GENERAL SCIENCE LABORATORY 181

Parallax Lab

DISTANCES TO NEARBY STARS

OBJECTIVE

To find the distance to an object with the concept of parallax

THEORY

Parallax effect is one experimental observation to prove that the Earth revolves around the Sun. As the Earth orbits the sun once a year, there is the apparent change of positions of nearby star with respect to more distant stars. This apparent motion, or shift, that occurs between two fixed objects when the observer changes positions is the ***parallax*** effect. To see parallax for yourself, hold out your thumb at arm's length, close one of your eyes, and examine the relative position of your thumb against some distant object, such as a window, wall, metal frame around the door at the back of the lab, or a tree, etc. Now look at your thumb with your other eye. Note the apparent motion between your finger and the distant object. This apparent motion becomes more as your thumb moves closer to your face. Parallaxes are usually measured as angles; your thumb should appear to move by about 3 degrees when your arm is fully extended.

Look at the following mosaic of photographs (Figure 1) from the 1995 passage of comet Hyakutake. The pictures were taken at the same time by two amateur astronomers at different places: one in Portugal and the other in Denmark.

It is clear that the comet's position appears shifted with respect to the reference star (SAO 101241). This is yet another example of a parallactic shift; the comet is much closer to the Earth than the star, so that its position in the sky depends on the observer's location.

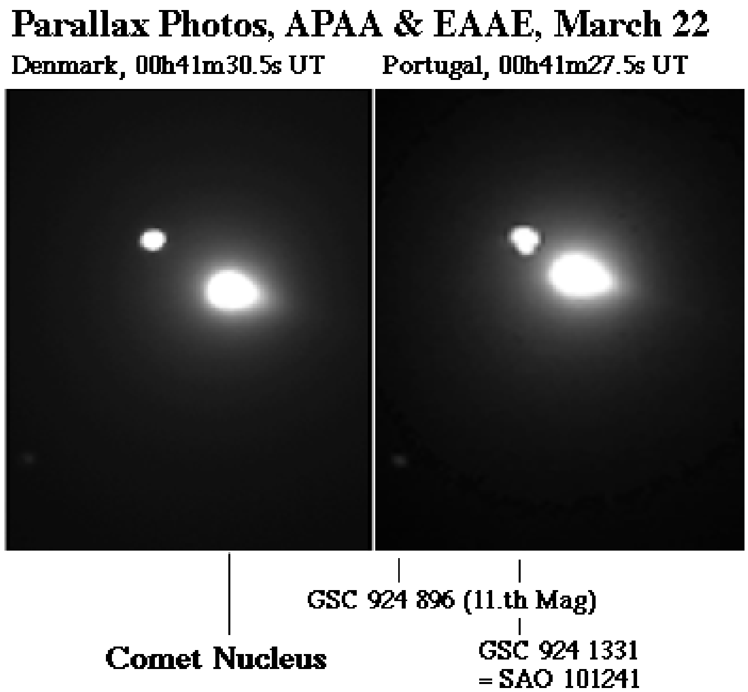

Figure 1

Measuring distances

In the preceding demonstration you noticed that your thumb exhibits larger parallactic shifts as it gets closer to your face. It is easy to see, then, that the amount of shift is proportional to the ratio between the separation of the observation stations (the "baseline") and the distance to the object. Or, in other words, if we know our baseline (say, the separation between our eyes), then we can determine the distance to any object by simply measuring its parallax.

In **figure 2** below, angle p is the parallax angle. By using the trigonometric function,

