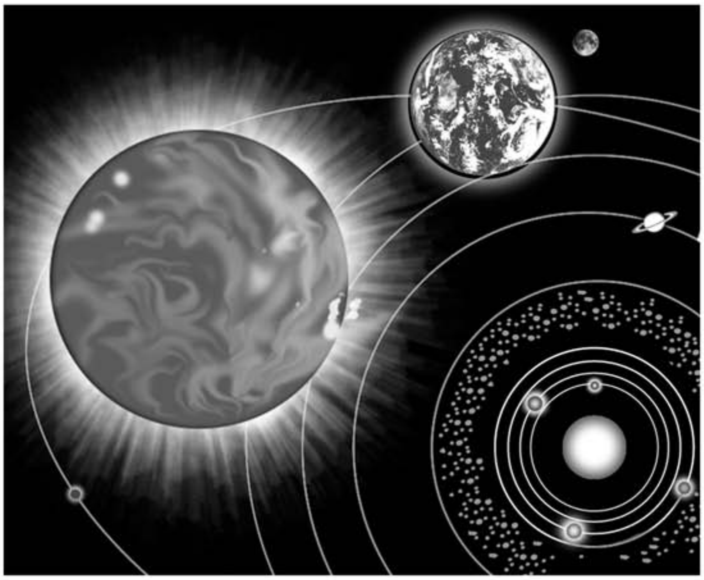


Introduction to

Earth and Space Science

Investigations

Tom Hsu, Ph.D.

cpo science

FIRST EDITION

CPO Science

Peabody, Massachusetts 01960

Table of Contents

UNIT 1: Energy in the Earth System

UNIT 2: Earth Science

UNIT 3: Astronomy

9.2 Galaxies and the Universe

Question: How do we measure the distance to stars and galaxies?

In this Investigation, you will:

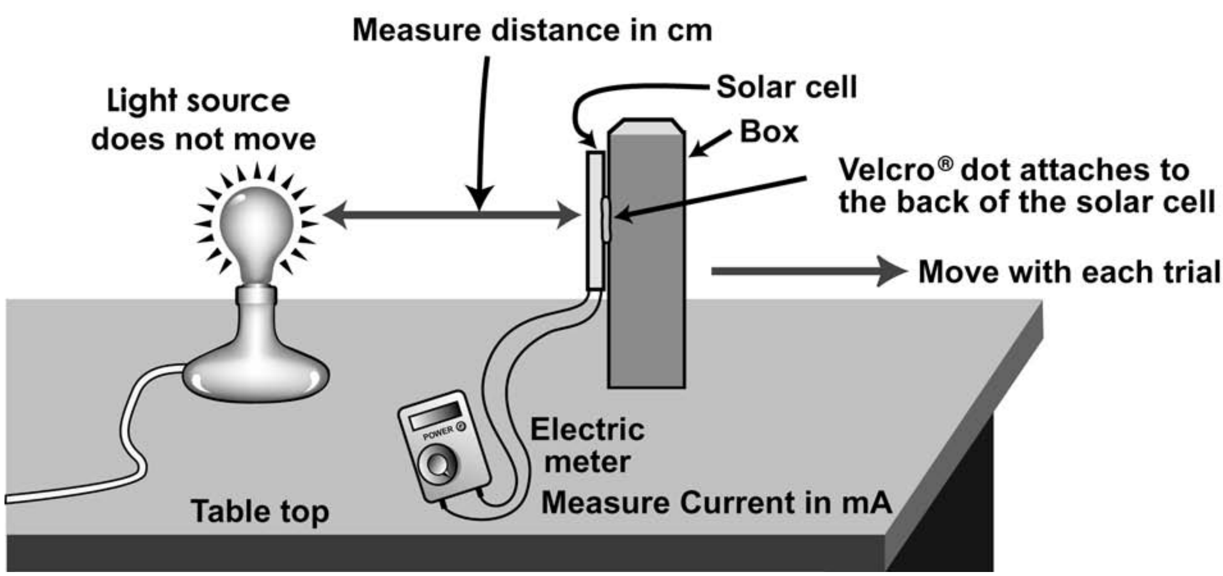
1. Use a solar cell and electric meter to measure brightness at various distances from a light source.
2. Discover the mathematical relationship between apparent brightness and distance.

