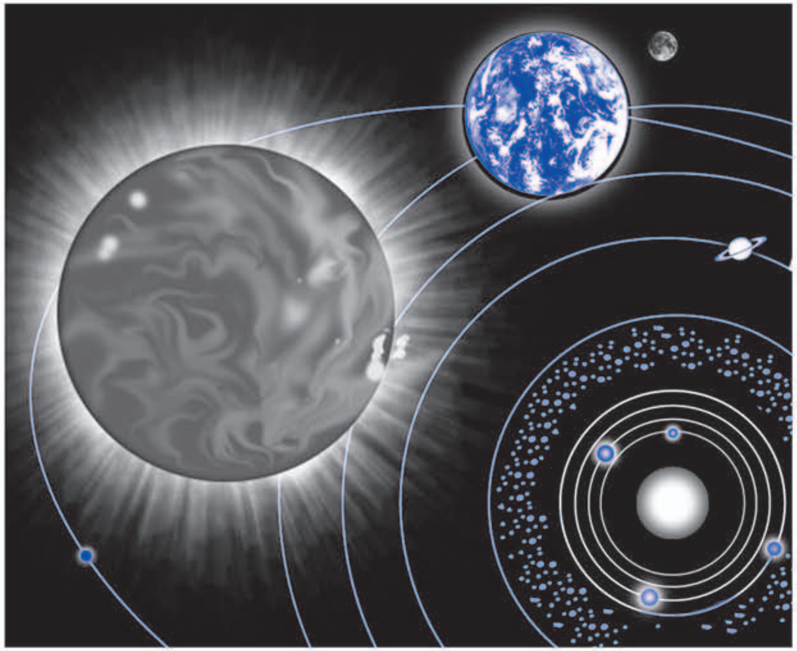


Introduction to

Earth and Space Science

Tom Hsu, Ph.D.

FIRST EDITION
CPO Science
Peabody, Massachusetts 01960

cpo science

UNIT 1 Energy in the Earth System

UNIT 2 Earth Science

UNIT 3 Astronomy

Teacher's Guide Contents

Introduction to Earth and Space Science Student Text Table of Contents

9.1 Stars

Learning Goals	Reading Synopsis	Materials and Setup
• Identify elements that are present in several light sources. • Identify elements that are common in main sequence stars like the sun. • Measure the wavelength of spectral lines and use this information to determine which elements are in a light source. **Key question:** What are stars made of? **Leading questions:** • What is a spectrometer and how is it used? • How do astronomers analyze star light? • What information can astronomers learn through spectroscopy? • Which elements are found in the sun?	Stars are powered by the fusion of hydrogen under conditions of enormous temperature, mass, and density. The light from stars can be analyzed using spectroscopy, to determine their chemical composition, mass, and density. Stars are classified according to their size, temperature, and brightness. The sun is a medium-sized star with a diameter of 1.4 million kilometers, a surface temperature of around 5,000 degrees Celsius, and an average brightness as compared to other stars. Like living organism, stars have a life cycle. They are born out of great clouds of dust and gas called nebulae. The most stable part of a star's life cycle is the main sequence. The length of this stage depends on the star's mass. Stars with a large mass stay in the main sequence for a shorter period of time than stars with smaller masses. When massive stars enter the final phase of their life cycle, a great explosion called a supernova occurs. During this explosion, atomic nuclei are smashed together and elements are formed. **Sequence:** Students complete the reading before the Investigation.	• Spectrometer • Colored pencils • Optional equipment: Atom Building Game **Duration:** One to two class periods

