Aurora Altitudes

Measuring an object's size and distance is an essential part of astronomy and other disciplines. Applying geometry, especially the use of triangulation is a powerful method of measuring size or distance. This activity simulates the actual method used by Carl Stormer, Swedish physicist, who was the first person to measure the height of an aurora.

Objectives

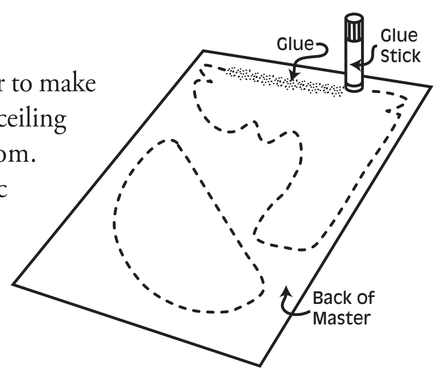
This activity uses applied geometry in the form of triangulation to measure the height of the aurora. The technique can be extended to determine how tall the aurora appears in the sky. It can easily be adapted to different ages and math ability levels. For those who have little to no geometry experience, the heights can be determined by a simple scale drawing analysis. More experienced math students can be asked to utilize their geometry and/or trigonometry skills with more direct calculations.

After this activity, students will be able to:

1. Explain how triangulation can be used to measure the size of, height of, or distance to a far away object.
2. Measure the height of a simulated aurora.
3. Describe the actual height above ground and size of the aurora.

Preparation

1. Use green or red cloth, plastic, or paper to make a simulated aurora hanging from the ceiling in a central location in the classroom. Green or red colored kitchen plastic wrap can be stretched over a simple wire frame. For more advanced students the top of the aurora can be varied while the bottom is kept at about the same level to more accurately simulate the appearance of the aurora in the sky. A large room with a high ceiling such as a gym is great, but the activity also works in a normal classroom.



Make a Height-O-Meter. Glue the template (page 3) onto a file folder.

2. Determine what scale (number of kilometers per meter) will give an accurate height of the simulated aurora. Since aurora begin at approximately 100 km altitude, calculate scale as follows:

   Scale (km/m) =100 km ÷ [Height of simulated aurora (m)]

3. If you do not already have a class set of Height-O-Meters (1 for every pair of students), make each as follows (teaching assistants can do this):
   a. Make photocopies of the Height-O-Meter template (master on p. 3).
   b. Cut the file folder in half.
   c. Paste the template onto the file folder.
   d. Cut out the pieces and make folds in order by number.

Materials

For each student

- graph paper and protractor OR
- Height Finder Chart (photocopy master on page 4).

For each pair of students

- meter stick or tape measure
- "Height-O-Meter" (from the LHS GEMS guide *Height-O-Meters*)

To construct each Height-O-Meter you need

- a copy of the Height-O-Meter template (photocopy master on page 3),
- paper glue (glue stick)
- half of a file folder
- push pin or thumbtack, large paper clip, and a small piece of eraser or cork (about 1 cm thick)

For the whole class

- green or red colored cloth, plastic, or paper—at least 30 cm x 100 cm (1' x 3')

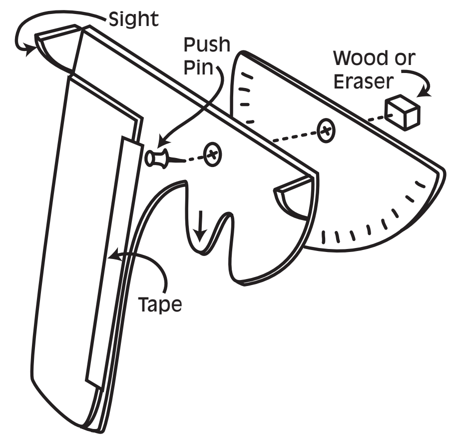
e. Bend the handle in half on the dotted line and tape it for strength.

f. Stick the push pin or thumbtack through the "Pointer Piece."

g. Enlarge the hole slightly with the tip of a pencil or pen.

h. Insert the push pin or thumbtack through the "Pointer Piece," then through the "Scale Piece," and into a piece of eraser or cork. Do not push it in all the way of the Scale Piece will not hang freely.

i. Slide a paper clip onto the Scale Piece near the "0" mark.



