Theodolite Instructions

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A theodolite is a telescope mounted to very sensitive horizontal and vertical protractors. It is capable of measuring angles and, when used in conjunction with graduated reference objects, distances with a high degree of accuracy. Theodolites are primarily used by surveyors to map out terrain.

In the ACME electron EDM experiment, a Topcon model DT-209L theodolite will be used to align the beam source with the detection region in order to maximize the molecular flux into the detection volume while excluding all molecule trajectories incident on the electric field plates, as the latter could cause systematic error inducing patch fields.

This document outlines the procedure for using the theodolite to measure angles.

1 Setup

1.1 Tripod setup

In this section we learn how to set up the tripod and roughly center and level it over a small positioning mark, such as a divot in a penny glued to the floor, a nail head, or any other small fixed object.

(a) Place the tripod over the positioning mark, setting the legs at a convenient height, and roughly center and level the tripod head by eye.

(b) Suspend the plumb bob included in the theodolite box from the hanger beneath the tripod head.

(c) Readjust the tripod to center the plumb bob over the positioning mark by moving all three tripod feet by the same amount in the same direction.

(d) Firmly fix the tripod feet in position. If necessary, adjust the heights of the tripod legs to re-center the tripod within 1 cm of the reference mark.

(e) Tighten the leg clamps on the tripod.

1.2 Theodolite setup

In this section we learn how to unpack, set up, center, and level the theodolite.

1.2.1 Seating and centering the theodolite

(a) Examine how the tripod is seated in its box. See Fig. 1.

(b) Lift the theodolite out of its box by the handle—never by the telescope.

(c) Place the theodolite on the tripod head and screw in the centering screw while holding onto the handle. Leave the centering screw just loose enough that the theodolite can still slide around the tripod head.

(d) Looking through the optical plummet, focus the centering index mark. Slide the theodolite on the tripod head until the reference mark is centered in the optical plummet.

(e) Fully tighten the centering screw. Look through the optical plummet again and adjust the theodolite foot screws for fine alignment with the reference mark.

Figure 1: Theodolite-in-a-box.

1.2.2 Leveling the theodolite

(a) Referring to Fig. 2, roughly level the instrument using the circular level:

   i. Turn the leveling screws A and B in opposite directions to center the bubble along the AB axis.

   ii. Turn leveling screw C to bring the bubble to the center of the circular level.

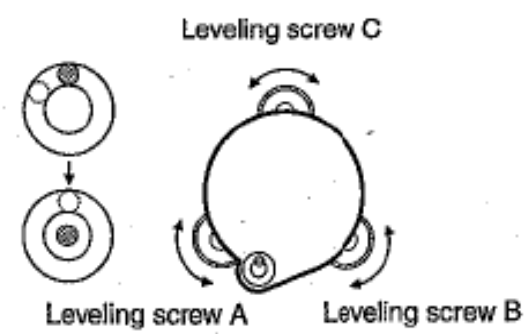

Figure 2: Diagram for rough leveling with the circular level.

(b) Referring to Fig. 3, precisely level the instrument using the plate level.

i. Free the horizontal motion clamp and rotate the instrument horizontally until the plate level is parallel with line AB.

ii. Bring the bubble to the center of the plate level by turning screws A and B in opposite directions.

iii. Rotate the instrument by 90° around its vertical axis and turn screw C to center the bubble once more.

iv. Repeat procedures i. and ii. for each 90° rotation of the instrument and check that the bubble is correctly centered for all four points. If after 180° of rotation, the bubble is off center, remove half the error in the bubble centering. Check that when you have swung another 180° back to the initial point, the bubble offset is the same as the offset you allowed to remain in the 180° rotated position.

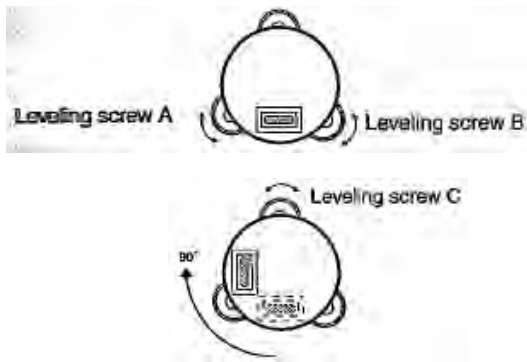

Figure 3: Diagram for fine leveling with the plate level.

