THE THEODOLITE: MEASURING AN ALTITUDE ANGLE OR ZENITH DISTANCE

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These angles are defined with respect to local gravity: altitude ALT is the angle up from the horizon, zenith distance Z is the angle from the vertical, so $ALT = 90^\circ - Z$.

You will be using a Universal Theodolite, model Wild T2, for these measurements. A scan of the full documentation for this device is located on the class webpage. Figure 1 shows a diagram of the theodolite with labels of important components.

It is essential that you treat this instrument gently. It achieves remarkable precision because it has been very well taken care of.

1. Preliminary leveling.

Before beginning any measurements, level the instrument. The theodolite has bubble levels, which allow you to level the instrument with respect to local gravity. There are *three levels* of accuracy in these bubble levels.

First, on the base of the instrument there is a two-dimensional ("spherical") level of low accuracy. Place the bubble inside the circle by varying the lengths of the legs of the tripod.

Second, on the theodolite itself there is a cylindrical level (the "plate level"; number 23 on the illustration). Turn the theodolite around the azimuth circle so that the axis of the plate level is parallel to a line connecting one pair of the three base-plate leveling screws (number 3). Then turn these two screws, in opposite directions, and center the bubble. Finally turn the theodolite around the azimuth circle by about 90°. Use the third screw to level the bubble. Finally, go back and check that the bubble is centered in both directions of azimuth.

Third, the “split bubble”. This must be leveled before each individual measurement, and you don’t need to worry about this yet. Thus, performing the first two steps above constitutes the act of “leveling the instrument”.

2. Focusing.

How many times have people been totally unable to locate the North Star, indeed totally unable to locate *any* star with the theodolite, only to find that it was completely out of focus? Uncountable!

There are two aspects to focusing: first, focus the crosshairs; next, focus on the object of interest. Focusing the crosshairs goes just like all optical instruments: point the telescope at a featureless background, let your eye totally relax, and turn the *black* knob (number 10) until the crosshairs are in focus. The numbers on the black knob indicate the number of diopters for which your eye needs correction. That is, people with perfect vision, even if they wear glasses, will see the crosshairs in best focus with the knob at “0”. If you require an adjustment significantly different from “0”, you need corrective lenses! (Actually, this isn’t really true, because many of our instruments have this zero point incorrectly set). After adjusting the black knob, *leave it alone.*

Next use the silver knob focusing knob (number 20). If you will be looking at a star, first focus on a bright star or, alternatively, a distant terrestrial light source (to get the focus roughly right) and then a star (to get it exact). Without focusing first on a bright star, you will never be able to see a dim star. Once you get the focus set, don’t change it.

Other students in your group may need to make *small* adjustments if their eyes are not properly corrected with glasses or contact lenses.

3. Measuring the altitude angle of an object.

To measure the altitude angle or zenith distance of an object there are four steps.

1. Make the “forward measurement”. Point the theodolite towards the object of interest. This isn’t as easy as it sounds—particularly for stars, because stars don't have labels on them and there is nothing easier than pointing towards the wrong star.

First, loosen both clamping screws (number 11 for the vertical circle; horizontal circle screw is not shown) and use your hands to point the telescope *close to* the object by using the "gunsights" on the barrel of the telescope.

Second, look through the telescope, make sure that the object is somewhere in the field of view, and tighten the clamping screws. Clamping screws should be tightened "finger-tight;" a strong twist is not necessary and can damage the instrument. Do not attempt to move the theodolite by hand after you have clamped it.

Third, use the tangent ("vernier") knobs to point *exactly* at the object. The final turn of the tangent knobs should be clockwise.

2. Level the "split bubble" (number 9 on the illustration). With the brand name "WILD" facing you, look at the left-hand upright (or if the brand name is not facing you, look at the right-hand upright); partway up you will find the "level prism" (number 9). This can be rotated towards you for convenient viewing. If you look at this you will see a vertical line that bisects the elliptical area. If the theodolite is in reasonably good adjustment you will see two bubbles. You must align these bubbles *before each angle measurement*. The knob to adjust these bubbles is directly behind the prism and is not shown on the diagram. To be more specific: align the bubbles *after sighting* and *before reading the scales*, **for each and every measurement.** This will ensure an exquisitely leveled theodolite and a reliable measurement of each altitude angle. To make this final alignment, use the *notched* (not knurled) tangent knob; this is not visible on the illustration because it sits on the back of the left-hand pillar, just below the level prism.

