PARALLAX

grades 9–12

Objective

To demonstrate parallax and to show how the distance to an object can be calculated using mathematical principles related to parallax.

Introduction

The stars in the night sky all appear to be the same distance from Earth because they are too far away for our eyes to detect their actual distances. To overcome the limitations of our eyes, astronomers have developed other methods for measuring the distances to celestial bodies. One important technique for measuring these distances involves using parallax.

Parallax is the apparent displacement of an object against the background when seen from two different perspectives. The example of parallax in Part 1 of this activity involves viewing your thumb first with just the left eye, then just the right eye. Your thumb will appear to jump from right to left. The difference between the perspective from each eye is what lets you estimate distances.

Astronomers use parallax to estimate the distances to stars. To get two different perspectives on a star, astronomers view it from two different locations in the Earth's orbit. When these two perspectives are compared, a closer star will appear to shift against the background just as your thumb did. The change in the apparent position of the star lets astronomers estimate its distance.

In Part 2 of this activity, students will calculate the height of a pole or building by using the same mathematical techniques involved in stellar parallax. To do this, they will construct a simple tool called an astrolabe.

Background Reading for Educators

The 3-D Universe, available at
http://www.amnh.org/education/resources/rfl/pdf/du_x04_3d.pdf

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Materials

Meter stick or tape measure

Astrolabe template (pg. 8)

Data sheet and tangent table (pg. 7)

Glue stick

Manila folder

String

Small weight (roll of tape, hex nut, or fishing weight)

Masking tape

Calculators

Procedure

Part One: Demonstrating Parallax

1] Have your students hold their thumbs close to their noses. Tell them to look at an object on the far side of the room, first with their right eye closed, then with their left eye closed. (They should select a particular object such as map or picture, not just stare at a blank wall.)
Ask: What happened to the thumb?
Explain: It should have appeared to jump from one side of the distant object to the other. This effect is called parallax.

2] Have your students hold their thumbs at arm's length.
Ask: How far did the thumb jump this time compared to what happened when they held their thumb closer?
Explain: The farther you hold your thumb from your eye, the less it jumps from side to side. The amount of this shift indicates how far away the object is. This is how your eyes judge distances.

When objects get too far away, however, they do not "jump" at all. This demonstrates the limitations of judging distance by parallax. The perspective from each eye is the same for distant objects because your eyes are only a few inches apart.

Astonomers use parallax to judge the distances to stars. To get two different perspectives of the star, they compare two pictures taken from viewpoints about 186 million miles apart. The amount the star seems to jump indicates its distance.

Parallax can only be used to judge the distance to the nearest stars, however. For extremely distant stars, even having two viewpoints separated by 186 million miles is not enough to make a star appear to jump from side to side.

Part Two: Making the Astrolabe

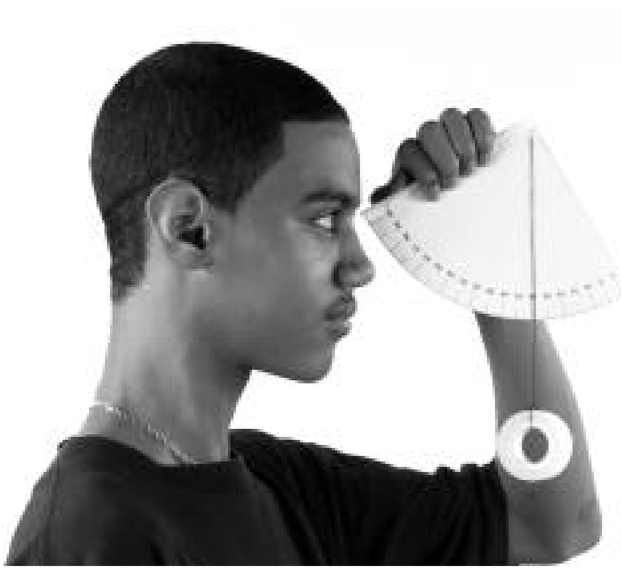
3] Pass out the following materials to each of your students: a copy of the Astrolabe template (pg. 8), a half of a manila folder, a straw, a 20-cm piece of string, and a small weight. Glue, tape, and scissors can be shared by several students.

4] First demonstrate to the class how to construct the astrolabe. Cut out the template and glue it to the manila folder to give it a firm backing, then cut out the astrolabe.

5] Tape a straw along the diagonal edge of the astrolabe.

6] Poke a hole in the circle marked on the astrolabe. Place a string through the hole so that the string hangs down in front of the astrolabe. Tape the other end securely to the back of astrolabe.

7] Tie a weight to the bottom of the string. You can now use the astrolabe to measure angles!



Meg Carlough/AMNH

Student demonstrating completed astrolabe.

Part Three: Measuring the Angle and Baseline

8] Pass out a copy of the data sheet, (pg. 7), to each student.

9] You will need to take your class to a tall object with a known height, so you will have to take a trip outdoors. A flagpole is an excellent choice; street lamps or telephone poles also work well. Another good option is to measure the height of your school.
Ask: Do your students have any ideas about how they could measure the distance to the top of the flagpole without touching the flagpole?

10] Your students will measure the distance to the top of the flagpole by using the same mathematical principles astronomers use to calculate the distance to stars. Tell your students to imagine that the highest point on the flagpole is a distant star and they are going to measure the distance to it from Earth.

11] Place a long piece of masking tape 6 meters from the flagpole. Have a student measure that distance using a meter stick or tape measure.
Explain: In parallax there is always a "baseline" distance that we know. Astronomers use the distance from one side of Earth's orbit to the other to measure stellar parallax, a baseline of about 186 million miles!