Once the theodolite is leveled, double check the optical plummet to make sure that it is still centered. If not, repeat the procedure in section 1.2.1 (d) through all of section 1.2.2.

2 Measurement

In this section we learn how to take accurate readings of horizontal and vertical angles using a theodolite.

(a) Determine how many reference points you will need to measure, and make sure that their horizontal and vertical positions are clearly marked. In order of measurement, these reference points will be referred to as X, Y, and Z in these instructions.

(b) Turn on the theodolite by pressing the green power key.

2.1 Horizontal measurement

To avoid confusion, all horizontal angle measurements should be completed before taking vertical angle measurements.

(a) Take face-left angle measurements.

i. Rotate the telescope about the trunnion axis until the instrument is in face-left position.

ii. Press the `OSET` key and rotate the telescope horizontally to give a reading between 0° and 1°.

iii. Press `HOLD` to lock this value.

iv. After making sure no one is in the telescope line of sight, press the laser on button on top of the telescope. Free the horizontal and vertical clamps and swing the laser spot to reference point X.

v. Roughly align the laser spot and focus it using the focusing ring on the telescope. Tighten the horizontal and vertical clamps. Turn off the laser.

vi. Place a blank sheet of paper in front of the telescope, and, looking through the telescope, focus the crosshairs using the eyepiece.

vii. Remove the paper and focus the telescope on the reference object using the focusing ring.

viii. Check for parallax by moving your head up and down and left to right. If the crosshairs move, refocus the crosshairs, and refocus the reference object as described above.

ix. Looking through the telescope, home in on the reference object using the slow-motion screws. For horizontal angle measurements, the vertical crosshair must be perfectly aligned with the reference point, but the horizontal crosshair need not be, as long as approximately the same part of the vertical crosshair is used for each horizontal measurement.

x. Check the telescope pointing, book the horizonal angle reading, and check the booking.

xi. Release the `HOLD` key (only applies to the very first reading).

xii. Repeat steps iv. to x. for reference points Y, Z, etc.

(b) Take face-right angle measurements to complete a round of angles.

i. Rotate the telescope about the trunnion axis until the instrument is in face-right position.

ii. Repeat steps (a) iv. - xi. in the face-right position. Now you've booked a series of angles between 0° and 360° and a series between 360° and 720°. This completes a round of angles.

(c) Take at least one more round of angles using an initial horizontal reading between 90° and 91° for the second round, 180° and 181° for the third round, etc. If you take only two rounds of angles, make sure that the readings agree within twice the precision of the theodolite.

(d) Once the desired precision is achieved, take the mean value of the measured angles.

2.2 Vertical measurement

The vertical angle scale is referenced absolutely to the ground, so it is impossible to use different initial readings for the multiple rounds of angles.

(a) Take face-left angle measurements.

i. Rotate the telescope about the trunnion axis until the instrument is in face-left position.

ii. After making sure no one is in the telescope line of sight, press the laser on button on top of the telescope. Free the horizontal and vertical clamps and swing the laser spot to reference point X.

iii. Roughly align the laser spot and focus it using the focusing ring on the telescope. Tighten the horizontal and vertical clamps. Turn off the laser.

iv. Place a blank sheet of paper in front of the telescope, and, looking through the telescope, focus the crosshairs using the eyepiece.

v. Remove the paper and focus the telescope on the reference object using the focusing ring.

vi. Check for parallax by moving your head up and down and left to right. If the crosshairs move, refocus the crosshairs, and refocus the reference object as described above.

vii. Looking through the telescope, home in on the reference object using the slow-motion screws. For vertical angle measurements, the horizontal crosshair must be perfectly aligned with the reference point, but the vertical crosshair need not be, as long as approximately the same part of the horizontal crosshair is used for each vertical measurement.

viii. Check the telescope pointing, book the vertical angle reading, and check the booking.

ix. Repeat steps ii. to viii. for reference points Y, Z, etc.

(b) Take face-right angle measurements to complete a round of angles.

i. Rotate the telescope about the trunnion axis until the instrument is in face-right position.

ii. Repeat steps (a) ii. - ix. in the face-right position. This completes a round of angles.

(c) Take at least one more round of angles. If you take only two rounds of angles, make sure that the readings agree within twice the precision of the theodolite.

(d) Once desired precision is achieved, take the mean value of the angles measured.

3 Packing up

(a) Open the theodolite box.

(b) Turn off the theodolite.

(c) Align the theodolite as it was before packing. Refer to Fig. 1.