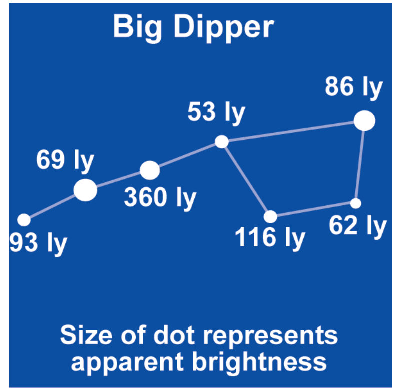
9.2 Galaxies and the Universe

Learning Goals	Reading Synopsis	Materials and Setup
• Use a solar cell and electric meter to measure brightness at various distances from a light source. • Discover the mathematical relationship between apparent brightness and distance. • Describe how the inverse square law is used by astronomers to measure the distance to faraway stars and galaxies. **Key question:** How do we use light to measure the distances to stars and galaxies? **Leading questions:** • Which variables affect how bright a star appears on Earth? • How can some bright stars be further away than some dimmer stars? • What does brightness have to do with distance? • How do you measure brightness? • How bright would the sun appear from the other planets?	A galaxy is a huge group of stars, dust, gas, and other objects bound together by gravitational forces. Galaxies are classified according to their shape. Our solar system is located in a spiral galaxy called the Milky Way. From above, a spiral galaxy looks like a giant pinwheel with arms radiating out from a central region called the nuclear bulge. There is evidence that a huge black hole exists at the center of our galaxy with enough mass to keep all of the stars in the galaxy in orbit. Light is very important to astronomers in measuring the distances to faraway galaxies and star. They use the mathematical relationship between apparent brightness, absolute brightness, and distance to determine these vast measurements. Many scientists believe the universe began as a huge explosion called the Big Bang. According to this theory, after the explosion, the universe began to expand and cool. Eventually clusters of stars formed and the first galaxies appeared. Astronomers have discovered that galaxies are moving apart from a central point in the Universe. This supports the Big Bang. **Sequence:** Students complete the reading before the Investigation.	• Small cardboard box with a velcro tab attached • Solar cell • Electric meter with red and black wires • Metric ruler or meter stick • Light source with a 100-watt bulb **Duration:** One to two class periods

9.2 Galaxies and the Universe

Key Question: How do we use light to measure the distances to stars and galaxies?

In this Investigation, students discover the relationship between the apparent brightness of a light source, and its distance from an observer. To do this, they use a solar cell and electric meter to measure the energy from a light source at different distances. Through graphical analysis, they discover that the apparent brightness of a light source varies with the inverse of the distance squared—the inverse square law. Finally, they learn how astronomers use this important relationship to measure the distance to faraway stars and galaxies.



Reading Synopsis

Students read section 9.2 Galaxies and the Universe, before the Investigation.

A galaxy is a huge group of stars, dust, gas, and other objects bound together by gravitational forces. Galaxies are classified according to their shape. Our solar system is located in a spiral galaxy called the Milky Way. From above, a spiral galaxy looks like a giant pinwheel with arms radiating out from a central region called the nuclear bulge. There is evidence that a huge black hole exists at the center of our galaxy with enough mass to keep all of the stars in the galaxy in orbit. Light is very important to astronomers in measuring the distances to faraway galaxies and stars. They use the mathematical relationship between apparent brightness, absolute brightness, and distance to determine these vast measurements.

Many scientists believe the universe began as a huge explosion called the Big Bang. According to this theory (after the explosion) the universe began to expand and cool. Eventually clusters of stars formed and the first galaxies appeared. Astronomers have discovered that galaxies are moving apart from a central point in the Universe. This supports the Big Bang.

The Investigation

Leading Questions

- Which variables affect how bright a star appears on Earth?
- How can some bright stars be further away than some dimmer stars?
- What does brightness have to do with distance?
- How do you measure brightness?
- How bright would the sun appear from the other planets?

Learning Goals

By the end of the Investigation, students will be able to:

- Use a solar cell and electric meter to measure brightness at various distances from a light source.
- Discover the mathematical relationship between apparent brightness and distance.
- Describe how the inverse square law is used by astronomers to measure the distance to faraway stars and galaxies.

Key Vocabulary

absolute brightness, apparent brightness, current, electric meter, inverse square law, solar cell

Setup and Materials

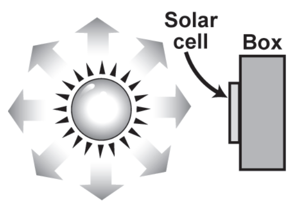
Students work in groups of four to five at tables

Each group should have:

- Small cardboard box with Velcro® tabs attached
- Solar cell
- Electric meter with red and black wires
- Metric ruler or meter stick
- Light source with a 100-watt bulb

NOTE: Attach the Velcro® tabs to the box so that the solar cell, when attached, will be level with the light source when the box is placed on a table (shown below).