To use the Height-O-Meter:

a. Hold Height-O-Meter by the handle and aim along the tops of the sights.

b. Make sure Scale Piece swings freely. If it is warped, bend it so that it is straight. If push pin is in too tigt, pull it out a little. If necessary, enlarge the "tack mark" hole in the Scale Piece.

c. Calibrate the Height-O-Meter by putting a mark on the wall or board at eye level, sight on the mark with the Height-O-Meter from across the room, and adjust the position of the paper clip, until the reading is "0".

Alternatively, you may elect to have each student make their own Height-O-Meter to keep.

Another angle-measuring device can be used, such as the simple quadrant described in the "What's Your Latitude" activity in the Astronomical Society of the Pacific's guide *The Universe in the Classroom*, or the quadrant from the PASS *Who 'Discovered' America?* activity on measuring latitude by measuring the elevation angle of Polaris.

4. Get graph paper and protractors OR make photocopies of the Height Finder Chart (page 4).

In Class

Part A: How to Measure Altitudes

1. How high is a cloud or an aurora? Ask:

Suppose we wanted to measure the height above ground of some clouds or even an aurora.

How could we do it?

Entertain student's ideas about how we can measure these quantities. At this point do not correct any of their responses other than to point out that we cannot reach out and touch them and we do not have a tape measure long enough to stretch from the ground to the base of the aurora.

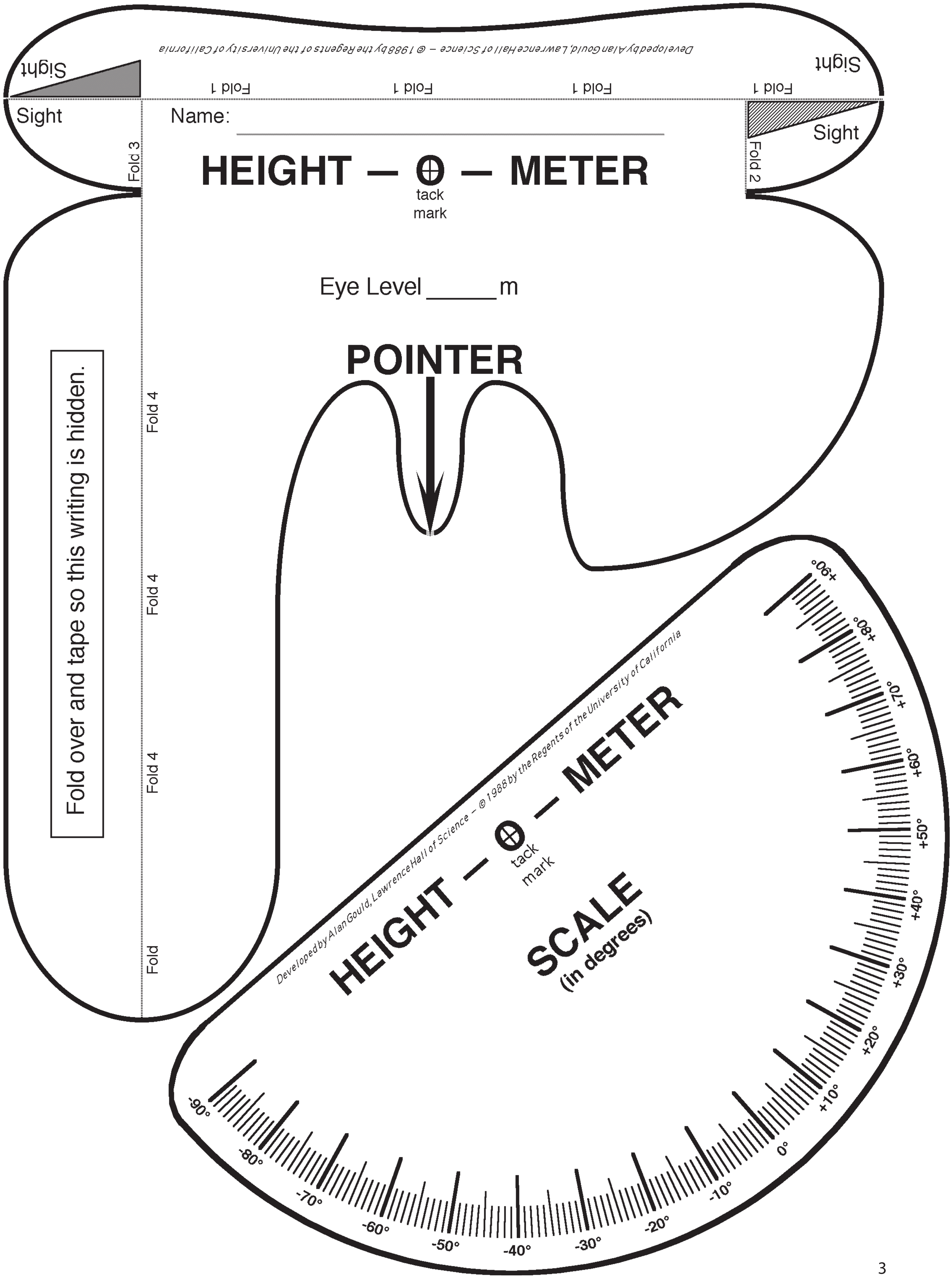
2. Introduce the concept of angular height.