(d) Bring the theodolite foot screws to the center of their travel.

(e) Holding the theodolite handle with one hand, undo the centering screw with the other.

(f) Put the theodolite back in the box in its original position and close the clasps. Refer to Fig. 1.

(g) Being careful not to disturb the positioning mark, lift the tripod away, collapse it, and put it away.

4 Glossary of terms

gradient - An alternative to measuring vertical angles in degrees, the gradient is defined as the tangent of the vertical angle with respect to the horizontal times 100%. For example, a gradient of -50% means a slope of 22.5° below the horizontal.
face left - The theodolite position in which the vertical circle is on the viewer's left while he looks into the telescope.
face right - The theodolite position in which the vertical circle is on the viewer's right while he looks into the telescope.
horizontal circle - The graduated circle in the horizontal plane that the theodolite reads out to measure horizontal angles.
horizontal clamp - Thumbscrew that can be used to fix the angle of the theodolite with respect to the vertical axis. When the horizontal clamp is tight, the instrument can be translated horizontally with the slow-motion screw.
line of collimation - The line of sight through the center of the telescope crosshairs.
optical plummet - Small telescope whose eyepiece is near the bottom of the theodolite that looks at the directly beneath the theodolite and is used for centering.
round of angles - A complete set of angle measurements performed first in the face-left, then in the face-right position.
slow-motion screw - The fine adjustment screw used to translate the theodolite in the horizontal or vertical plane when the horizontal or vertical clamp is tightened.
tangent screw - See **slow-motion screw**.
trunnion axis - The axis about which the telescope pivots.
vertical axis - The axis about which the horizontal circle pivots.
vertical circle - The graduated circle in the vertical plane that the theodolite reads out to measure vertical angles.

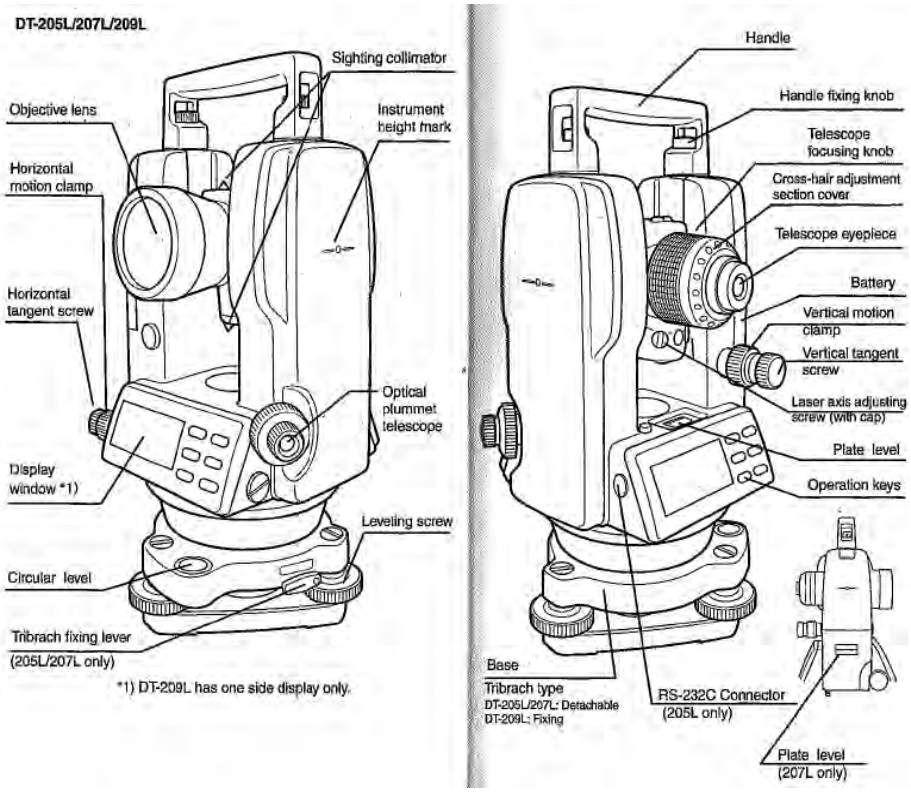

Figure 4: Theodolite diagram from manual.

vertical clamp - Thumbscrew that can be used to fix the angle of the theodolite with respect to the trunnion axis. When the vertical clamp is tight, the instrument can be translated vertically with the slow-motion screw.