3. Read the angle.

First, rotate the "inverter knob" (number 22) so that the black line on the knob is vertical (which indicates you are measuring an angle with the vertical circle—the altitude).

Second, make the "coincidence adjustment" by using the "optical micrometer knob" (number 18) on the right-hand upright, the same pillar you grasped to lift the instrument out of its case. The "coincidence adjustment" means that you must align the graduations on the top and bottom scales; see Figure 2. After alignment, you will see something like in Figure 2, which shows two windows. In the upper window, find the numbers on top and bottom that differ by 180°. The *number on the bottom left* is the number of *degrees*. Count the number of spaces between the gradation marks of the number on the bottom left and that on the top right; in Figure 2 there are 5. This is the number of *tens of arcminutes*. Add this to the number of degrees. Finally, in the lower window, there is a scale marked in arcminutes and arcseconds. The lower number is arcminutes, the upper arcseconds.

4. Take the "reverse measurement": loosen both clamping knobs, rotate the azimuth by 180°, and again point the telescope towards the object. Then repeat steps (2) and (3) above.

In the ideal world, the reverse measurement and the forward measurement add to 360° ($F = 360° - R$) and $Z = F = 360° - R$; in the real world we take the average, so $Z = \frac{F-R+360°}{2}$.

4. Measuring the azimuth angle of an object.

This goes just like measuring the altitude angle, with three exceptions: one, the black line on the inverter knob must be horizontal; two, you don't have to worry about the split bubble for azimuth; three, forward and reverse obey $F - R = 180°$. One more point: the zero point for azimuth is true north. You can determine true north only by using astronomical techniques. We will not do this in this course. Thus, if you measure azimuth angle, you will be measuring it with respect to an arbitrary zero point.

