Kit Activity 3-2

Constructing and Using an Astronomical Quadrant

After completing this activity you should be able to do the following:

• Make a quadrant and use it to measure altitudes.

• Use the quadrant to measure the height of a building and determine the uncertainty of the measurement.

Use the answer sheet at the end of the Activity.

The quadrant is an instrument for measuring the altitudes of celestial objects. The altitude of an object is the angle between the horizon and the object, as shown in **Kit Figure 3-2-1**. It should be apparent that the altitude of the horizon itself is 0°, whereas that of the zenith, or point overhead, is 90°. *Do not confuse the term "altitude" with the same word that is used in aviation to mean the distance of a plane above the ground. They are entirely different concepts!*

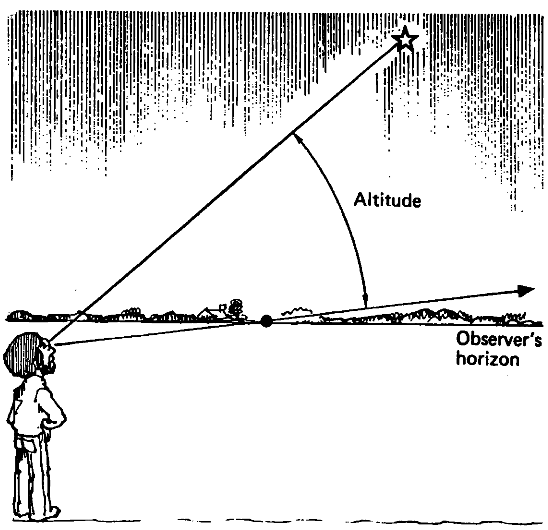
The quadrant you will make is similar in function to the large mural quadrant used by the Danish astronomer Tycho Brahe. Brahe's exquisitely accurate naked-eye observations played a crucial role in overthrowing the 2000-year-old Ptolemaic theory of the universe and substituting the modern Sun-centered solar system. Even today, Tycho's observations could not be improved on without a telescope. The instrument you will construct will be similar to his in operation, although not as large, and it will be hand-held rather than mounted on a solid base. It will be a good example, however, of a type of instrument used to observe the heavens for over a thousand years.

In this activity, you will practice making measurements. In the next chapter, you will make measurements on the sky.

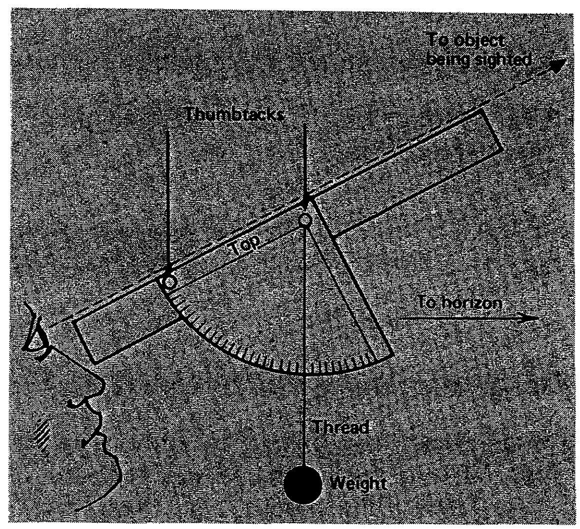
ASSEMBLING AND USING THE QUADRANT

Remove the quadrant pattern (marked QUADRANT) from your experiment kit and attach it to a straight stick with thumbtacks, as shown in **Kit Figure 3-2-2**. The stick should be at least 6 inches in length, and it should have some thickness to it to help attach the pattern and to aid your eye in sighting along it. In other words, it should be a board rather than a stick. (You can also use tape with a paperback book instead of a stick; it is very effective. Using the meter stick or yard stick does not work very well.)

The top of the pattern should be aligned carefully with the top edge of the stick, and



Kit Figure 3-2-1 The definition of altitude as an angle above the horizon.



Kit Figure 3-2-2 The quadrant. The thread and weight define a vertical line, and the altitude is measured with respect to it.

thumbtacks should be pushed through the two crosses on the top of the quadrant. If the pattern is attached correctly, then the quadrant should give a reading of 0° when the distant horizon is sighted. Suspend a small weight from the front thumbtack on a foot-long piece of white thread or fishing line. Do not use ordinary string, which is too thick and will not swing freely. The weight should not be too light or it will blow in the wind and introduce errors. The weight of half a dozen keys is about right.

To use the quadrant, sight along the top edge of the stick at the object whose altitude is to be measured. Wait for the weighted thread to stop swinging. At this time, the Earth's gravity causes it to define a line that points exactly toward the zenith and the nadir, the point directly underneath the observer. Carefully, so as not to disturb the position of the thread, trap it against the scale with your finger or thumb, remove the quadrant from your eye, and read off the value where the thread crosses the protractor scale. Try to estimate your reading to the nearest tenth of a degree.

To practice using your quadrant, pick an object that is at a small altitude (less than 10°) and another at a large altitude (50° or greater). You could stand outside a building and observe a first-story window and compare it with a window much higher up. Do each of the following: measure the altitude of each object you have chosen for a total of five times using the quadrant, compute the average altitude of each, and estimate the error of each measurement in degrees. Now compute the percent error of each measurement:

$$\text{percent error} = \frac{\text{estimated error}}{\text{measured value}} \times 100 .$$

For example, if the altitude were 30° and its error were 1°, the percent error would be $1/30 \times 100 = 0.033 \times 100$ or about 3%.