$\tan p =$ opposite side / adjacent side, we obtain

$\tan p = (1/2)\, b / d.$

Solving for d, yields **$d = (1/2)\, b / (\tan p)$** **(1)**

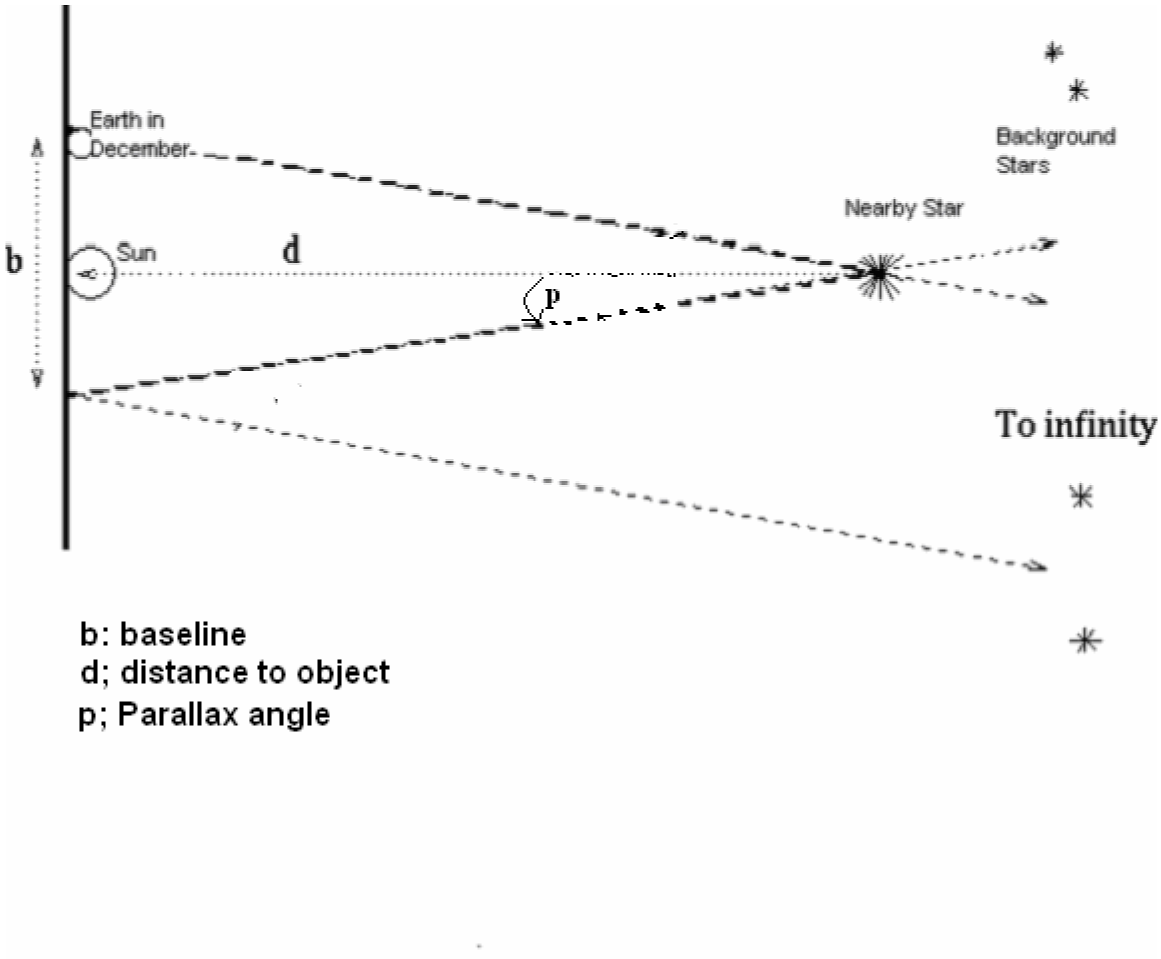

Figure 2
In our experiment we will not be measuring the distance to a nearby star, but to a piece of paper with a black stripe printed on it.

APPARATUS

Linear graph paper (The graph paper has two sides. The long side is 25.0 cm long and the short side is 18.0 cm long), cardboard, tape, four pins, a piece of marked paper as distant object, and a 2-meter stick

In our experimental setup we will use one side of the graph paper to be one-half of baseline, (1/2)b, as in Figure 2 **Also note: if we were using this method to measure the distance to nearby star the distance AO and BO are almost the same distance, because the star is so far away.**

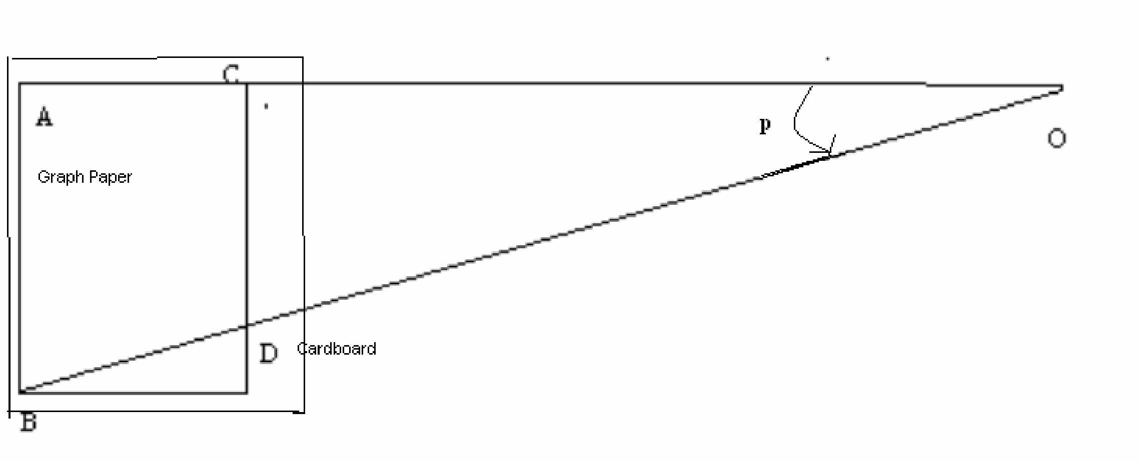

Figure 3

In figure 3 above, AB represents one side of the graph paper as (1/2) baseline and O represents the distant object which is the piece of paper with the black stripe.