View from above



Solar cell is directly facing the light bulb

Details

Time

One to two class periods

Preparation

Gather the materials and try out the experiment yourself before the Investigation.

Assignments

Section 9.2 Galaxies and the Universe in the **Student Edition** before the Investigation.

Chapter 9 Review in the **Student Edition** after the Investigation.

Skill Sheets

9-B Doppler Shift

Reference Guide

Equipment Setup: Earth and Space Science Kit (Solar Cell)

Teaching the Investigation

1. Discussing brightness
2. Setting up the experiment
3. Doing the experiment
4. Analyzing the data
5. Discussing inverse relationships
6. Identifying the correct inverse relationship
7. Testing the mathematical relationship
8. How bright would the sun appear on the planets?
9. Discussing the inverse square law as used by astronomers

Discussing brightness

Apparent brightness = how bright a light source appears to an observer.

Absolute brightness = how bright an object appears from a standard distance. Astronomers use a standard distance of 10 parsecs.

1 parsec = 3.26 light years

Today we are going to learn about light and how astronomers use it to determine the distances to faraway stars and galaxies. What is the brightest star in our sky?

Students may not always think of the sun as a star, but it is the brightest in our sky.

Does this mean that the sun is the brightest star in the entire universe?

Prompt students to conclude that the sun is not the brightest star in the universe. You may wish to review the star life cycle and the various sizes of stars.

How bright any light source appears, that is its *apparent brightness*, depends on two factors. Can anyone name them?

Students should respond that the brightness of a light source depends on its distance from the observer, and how much light it actually emits, or gives off.

Astronomers use the term *absolute brightness* to describe how bright a light source would appear if it were a standard distance from Earth. Absolute brightness therefore is a measure of how much light a source actually emits. If we could move all of the stars in the sky to a standard distance of 10 parsecs (3.26 light years) from Earth, would they appear equally bright? Would the sun still be the brightest star in the sky?

No, they would vary in their brightnesses. The sun would not be the brightest because it is a medium-sized star.

Setting up the experiment

Materials for the Investigation:
- -Lamp with 100-watt bulb
- -Metric tape measure
- -Solar cell
- -Electric meter with red and black wires
- -Cardboard box with velcro tab

1

Today you are going to discover the mathematical relationship between the brightness of a light source, and the distance from it. Each group will need the following materials: lamp with a 100-watt bulb, metric tape measure, solar cell, electric meter with red and black wires, cardboard box with velcro tabs.

Allow students to get into groups and gather their materials.

Now, set up the experiment as shown in the diagram in your Investigation Manual. Make sure that when you stick your solar cell to the box, it is level with the light bulb.

Walk around and make sure students are setting the experiment up correctly. Setup is very important for getting good data. Specifically check for the following:

1. Light source is at one end of the table with plenty of space for moving the box with the solar cell to at least 100 centimeters from the light bulb.
2. The solar cell is on the box at the same height as the middle of the light bulb.
3. Students measure the distance from the front of the light bulb to the surface of the solar cell.
4. The solar cell is firmly attached to the box.
5. The wire leads are connected from the electric meter to the solar cell correctly.
6. The electric meter is set to measure milliamps (mA).

Everyone turn on your lamps.

Once the lamps are turned on, turn off the overhead lights in the classroom. You may need to have some students move their lamps so they do not interfere with the results of other groups.

Discuss the questions in Part 1 with your group and write your answers down.

Doing the experiment

2

Read over the procedures for the experiment carefully. These are found in Part 2. Once you understand the procedures, you may begin the experiment. Please make careful measurements and write your data down for each trial.

Make sure groups are doing the experiment correctly and recording their data.