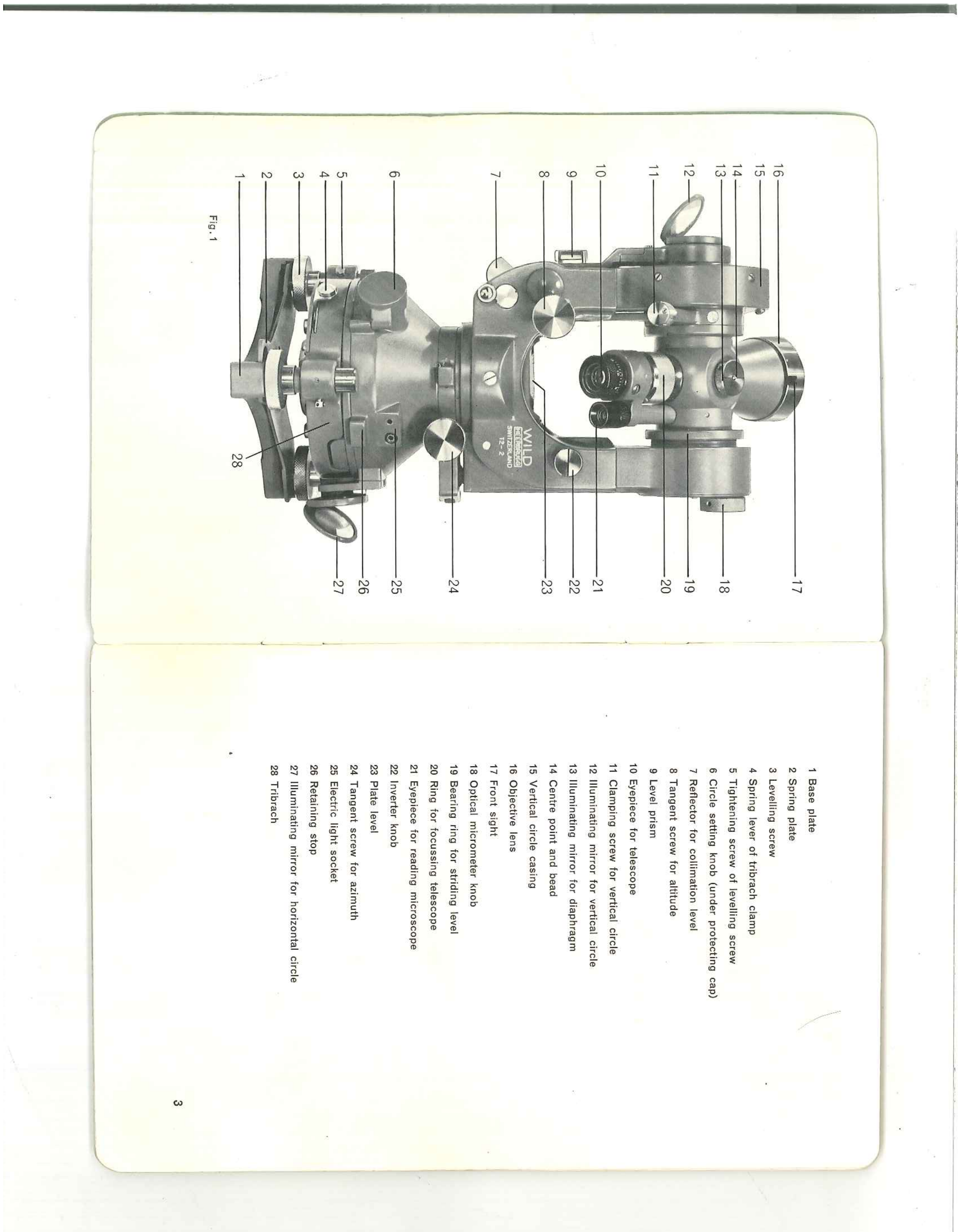
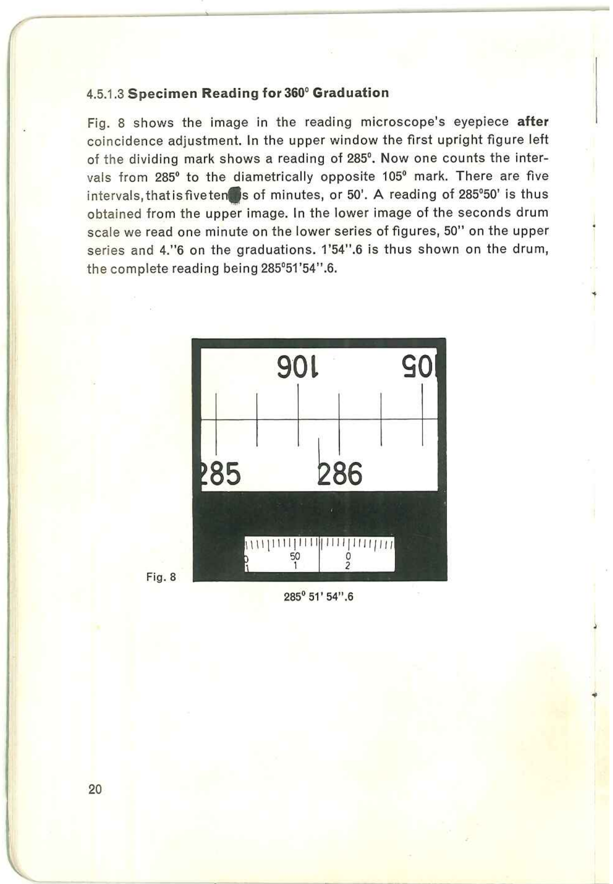


Figure 1: Instrument image from the manual.



4.5.1.3 Specimen Reading for 360° Graduation

Fig. 8 shows the image in the reading microscope's eyepiece **after** coincidence adjustment. In the upper window the first upright figure left of the dividing mark shows a reading of 285°. Now one counts the intervals from 285° to the diametrically opposite 105° mark. There are five intervals, that is five tenths of minutes, or 50'. A reading of 285°50' is thus obtained from the upper image. In the lower image of the seconds drum scale we read one minute on the lower series of figures, 50'' on the upper series and 4.''6 on the graduations. 1'54''.6 is thus shown on the drum, the complete reading being 285°51'54''.6.

Fig. 8

285° 51' 54''.6

Figure 2: How to read angles with the theodolite.