Point out the simulated aurora overhead.

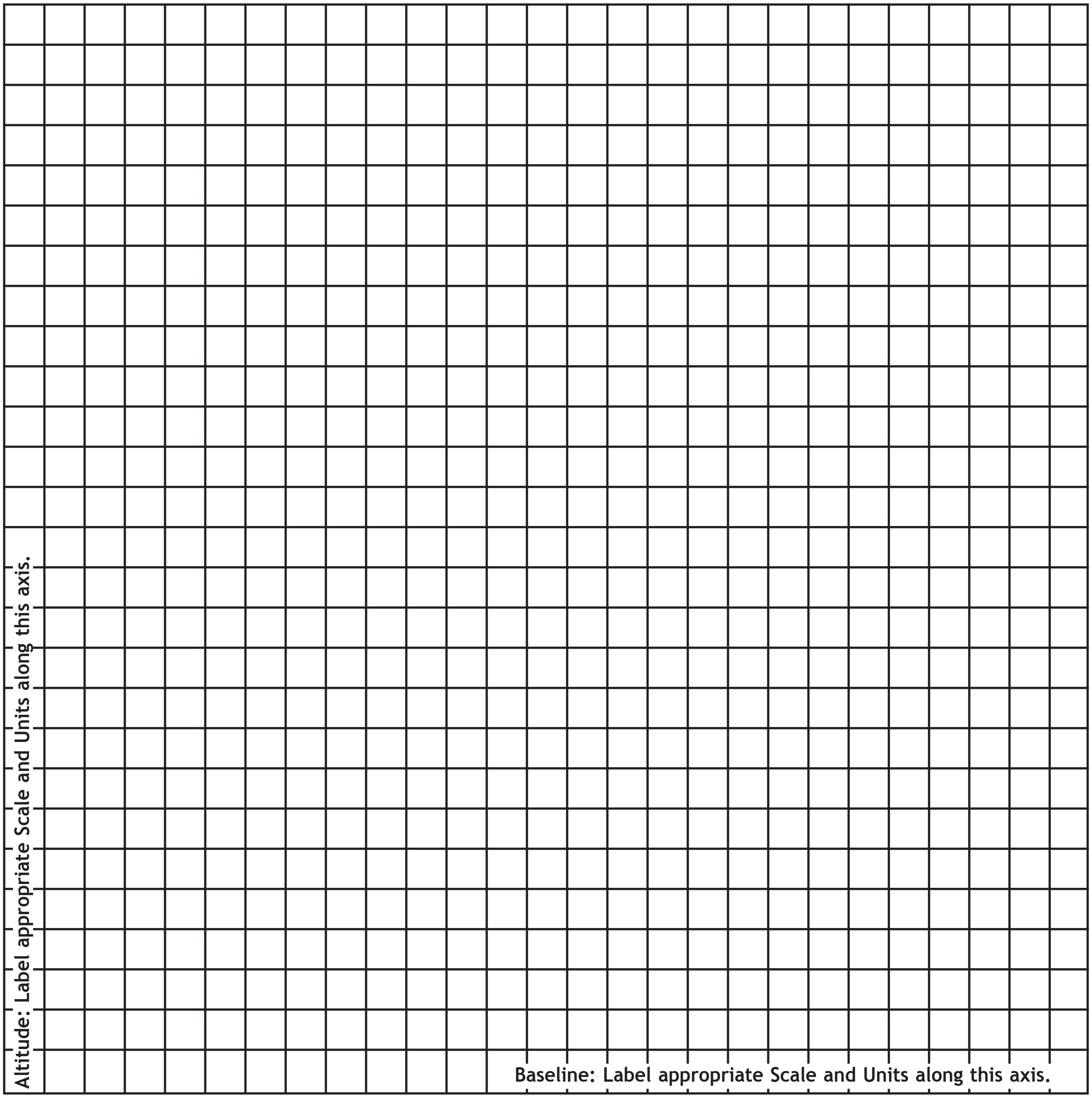
Imagine drawing a line from the point on the ground directly below the aurora to where you are standing. Now imagine drawing another line from your feet to the bottom of the aurora.