9.2 Galaxies and the Universe

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

In this Investigation, you will:

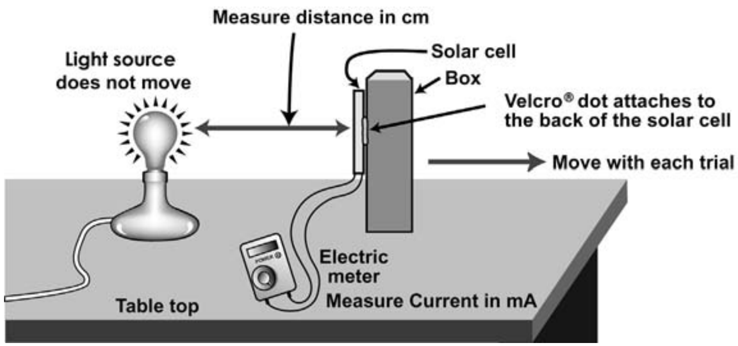
1. Use a solar cell and electric meter to measure brightness at various distances from a light source.
2. Discover the mathematical relationship between apparent brightness and distance.

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?

Comparing brightnesses of stars

In the Student Text, the terms *apparent brightness* and *absolute brightness* are introduced to describe the brightness of stars. Units of brightness are discussed only briefly. The *magnitude scale* is often used by astronomers to compare the brightnesses of stars. Hipparchus first introduced the magnitude scale around 120 BC to describe the apparent brightness of stars. He classified the faintest stars in the sixth magnitude and the brightest stars in the first magnitude. Others fell somewhere in between. Today the magnitude scale is much larger because modern instruments allow astronomers to see much fainter objects. The absolute brightness of a star can also be compared using the magnitude scale. The table below gives magnitude values for the apparent and absolute brightness of some familiar stars. Negative numbers indicate greater brightness.

Star	Apparent brightness	Absolute brightness	Distance (ly)
Sun	-26.7	+4.84	-
Rigel	+0.12	-7.2	945
Betelgeuse	+0.50	-5.5	522
Vega	+0.03	+0.6	24.5
Sirius	-1.46	+1.4	8.6
Alpha Centauri	-0.01	+4.4	4.3

Example Answers

1a. This experiment measures the apparent brightness of the light source because it is a measurement of the brightness of the light source at various distances.

1b. The power rating of the light bulb is closest to a measurement of the absolute brightness of the light source. This value does not change with distance because it is how much light the bulb is actually emitting.

1c. We think that increasing the distance will decrease the brightness of the light source.

Analyzing the data

3

After the experiment, students should graph their data. You may wish to review dependent/independent variables at this point.

In this experiment, which is the independent variable? Why is it called independent?

Distance is the independent variable because it is the variable we changed.

Which is the dependent variable? Why is it called dependent?

Brightness is the dependent variable because the brightness of the light source depends on the distance from the solar cell.

When you graph your data, on which axis should you put each variable?

You put the independent variable on the x-axis and the dependent variable on the y-axis.

Now, work independently to complete your graphs.

Allow students plenty of time to complete their graphs.

Discussing inverse relationships

4

Look at your graphs. What is the general relationship between brightness and distance?

It appears that the brightness of the light source decreases as distance increases. It decreases more the further away the solar cell is located.

What type of relationship is it called when one variable changes in the opposite direction as the other variable?

Students should recognize that this is an inverse relationship.

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

Good, how can we state the relationship between brightness and distance in a sentence?

Brightness varies inversely with distance.

That's correct, and how could we show this mathematically as an equation?

Many students may have trouble with inverse relationships. Be careful during this discussion not to move too fast for students who have trouble with fractions and equations. One of the purposes of this experiment is to help students recognize inverse relationships from mathematical data and graphs.

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

Your graph shows an inverse relationship between brightness and distance, but can you tell from the curve exactly how much brightness will decrease when distance increases by a certain amount? It is useful to find an equation for your curve. Equations are mathematical tools that help scientists make predictions. Three possibilities are:

- Brightness varies with the inverse of distance
- Brightness varies with the inverse of the distance squared; or

Can anyone tell me what the third equation I've written on the board states?

Brightness varies with the inverse of the distance cubed.

