third of an inch thick, of ebony, with a brass sight vane at each end, and a fiducial edge parallel to the line of sight ; the vanes are about 5 inches high, which gives sufficient elevation and depression for general use. The magnetic needle is about 6 inches long and is held in a rectangular brass box an inch broad, placed on the table whilst it is being set and afterwards removed. Heights may be determined on the spot with the aid of a clinometer, formed of a bar carrying a spirit-level and a pair of sights, one of which has a scale of tangents graduated to radius = the interval between the sights. For the method of employing the table see § 4, p. 709 above.

The theodolite, the most important of all instruments for the purposes of a survey, is a combination of two graduated circles placed at right angles to each other, for the measurement of hori­zontal and vertical angles, a telescope, which turns on axes mounted centrically to the circles, and an alidade for each circle, which carries two or more readers of the arcs through which the telescope is moved. The whole is supported by a pedestal resting on foot- screws, which are also employed to level the instrument. The size varies from a minimum with circles 3 inches in diameter to *a* maxi­mum with a 36-inch horizontal and an 18-inch vertical circle, the weight ranging from 4 lb to 1000 lb ; the dimensions and magni­fying powers of the telescope increase with the diameter of the horizontal circle. The telescope may be connected rigidly with the alidade and move with it while the circle remains stationary, or with the circle and move with it while the alidade remains stationary. The varieties of form as well as of size are numerous : in some the telescope may be completely turned round in altitude as well as azimuth, and pointed to any object celestial or terrestrial ; in others the range of movement in altitude is restricted to about 25° above and 25° below the horizon, and a pair of sectors are substituted for the complete vertical circle ; in some the telescope and vertical circle are placed between, in others outside of, the pillars which support their common axis ; in some the pedestal is a simple tribrach resting on three foot-screws, in others it takes the objectionable form of a ball carrying the vertical axis and a socket holding the ball between two parallel plates, which are antagonized and set firm by two pairs of foot-screws, turning in sockets fixed to the lower plate, while their heads are pressed against the upper plate, to fix it and bring the instrument into level at the same time. There are numerous other specialities of form which have been introduced to meet specific requirements ; but these cannot be noticed here.

The transit theodolite is an alt-azimuth instrument with the graduated circles of equal diameter, usually 6 to 8 inches. The telescope is mounted between a pair of conical arms which taper outwards and end in cylindrical pivots, constituting what is called the transit axis of the instrument. The pivots rest on Y’s or in semicircular collars, on the heads of a pair of pillars, which are made of sufficient height to enable the telescope to revolve between them and be pointed to stars in the zenith. These pillars stand on a circular plate, which serves as the alidade of the horizontal circle and is usually constructed to revolve round a vertical axis fixed in the centre of the plate of the horizontal circle ; this axis passes downwards into a socket in the centre of a tribrach, which forms the pedestal of the instrument and rests on three mill- headed foot-screws by which the instrument is levelled. The vertical circle is mounted centrically on one of the cones of the transit axis, near the pivot end ; its alidade, usually a rectangular plate carrying a pair of verniers, is fitted centrically over that axis, in contact with the circle but nearer the shoulder of the pivot, and, while the telescope and the circle revolve together, it is held station­ary by an adjustable arm the end of which is pinched between a pair of antagonizing screws mounted on the nearest pillar. The alidade of the horizontal circle carries two or three equidistant verniers, because any error in centring an alidade over a circle is eliminated in the mean of the readings whenever two or more verniers, placed at equal distances apart round the circle, are read. A clamp, with a tangent screw for communicating slow motion, is attached to the nearest pillar, to act on the vertical circle and the telescope ; another is attached to the plate of the horizontal circle, to act on the alidade of that circle and so also on the telescope for azimuthal motion ; and a third to the pedestal, to act on the plate of the horizontal circle. The first two are employed in measuring the vertical and azimuthal angles, the third in setting the zero-diameter of the horizontal circle in any specific direction, with a view to the repetition of the mea­surements of the azimuthal angles at different parts of the circle. For levelling the instrument, two levels are fixed at right angles to each other on the plate of the alidade of the horizontal circle ; a third is attached to the telescope, or, preferably, to the alidade of the vertical circle ; a fourth is mounted on the transit axis when levelling for astronomical observations. A magnetic compass or needle is added, and also a plummet for centring the instrument over the station mark.