- **Kit Inquiry 3-2a** Does the percent error increase or decrease with larger measured angles?

Measuring the Height of a Building with the Quadrant

Select a relatively tall building (more than two or three floors) that is surrounded by a sufficient amount of level ground so that you can stand off from it at a distance approximately equal to the height of the building. Back away from the building, taking occasional sightings with the quadrant on the top of the building, until the altitude of the building is as close to 45° as you can get it (see **Kit Figure 3-2-3**). Mark the spot where you are standing and carefully pace off the distance to the building. Multiplying the number of paces by the average length of your pace will give the distance to the building. To measure your pace, step off 10 paces and measure the distance with your meter stick; then divide this distance by 10. If you pace in a deliberate and uniform manner, you will be able to measure distances with fair accuracy this way. (Record the resulting distances.)

Now repeat this process one more time (stepping back from the building, marking the point where you stand, and pacing off the distance), and again record your result. If your answers are reasonably close to your first results, you need not repeat them again.

It is now possible to estimate the height of the building. Kit Figure 3-2-3 shows that, when the altitude of the building is just 45°, the distance AB from the building is equal to the distance AC, the amount of the building that is above eye level.

- **Kit Inquiry 3-2b** How should you figure in the effect of your height (refer to Kit Figure 3-2-3)?

- **Kit Inquiry 3-2c** Determine the height of the building.

If you are in a class, your instructor may want everyone to measure the same building, so that the measurements can be compared with each other and averaged together as an additional example of the method of averaging.

Like the cross-staff, the quadrant is imperfect and measurements made with it are subject to errors, both random and systematic.

- **Kit Inquiry 3-2d** What kind of error (random or systematic) would each of the following effects introduce?

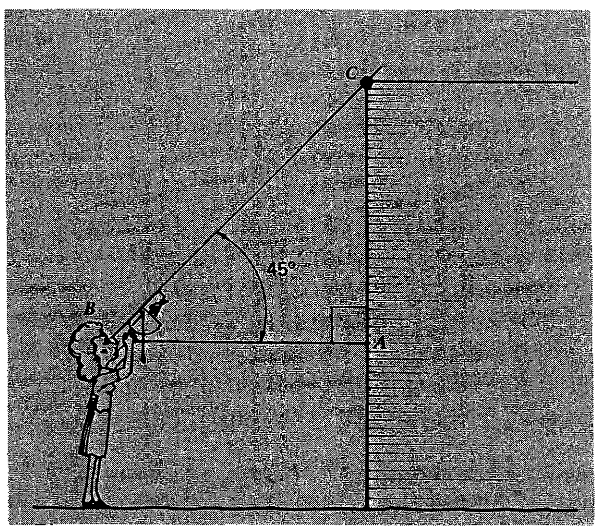
  (a) The quadrant is poorly assembled, as in **Kit Figure 3-2-4.**

  (b) The weight swings back and forth.

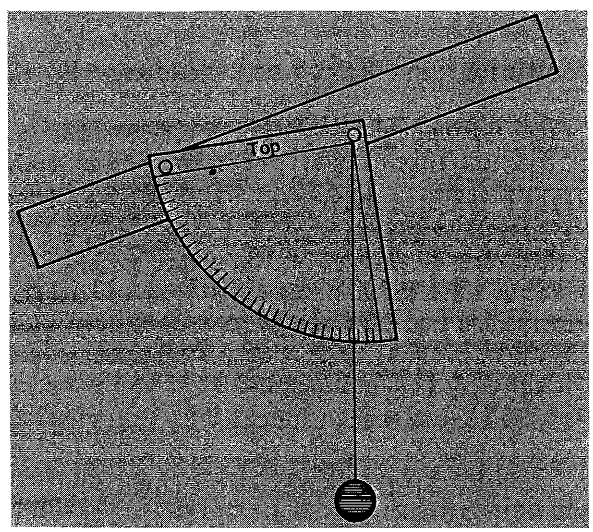
  (c) You are unable to sight the object in exactly the same way each time.

  (d) The wind blows toward you and moves the weight slightly toward you.

  (e) Suggest three other possible sources of error.



Kit Figure 3-2-3 Measuring the height of a building



Kit Figure 3-2-4 A poorly assembled quadrant.

Activity 3-2 — Constructing and Using an Astronomical Quadrant

Answer Sheet

NAME ____________________

1. Record the five measurements you made of a small- and large-altitude angle below. Then calculate the average and estimate the error and percent error. Record these numbers in the space provided.

	Small Altitude	Large Altitude
Measurement #1	____________	____________
Measurement #2	____________	____________
Measurement #3	____________	____________
Measurement #4	____________	____________
Measurement #5	____________	____________
Average ± Error	_____ ± _____	_____ ± _____
Percent Error	____________	____________

Answer to Inquiry #3-2a

What building did you measure the height of? ________________

Length of ten of your paces: ________ Length of one pace: _______

Number of paces to the building: ________

Inquiry 3-2b:

Inquiry 3-2c: Height of building (corrected for your height): ______

Inquiry 3-2d:

Part I
Discovering the Science of Astronomy