Identifying the correct inverse relationship

5

To identify the correct inverse relationship, you will need to further analyze your data. Follow the procedures in Part 5 of the Investigation. You will also need to make three graphs.

Allow students time to complete the calculations and graphs. If you have access to computers and a spreadsheet program, this is a good opportunity to teach students how to use this important tool. This will also make the graphs more consistent and easy to read. Once students are finished, have them share their results with the rest of the class. Prompt your students to reach the conclusion that brightness varies with the inverse of the distance squared.

9.2 Galaxies and the Universe

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.

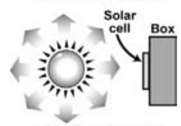


Table 1: Brightness and distance data

Distance (cm)	10	20	30	40	50	60	70	80	90	100
Brightness (mA)	92.5	28.5	15.2	9.2	6.6	4.8	3.8	3.0	2.5	2.0

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:

$$\text{Brightness} \longrightarrow B = \frac{1}{D} \Big\} \text{Inverse of distance}$$

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:

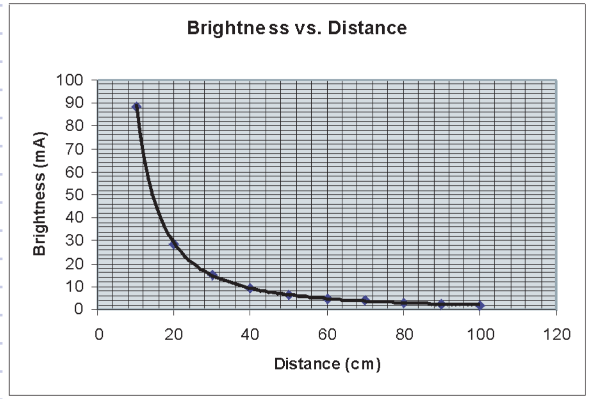
$$B = \frac{1}{D} \quad \text{or} \quad B = \frac{1}{D^2} \quad \text{or} \quad B = \frac{1}{D^3}$$

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.

Example Answers

Graph:



3a. The graph is decreasing from left to right.
3b. The curve shows that brightness decreases as distance increases by a certain factor. It looks like an exponential relationship.
3c. No, I cannot determine the mathematical relationship because the line is a curve. If it were a straight line, I could find the slope of the line and determine the mathematical relationship.

4a. The third equation states that brightness varies with the inverse of the distance cubed.
4b. I would need to plug the data into each equation to see which one works for each data point on the graph.
4c. I think that $B = 1/D^2$ is correct because I have seen this type of relationship graphed before and the curve looked similar.

Testing the mathematical relationship

6

Now you should test the inverse relationship to see if it allows you to predict the brightness of the light source at a distance for which you did not take a brightness measurement. To do this, answer the questions in part 6 of the Investigation.

Allow students to work in their groups to answer the questions in Part 6. They will need to use the same setup they used for the experiment in Part 2. When they are finished, allow each group to present the results of their test to the rest of the class.

If the percent error was high in any or all of the groups, have a discussion about where errors could come from in this experiment.

How bright would the sun appear on the planets?

7

In Part 7 of the Investigation, students apply their equation to solving a real-world problem. Specifically, they use their equation to predict how bright the sun would appear from each of the nine planets. To do this, they use an arbitrary unit called a solar brightness unit (SBU). The brightness of the sun from Earth is equal to 1.0 SBU.

Students should work in groups to complete Table 3, and then answer the questions.

After they have completed the questions, have each group share their answers.

Discussing the inverse square law as used by astronomers

8

Inverse square law:

$$\text{Apparent brightness} = \frac{\text{Absolute brightness}}{4\pi D^2}$$

The inverse square law shows the mathematical relationship between apparent brightness, absolute brightness, and distance. How is this equation like the one you derived? How is it different?

Students should immediately see that apparent brightness varies with the inverse of the distance squared—just like their equation. However, this equation incorporates the absolute brightness of the light source as a variable. It also includes a constant—4π. This constant is related to the fact that as distance increases, the light from the source also spreads out. 4π is an area-related constant.

Which variables would an astronomer need to know in order to predict the distance to a faraway star or galaxy?