Procedure

I. Part One

1. Tape the graph paper to the piece of cardboard as shown in figure 3 with the long side facing the object O.
2. Press down 3 pins in corners of the grid of the graph paper at points A, B, and C as in figure 3.
3. Kneel down and place one of your eyes behind point **A.** Align the cardboard so that points **A, C, and O** are in a straight line
4. Now tape down the cardboard so that it does not move. **Be very careful during the rest of part one and also part 2 of the lab so that the cardboard is not moved. Any slight change in its position can cause large error in your results. Also note where point A is located on the lab table. You will need to have this exact place for part 2.**
5. One lab partner will now kneel down and place one of the eyes behind point **B**. This person will now move his/her head back and forth slightly until point **B and O** are in alignment. Now move the 4^{th} pin along the line on the graph paper until **B, D, and O** are all aligned. Put the pin down. This fourth pin is now located at D as in figure 3.
6. Since ΔOAB and ΔOCD are similar triangles, the ratio of the two corresponding sides must be equal. That is, AB/CD = L1/(L1-AC) where L1 is the distance from A to O. Solving for L1, yields

   L1 = (AC*AB)/(AB-CD) (2)

   Measure CD and calculate L1. Record them in the data table.

7. Calculate the trigonometric function, tan p**,** and record this value in your data table

   tan p = AB/L1 (3)

8. The angle p in degrees can be found using the key of TAN^{-1} in your calculator. **Make sure your calculator is set to the degree mode (ask if you are not sure).** Record this value in your data table.

$$\mathbf{p = tan^{-1} (AB/L1)} \qquad \mathbf{(4)}$$

9. To calculate the distance L2 (point B to point O in figure 3), one must use the trigonometric function,

    sin p = opposite side/ hypotenuse (the longest side of a right triangle)

   That is,

    sin p = AB/L2.

   Solving for L2, yields **L2 = AB/sin p** (5)

   Calculate L2 and record in the data table.

10. Measure very carefully the distances AO and BO directly with the 2-meter stick. Record these values in your data table.

PART II

1. Rotate the cardboard by 90 ^{o} so that the shorter side (18.0 cm side) of the graph paper is now facing the distant object O as in figure 4. **Make sure your point A is located at the same spot on the lab table as point A was in part I.**

2. Repeat steps 1 through 10 of Part I.

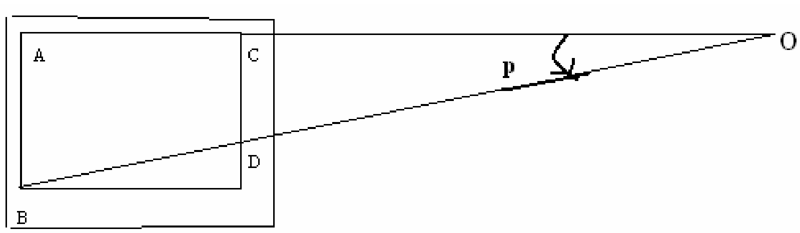

Figure 4

DATA ANALYSIS

1. Find the average $L1_{avg}$ of the two L1's.
2. Find the average $L2_{avg}$ of the two L2's
3. Find the average of the two directly measured distances AO, AO_{avg}
4. Find the average of the two directly measured distances BO, BO_{avg}
5. Calculate percent errors of the two distances using AO_{avg} and BO_{avg} as the correct values. That is,

$$\% \text{ error for L1} = \left(\left| L1_{avg} - AO_{avg} \right| / AO_{avg} \right) \times 100$$

and

$$\% \text{ error for L2} = \left(\left| L2_{avg} - BO_{avg} \right| / BO_{avg} \right) \times 100$$

Data Table

	AB	AC	CD	L1	tan p	p	L2	AO (measured)	BO (measured)
Part I	25.0 cm	18.0 cm							
Part II	18.0 cm	25.0 cm							
average	-------	-------	------	$L1_{avg}$ =	-------	-------	$L2_{avg}$ =	AO_{avg} =	BO_{avg} =

% error for L1 =
% error for L2 =

Questions

1. What is the relationship between parallax angle p and the distance AO (L1)?
2. What are the possible sources of error in this experiment?
3. Are you a bit more confident in scientists' measurements to nearby stars after doing this experiment? Why?
4. What is the distance to a star that has a annual parallax angle of 0.376 arc second? (1 arc second is 1/3600 of a degree.) Us the equation,

$$\mathbf{d = 1/p} \qquad \textbf{(6)}$$

where d = distance in pc (parsecs)
p = parallax angle in arc seconds

Express the distance in pc, ly, and in km. Use the following conversion factors:
1 pc = 3.26 ly (light year, the distance the light travels in one year)

$= 3.09 \times 10^{13}$ km