What do we call the shape defined by these two lines?

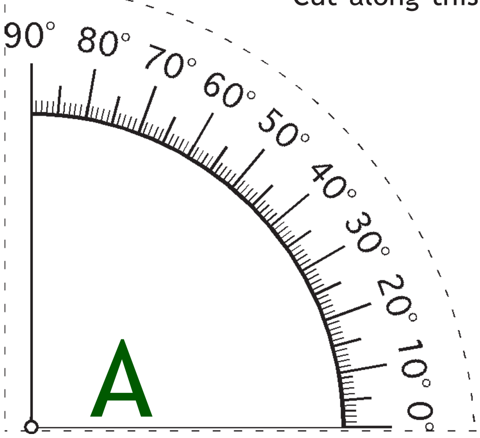
You can sketch this on the board during your discussion.

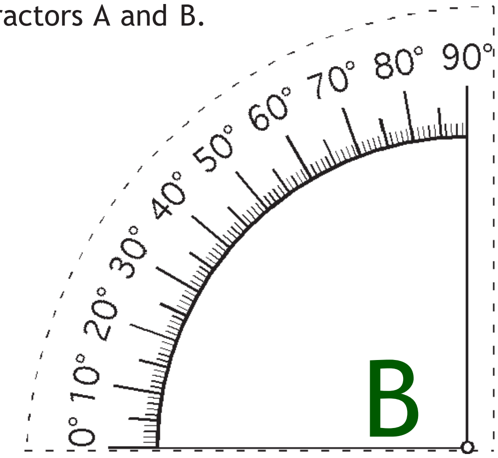

Developed by Alan Gould, Lawrence Hall of Science – © 1988 by the Regents of the University of California
Sight
Fold 1
Fold 1
Fold 1
Fold 1
Sight
Sight
Name:
HEIGHT — Θ — METER
tack mark
Sight
Fold 3
Fold 2
Eye Level _____ m
POINTER
Fold over and tape so this writing is hidden.
Fold 4
Fold 4
Fold 4
Fold
Developed by Alan Gould, Lawrence Hall of Science – © 1988 by the Regents of the University of California
HEIGHT — Θ — METER
tack mark
SCALE
(in degrees)
+90°
+80°
+70°
+60°
+50°
+40°
+30°
+20°
+10°
0°
-10°
-20°
-30°
-40°
-50°
-60°
-70°
-80°
-90°

Height Finder Chart



Cut along this line, then cut out protractors A and B.





Student responses should be that the two lines form an angle or just as appropriately that you have drawn a triangle if you include the vertical line up to the aurora. Explain that . . .

The angle is called the *angular height* of the object.

