are drawn to the outer circle in such a manner that the diagonal cutting the first circle at 0° cuts the ninth circle at 3°. That cutting the first circle at 3° cuts the outer circle at 6°. So with the other diagonal lines. Consider the diagonal passing from 0° on the inner circle to 3° on the outer. If the pointer cuts the scale at the former point, an observation of 0° will have been made; if it cuts at the latter point, an observation of 3° will have been made. But it may cut the scale at some intermediate point. Suppose it falls on the eighth of the nine concentric circles, then the value of the observation will be 7/8ths of 3°. Should the pointer fall half way between 0° and 3°, the reading