Theodolites are designed to measure horizontal angles with greater accuracy than vertical, because it is on the former that the most important work of a survey depends, and they are measurable with greatest accuracy ; measures of vertical angles are liable to be

much impaired by variations in the refractive condition of the lower strata of the atmosphere, more particularly on long lines, so that when heights have to be determined with much accuracy the theo­dolite must be discarded for a levelling instrument, to be set up repeatedly with staves at short distances. When truly adjusted the theodolite measures the horizontal angle between any two objects, however much they may differ in altitude, as the pole star and any terrestrial object ; but, as adjustments are not always made with accuracy nor permanently maintained, it is desirable always to take the observations in pairs, with the face of the vertical circle alternately to the right and left of the observer, for this eliminates collimation error from the horizontal angles and index error in the setting of the spirit-level from the vertical angles.

When a horizontal angle is measured several times for greater accuracy, one of two methods of procedure is adopted. (1) The angle is measured once or oftener in the usual way, the horizontal circle remaining clamped and the telescope and alidade moving over it ; then the position of the horizontal circle is shifted@@1 as often as may be desired, and after each shifting the angle is again measured as formerly ; thus a separate numerical result is obtained for each operation. Or (2), the first object A having been observed and the telescope set on the second object B, the horizontal circle is undamped and turned round until the telescope is brought back on A, when it is again clamped ; then the alidade is undamped and the telescope again moved over the horizontal circle to be set on B. The operation is repeated as often as may be desired. The vernier readings are only taken for the first telescope pointing to A and the last to B ; their difference +360o for every complete revolution of the circle, divided by the number of repetitions, gives the angle. This method is objectionable when a round of several angles has to be measured, but it enables the value of a single angle—more par­ticularly a small one, as between objects in the same field of the telescope—to be determined accurately with much greater rapidity than the first method.

An auxiliary telescope is sometimes fixed below the plate of the horizontal circle of a theodolite, to be pointed to a referring mark while the upper telescope is being moved about, and thus to serve as a check on the general stability of the instrument and on the per­manence of the initial setting of the circle during the measurement of a round of angles. When a theodolite is set up on a lofty scaffolding W’hich is liable to be swayed by the wind, or on a stand which cannot be readily isolated from the observer, horizontal angles may be measured accurately by employing a second observer to keep the auxiliary telescope truly pointed to a referring mark while the observing telescope is being pointed.

The subtense transit theodolite differs from the ordinary transit theodolite merely in having a pair of wire-carrying micrometers mounted in the telescope tube, in order that the small angle sub­tended by a distant object of known dimensions, or by two objects sufficiently near each other to be seen in the same field of the tele­scope, may be measured with greater facility and precision than on the graduated circles in the usual way. The micrometers are held in a rectangular box, one on the right hand, the other on the left, with the wires brought as closely as possible into the plane of the fixed wires in the ordinary diaphragm ; the box can be turned on the telescope tube through an angle of rather more than 90°, to enable the micrometer wires to be set parallel to either the hori­zontal or the vertical wire of the diaphragm, or to be placed at any desired angle of inclination. The subtense object usually employed in survey work is a pole of known length ; if held perpendicularly to the line of sight of the telescope, its direct distance may be determined from the angle measured by the micrometers with a sufficiently small percentage of error to make this method preferable to chaining over rough ground. The instrument has been advan­tageously employed in carrying traverses of considerable length over ground which was impracticable for direct linear measurements. The micrometers are also serviceable in astronomical observations for time and longitude, for they give additional wires on which to observe the passage of a star, at distances from the fixed wire which may be varied with the speed of the star ; and for determining the longitude they permit numerous measures of the distance between the edge of the moon and a star to be taken, immediately before and after occultation.

Eckhold’s omnimeter is a theodolite furnished w’ith a microscope of considerable magnitude facing a graduated linear scale ; the tube of the. microscope is rigidly attached to the telescope tube, either at right angles or parallel to it, so that the two always move to­gether. The scale is fixed either parallel or perpendicular to the alidade plate of the horizontal circle ; thus, when the telescope is moved through vertical arcs within the range of the scale, the tangents of the arcs are measured by the microscope on the scale. The latest and best form of the instrument is shown in fig. 8, which represents a transit theodolite converted into an omnimeter by the application of a microscope *AB* to the telescope at right

@@@1 This is often done arbitrarily, but systematic shifts which bring equidis­tant graduations of the circle under the verniers during all the telescope point­ings to any one object are always preferable (see sect. I., § 9, p. 69S above).