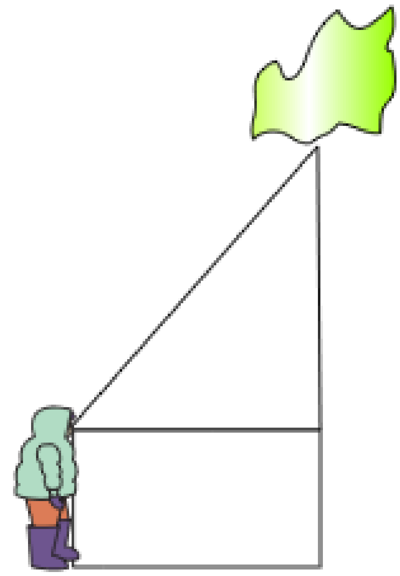
What units would we use to measure that angular height? [Degrees.]

Dispel confusion as much as possible by explaining that . . .

The units are degrees, not meters or any other unit of length, even though the term "angular height" has the word "height" in it, and height is normally measured in the same way as a length. The key to knowing that you are measuring an angle is the word "angular". Other terms for angular height are "elevation angle" and "altitude angle". Both terms have the clue "angle" that signals to us that we are measuring in degrees and not a length, even though the terms elevation or altitude by themselves would be measured in units of length (e.g. meters, kilometers, feet, miles).

Review the concept of measuring angle by asking . . .

How many degrees of angle are in a complete circle? [360°] A quarter circle? [90° .]



3. What controls the angle? Ask:

What physical quantities control the size of the angle defined by these two lines?

(The size of the angle is relative to the distance from the object and how high in the sky the object really is.)

4. Can we determine the height of the aurora using angles without having to actually go up and touch the aurora? (Yes, an observer can get a measurement of height from a location that is distant from the object.)

To get the actual height of the object what else do you need to know besides the angle? (You need the distance from the observer to the point on the ground directly below the object.)

Optional

If you are having students build their own Height-O-Meters, hand out materials and give instructions on how to make the measuring devices.

Part B: Measuring the Aurora

1. Height-O-Meters.

Now it is time to use these ideas to measure the height of our aurora near the ceiling. We will use some simple devices to measure the angular height above the ground of our aurora. You will be divided into observing teams to take your measurements.

Have students work in pairs.

2. One small problem: Where is the point just below the aurora?

In our previous discussion, we noted that to get an actual height of the aurora, we needed to measure its angular height and the distance between the observer and a point just below the object. In the case of the aurora, it may be difficult to know exactly where the aurora is located. As luck would have it, we do not really need to know where that point is if we use two sets of observers at observing stations on opposite sides of the aurora and measure the distance between those two observing stations. This will be our "baseline distance". Each observer in a group should take a measurement from their station. Then switch stations with the other half of your group and take measurements from the other station. Measure the baseline distance between your stations.

Draw a diagram on the board to show why it is unnecessary to measure the distance along the ground to a point right below the aurora.

3. How to take the measurements.

Each team will take measurements from each side of the room. If there is one Height-O-Meter per team, students take turns measuring the angles. For now, just measure the height angle to the bottom edge of the aurora.

Have students measure and record on paper the angles and baselines.

4. Analyze the data.

Discuss how to analyze the data. Students must make scale drawings of the baseline and angles that they measured. They must select a scale for the drawing that fits on the paper they are using. For example, if the baseline they measure is 5 meters and the width of their paper is 20 cm, then an appropriate scale would be . . .

20 cm = 5 meters or

20÷20 cm = 5÷20 meters

1 cm = 0.25 meter

Students should label the axes and parts of their drawings accordingly.

Example:

Have students use the Height Finder Chart or simple graph paper and protractors. The baseline distance should be laid out on the graph paper x-axis, representing the distance along the ground. The protractors should be used to draw lines from each end of the baseline using the angular height measured by the students. Where these lines converge is where the bottom portion of the aurora is located. The distance along the y-axis is the same units as the x-axis so they can get read their graphs to determine the height.

5. Discuss results.

Have students discuss their results and possible sources of error.