Students should conclude that astronomers would need to know the apparent brightness and the absolute brightness of a star or galaxy.

Which variable could be measured from Earth? How could it be measured?

The apparent brightness of a star or galaxy could be measured from Earth. Students should remember the definition of apparent brightness as how bright an object appears to an observer at a distance. Astronomers use various instruments such as photometers, to measure apparent brightness.

Why would it be difficult to measure the absolute brightness of a star or galaxy?

Absolute brightness is the measure of how much light a source actually emits from a standard distance of ten parsecs. Because astronomers cannot move all stars to a distance of ten parsecs, they cannot measure this quantity directly. Instead, they use indirect means to infer the absolute brightnesses of stars and galaxies. These ideas are discussed in the Student Text.

Now, answer the questions in Part 8.

Allow students to answer these questions in class, then discuss the answers.

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	7.3
Venus	0.72	1.9
Earth	1.0	1.0
Mars	1.5	0.4
Jupiter	5.2	4.0×10^{-2}
Saturn	9.5	1.0×10^{-2}
Uranus	19.2	2.7×10^{-3}
Neptune	30.0	1.1×10^{-3}
Pluto	39.5	6.4×10^{-4}

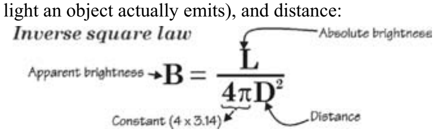
a. How much brighter is the sun viewed from Mercury compared with its brightness viewed from Earth?

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:



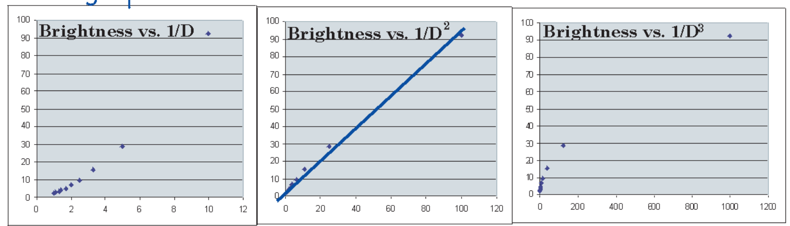
a. Which variables would an astronomer need to know in order to determine the distance to a faraway galaxy or star? Describe how an astronomer could determine each variable.

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

Galaxy A Galaxy B

5 6 Answers from page three (page not shown)

Three graphs:



6a. The graph of brightness vs. 1/distance^2 is the correct relationship because it is the closest one to a straight line.

6b. $B = 1/D^2$

6c. Prediction for 0.45 meters = 4.9. Actual = 5.5.
% error = (4.9 - 5.5)/4.9 = 12.2%.

6d. Reasons for differences include: inaccurate distance measurements, interference from ambient light, movement of solar cell, inaccurate brightness measurements.

7 8 Answers from page four (shown at left)

7a. The sun would appear about 7 times brighter.

7b. The sun would appear 6.4×10^{-4} times fainter.

7c. Solution:

$$4.1 \times 10^{13}\,\text{km}\left(\frac{1\ \text{AU}}{150{,}000{,}000\ \text{km}}\right) = 2.7 \times 10^{5}\,\text{AU}$$

$$\frac{1}{(2.7 \times 10^{5})^{2}} = 1.4 \times 10^{-11}$$

8a. The astronomer would need to know the absolute brightness and the apparent brightness. Apparent brightness could be measured from Earth using a photometer. Absolute brightness could be inferred using a standard candle.

8b. Galaxy A is farthest from Earth because if you rearrange the equation to solve for distance (ignoring the constant), you get:

$$D = \sqrt{\frac{L}{B}}$$

Plugging in the values for Galaxy A gives you a greater value for distance (2.4) than Galaxy B (1.2).

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. Not surprisingly 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, a familiar "face" in the sky. Earth's surface has changed again and again over its long history due to the powerful and slow movement of tectonic plates and the relatively fast 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 can 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 Science

ISBN 1-58892-066-6
1 2 3 4 5 6 7 8 9 - QWE - 05 04 03

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Printed and Bound in the United States of America