12] Have your students stand on the tape and look through the straw of their astrolabe so that they can see the top of the pole. Make sure that the string and the weight hang freely from the device. When they tilt the astrolabe up to view the top of the flagpole, the hanging string marks the angle at which they are viewing the pole. Once they have sighted the top of the flagpole have them hold the string against the astrolabe and read the angle to the nearest five degrees. This is the parallax angle. Students should record this angle on their data sheets. They should perform this numerous times until they get a consistent reading.

Part Four: Calculating the Distance

13] In order for students to understand parallax they need to understand simple right triangles. Draw figure 1 (pg. 6) on the blackboard.
Ask: Can your students suggest ways to calculate the height of the flagpole without going near it?
Explain: The flagpole, the ground, and the student form a right triangle, and right triangles have special properties that make them useful for determining distances. When one angle of a right triangle is known, and the length of one side is known, the length of the other sides can be calculated using trigonometry.

14] Draw figure 2 (pg. 6) on the blackboard and relate this triangle to the activity the students just performed.
Ask: Can your students identify the parts of the right triangle that correlate to the measurements that they made in the exercise?
Explain: The distance they measured from the flagpole to the tape represents the base of the triangle. The angle that they measured using the astrolabe represents the angle connecting the base to the diagonal side (the **hypotenuse**).

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Teacher's Note

Advanced students may question how their height from the ground affects this measurement. Explain that they will take this into account in the last step of the data sheet.

15] Draw a simple right triangle on the blackboard. Then draw another right triangle with a vertical side marked "flagpole" and a horizontal side marked "baseline." Draw a stick figure at corner opposite the base of the flagpole. Mark the angle at this corner **parallax angle.**
Explain: For all triangles containing a given angle, the ratio of the opposite and adjacent sides is the same. (Show which two sides you are talking about on the blackboard.) This ratio is called the tangent of the angle. When you know the length of one side of a right triangle, you can compute the length of the other side using the tangent.

You measured the length of the baseline with your meter stick. You also measured one angle of the triangle with your astrolabe, and you can find the tangent of this angle on your data sheet. You now have enough data to calculate height of the flagpole!

16] Pass out copies of the tangent table (pg. 7). Look up the angle you measured with the astrolabe in the table and write its tangent on your data sheet.
Explain: The tangent is the ratio between the opposite and adjacent sides of any right triangle containing this angle—in this case, the flagpole and the baseline. To calculate the height of the flagpole, all they have to do is multiply the length of the baseline times the tangent!

The math can be demonstrated on the blackboard like this:

$$\text{tangent} = \frac{\text{opposite}}{\text{adjacent}} = \frac{\text{flagpole}}{\text{baseline}}$$

$$\text{tangent} = \frac{\text{flagpole}}{\text{baseline}}$$

Multiply both sides by baseline and you get:

baseline x tangent = flagpole

Plug in the numbers for tangent and baseline, and you have the height of the flagpole!

17] Tell the students to calculate the height of the flagpole and finish filling in their data sheets. Then reveal the actual height of the flagpole (or whatever you were measuring) and see how they did.
Explain: Astronomers calculate the distance to stars from giant triangles in space made from two opposite points in Earth's orbit and a star. The math is a little more complicated, because they need to divide this triangle into two right triangles, but the basic idea is the same.

fig. 1

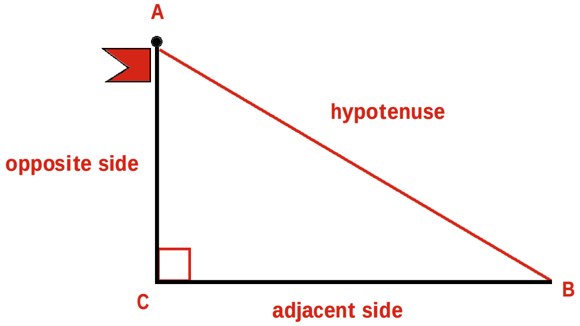

fig. 2

DATA SHEET AND TANGENT TABLE

Tangent Table

Measurement of angle B	Tangent of angle B
5°	.09
10°	.18
15°	.27
20°	.36
25°	.47
30°	.58
35°	.70
40°	.84
45°	1.0
50°	1.2
55°	1.4
60°	1.7
65°	2.2
70°	2.8
75°	3.7
80°	5.7
85°	11

Here's how to use the astrolabe to find the height of a tall object.

1. Stand where you can easily see the top of the flagpole through the straw on the astrolabe. Make sure the string and the weight hang freely. As you look through the straw at the top of the flagpole, the string will move alongside the astrolabe. Once you have sighted the top of the flagpole, let the string come to rest. Hold the string against the side, and read the angle to the nearest five degrees.

   ≤B = ____________°

2. Use the Tangent Table to find the tangent for the angle measured.

   tangent ≤B = ____________°

3. Measure the distance in meters from where you are standing to the base of the flagpole. On the diagram this distance is the side next to the angle you measured, so it is the adjacent side in the tangent ratio.

   distance to flagpole or adjacent side = ____________ m

4. Find the height of the flagpole. In the diagram the flagpole height is the side opposite the angle you measured. For the tangent ratio, it is the opposite side.

   tangent ≤B = opposite side/adjacent side, so
   tangent ≤B = flagpole height/distance to flagpole

   flagpole height = tangent ≤B x distance = ____________ x ____________ m =

   ____________ m

5. Since you did not lie on the ground to measure the angle, you will have to add the height to your eye level to the calculation in Step 4 to get the actual height of the flagpole.

   actual height of flagpole = answer in Step 4 + your height to eye level

   actual height of flagpole = ____________ m + ____________ m = ____________ m

ASTROLABE TEMPLATE