What can you conclude about the height of our simulated aurora? Can we confirm our measurements?

Student groups can write their results in a class-wide data table on the board. They can also confirm their measurements by directly measuring the height of the simulated aurora. It should be noted that a significant error can result from ignoring the student's eye level above the ground. This error is easily corrected by measuring the height of the eye above the ground and adding that to the graphically determined height.

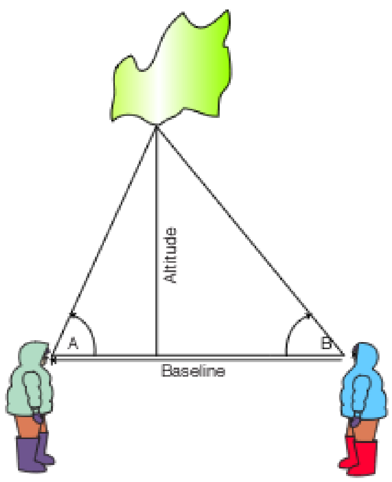
6. History

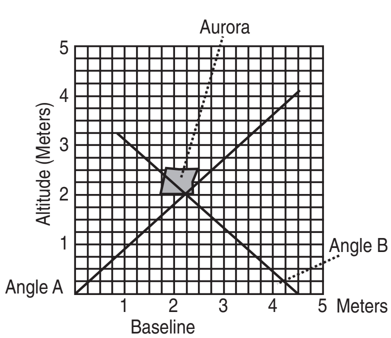
Explain to the students:

The first measurements of the height of the aurora were made using the same techniques you have used today. Carl Stormer, a Swedish physicist, made the first measurements of the height of the aurora early in the century. Today we know the height of the aurora at the base is fairly constant at 110 km (65 miles). Before these types of measurements were taken, there was no idea how high the aurora was located.

Optional

For those teachers who wish to develop a more advanced mathematical approach, trigonometric functions can be used in the analysis.





Going Further

1. Have students make a more realistic estimate of the height of the aurora. Before class you will have to create a scaling factor to use. This scaling factor (K) can be determined by the following formula:

(Height of real aurora in km) = K • (Height of Simulated Classroom Aurora in meters)

K = (Height of real aurora in km) ÷ (Height of Simulated Classroom Aurora in meters)

This scaling factor K can be used to convert the student measurements in meters into distances that are an approximation of the distances that would be used in the real world.

2. Have students measure the top of the aurora. If you construct your simulated aurora with a variety of heights along the auroral curtain, they can measure a range of heights at the top. In reality, this is what would be measured. Discussion can also be generated about how to take these measurements, and what criteria should they use, such as lowest point, highest point, etc. This will also allow estimates of the height of the aurora.
3. Discuss how similar measurements can find the distance to solar system objects such as asteroids. Two telescopes at widely spaced locations simultaneously photograph the same asteroid. Since they are viewing the asteroid from different perspectives, the asteroid will appear at different locations compared to background stars. This phenomenon, which is referred to as parallax, can be seen by holding up one finger at arms length. By alternately closing and opening each eye, your finger will appear to move against the background. Astronomers convert this shift into angles, and by knowing how far apart the telescopes are spaced, use this angle and distance to find the distance to the asteroid.
4. Similar to the parallax example in number 3, astronomers use “Stellar Parallax” to determine the distance to nearby stars in this case, the baseline in the Earth’s orbit. By imaging a star, waiting 6 months and imaging the same star again, the astronomers have created a triangle with a baseline of 300 million km. This allows a fairly accurate measurement of the distance to nearby stars, but is less accurate for more distant stars.

   Can you explain why this may be true? [The measured angles are very small, and for more distant stars, the angles are too small to measure, even for our best instruments.]

References

“Height-O-Meter,” LHS GEMS Guide, University of California, Lawrence Hall of Science, Berkeley, California, 94720-5200; 510-642-7771; http://www.lhsgems.org/

The Universe at Your Fingertips, edited by Andrew Fraknoi, Astronomical Society of the Pacific, San Francisco, copyright 1995; 415-337-5205; http://www.astrosociety.org/