The **apparent brightness** of any light source depends on the distance from which it is being observed, and how much light it actually emits (its **absolute brightness**). When astronomers know the values for absolute and apparent brightness for a star or galaxy, they can calculate the distance to these objects. In this Investigation, you will discover the mathematical relationship between how bright a light source appears and the distance from which it is observed. You will then understand how astronomers are able to use light to measure the distances to faraway stars and galaxies.

1 Setting up the experiment

For the experiment, you will use a 100-watt light bulb as a light source. You will measure the brightness of the light source at various distances from the light bulb using a solar cell and electric meter.

Set up the experiment as shown in the diagram, then answer the questions below.

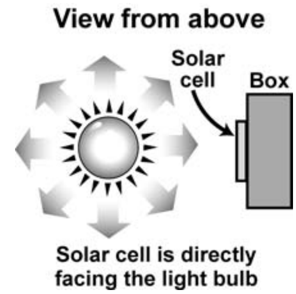


a. Does this experiment measure the *absolute brightness* or the *apparent brightness* of the light source? Explain your answer.

b. Is the power rating of the light source (100 watts) a measure of the light bulb's *absolute brightness* or *apparent brightness*? Explain your answer.

c. What effect do you think increasing the distance will have on your measurements of brightness?

2 Doing the experiment



1. Turn on your light source and turn off the overhead lights in the classroom.
2. Place the solar cell exactly 10 centimeters from the light bulb. Make sure the solar cell is directly facing the light bulb and is not at an angle.
3. Make sure the electric meter is set to measure current in milliamps (mA).
4. Measure the light's brightness in mA and record your results in Table 1.
5. Measure the brightness at 10-centimeter intervals and record your data in Table 1.

Table 1: Brightness and distance data

Distance (cm)	10	20	30	40	50	60	70	80	90	100
Brightness (mA)										

3 Analyzing your data

Make a graph of brightness versus distance. Plot brightness on the *y*-axis and distance on the *x*-axis.

a. Is your graph increasing or decreasing from left to right?

b. Describe the shape of the curve on your graph. Have you seen a curve like this before?

c. Is there a mathematical relationship between brightness and distance from your graph? Explain your answer.

4 Inverse relationships

From your graph, you can tell that the brightness of the light bulb *decreases* as the distance *increases*. When one factor increases as another decreases, it is called an **inverse relationship**. In this case, we can say the brightness varies inversely with distance. This can be shown as a mathematical relationship using the variables *B* for brightness and *D* for distance, where:

Brightness → $$B = \frac{1}{D}$$ } Inverse of distance

Your graph shows an inverse relationship between brightness and distance, but can you tell from the curve exactly by how much brightness will decrease as distance increases? Here are three possible mathematical relationships:

$$B = \frac{1}{D} \quad \text{or} \quad B = \frac{1}{D^2} \quad \text{or} \quad B = \frac{1}{D^3}$$

The first equation says the brightness is inversely related to the distance. The second equation says the brightness varies with the inverse of the distance *squared*.

a. What does the third equation state?

b. Assuming that the correct equation is one of the three above, how could you figure out which is the correct one?

c. Which equation do you think is the correct one? Explain your reasoning.

5 Identifying the correct inverse relationship

To figure out which equation is correct, you will need to further analyze your data from Part 2.

1. Enter your distance data from Table 1 into the first row of Table 2 below. You will need to convert centimeters to meters. The first two values are done for you.
2. Calculate 1/D and enter the results in the second row of Table 2. The first two are done for you.
3. Calculate $1/D^2$ and $1/D^3$ and enter the values in rows three and four of Table 2.
4. Enter your brightness data from Table 1 into the fifth row of Table 2.
5. Make the following three graphs:

   Graph 1: *Brightness vs. 1/D*

   Graph 2: *Brightness vs.* $1/D^2$

   Graph 3: *Brightness vs.* $1/D^3$

Table 2: Analyzing your distance and brightness data

Distance (cm)	10	20	30	40	50	60	70	80	90	100
Distance (m)	0.10	0.20								
1/D	10	5								
$1/D^2$	100	25								
$1/D^3$										
Brightness (mA)										

6 Reaching a conclusion

a. Which graph identifies the correct inverse relationship between brightness and distance? Explain your choice.

b. Write down the correct formula for the relationship between brightness and distance.

c. Test your formula by following these steps:

(1) Choose a distance for which you did not measure brightness (for example, 45 centimeters).

(2) Calculate brightness using your formula. This is your *predicted brightness*.

(3) Move the solar cell to the distance you chose and measure the brightness of the light. This is your *actual brightness*.

(4) Calculate your percent error using the following formula:

$$\left(\frac{\text{predicted brightness - actual brightness}}{\text{predicted brightness}}\right)\times 100 = \text{percent error}$$

d. Your actual brightness should be fairly close to your predicted brightness. What are some possible reasons for differences between predictions and measurements in this experiment?

7 Applying your knowledge: How bright would the sun appear on Pluto?

You have learned that the average distance of Earth from the sun is 150 million kilometers. This is also defined as 1.0 astronomical unit (AU). Using the relationship between apparent brightness and distance that you discovered in this Investigation, we can determine that the brightness of the sun from Earth is equal to 1.0 solar brightness units (SBU):

$$\text{Brightness of the sun from Earth} = \frac{1}{(1.0\ \text{AU})^2} = 1.0\ \text{SBU}$$

Use what you have learned in this Investigation to complete Table 3 below. Then answer the questions.

Table 3: Apparent brightness of the sun from the planets

Planet	Average distance from the sun (AU)	Apparent brightness (SBU)
Mercury	0.37	
Venus	0.72	
Earth	1.0	1.0
Mars	1.5	
Jupiter	5.2	
Saturn	9.5	
Uranus	19.2	
Neptune	30.0	
Pluto	39.5	

a. How much brighter is the sun viewed from Mercury compared with its brightness viewed from Earth?

b. How much fainter is the sun viewed from Pluto compared with its brightness viewed from Earth?

c. CHALLENGE! Alpha Centurai is 4.1×10^{13} km from Earth. How bright would the sun appear in SBU from Alpha Centurai? (Hint: You must first convert kilometers to astronomical units.)

8 Using light to measure distances to stars and galaxies

In the Investigation, you determined that the apparent brightness of a light source decreases as the distance increases. However, the brightness of the light source also depends on how much light it actually emits (its absolute brightness). The inverse square law of brightness shows the relationship between apparent brightness (how bright an object appears from a certain distance), absolute brightness (how much light an object actually emits), and distance:

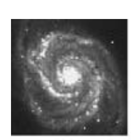
Inverse square law

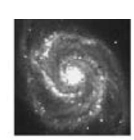
$$B = \frac{L}{4\pi D^2}$$

Apparent brightness → B; Absolute brightness → L; Distance → D; Constant (4 x 3.14) → 4π

a. Which variables would an astronomer need to know in order to determine the distance to a faraway galaxy or star? Describe how an astronomer could determine each variable.

b. In the diagram to the right, which galaxy is the farthest from Earth? Explain your reasoning.


B = 3.0
L = 18.0
Galaxy A


B = 6.0
L = 9.0
Galaxy B

Dramatic is a good word to describe both this cover and the study of Earth and space science. The cover is a universal-scale palette of what you will find in this text. On the front, we witness Earth's interior and see magnetic field lines radiating from the core. Following the magnetic field lines to the back cover, you will encounter the arcing solar prominences on the sun's fiery surface. Central in our solar system, the sun provides a source of energy that drives our weather, seasons, ocean currents, and food synthesis as long as there is water to cycle from place to place. Water moves on the cover in the images of a brewing storm, global cloud patterns, and the curl of an ocean wave reaching shore. In the deeper blues of the cover are images of nebulae, the birthplace of stars. The nebula on the back cover is called the Horsehead Nebula. In striking contrast with the drama that unfolds on Earth, we have our moon. Earth's surface has changed again and again over its long history due to the powerful movement of tectonic plates and the effects of water and wind. The moon does not experience plate tectonics. It, therefore, remains unchanged and an excellent "lab" to study ancient rocks and land formations. With today's technology, we see billions of years into the past and bring astronomically distant regions of the universe closer to us. We at CPO Science with Bruce Holloway, the spirited illustrator of the cover, hope these images will bring you closer to the wonders of Earth and space science and scientific discovery.

The CPO Science Development Team

Introduction to Earth and Space Sciences - Investigations

ISBN 1-58892-065-8
1 2 3 4 5 6 7 8 9 - QWE - 05 04 03

CPO Science
26 Howley Street,
Peabody, MA 01960
(866) 588-6951
http://www.cpo.com

Printed and Bound in the United States of America