SECTION 5

Shadows

Section Overview

Students learn in the *Investigate* that light travels in straight lines. They observe how shadows are produced on a screen, which is illuminated by a white light bulb. They draw diagrams to see the path of light rays and describe the shadows that are formed when the rays are blocked by a small cardboard puppet. Students also learn the concepts of umbra and penumbra by observing the unlit and partially lit spaces on the screen placed at the other end of the light source.

Throughout the section, students continue to reflect on the physics of light and shadows. They also solve problems regarding why the size of a shadow varies when a light source, an object, or a screen, are moved. In *Inquiring Further*, students make a sketch of what they see when their puppet is illuminated by two light bulbs.

Background Information

To begin their exploration of light and how to manipulate it for their sound and light show, students will explore shadows. The main concepts to be grasped here are that light travels in straight lines (called light rays), unless the light hits something like a partially reflecting object or a mirror or lens.

A source of light such as a candle flame or a light bulb sends light rays out in all directions. Only those light rays are seen that enter the eye. The objects seen are not directly sources of light, because they reflect light—for example, from the Sun or a light bulb—to your eyes.

Shadows are produced when one object blocks some of the light that would otherwise hit another object. Outside on a sunny day, people can see a sharp shadow of themselves on the ground. They can also see shadows of objects such as leaves on the ground. Notice how sharp—or rather, fuzzy, the border is of these shadows. The same effect can be seen in a dark room by turning on a single frosted bulb. Because the bulb and the Sun are extended light sources, they produce shadows with a so-called penumbra region, a fuzzy border around the shadow illuminated by some, but not all, of the light source. If the light source were extremely small (a point light source), the edges of the shadow would be rather sharp. The size of this fuzzy border is directly proportional to the distance from the object to the screen. The top of a flagpole or a tall building would cast a fuzzy shadow.

Another example of a dramatic shadow effect is a lunar eclipse. A lunar eclipse occurs when the Moon moves into Earth's shadow. Earth blocks the sunlight that would otherwise have hit the Moon. The Moon is visible because of the sunlight reflected from its surface.

Crucial Physics

- Light must reach your eyes to see something.
- For most practical purposes, you can think of light rays as traveling in straight lines except for reflection and refraction.
- Shadows are formed when an object interrupts some of the light rays coming from a light source (the Sun, a light bulb, a laser, and so on).
- For an extended light source, some of the light rays may be blocked and others not, so a shadow may have a "fuzzy" border.

Learning Outcomes	Location in the Section	Evidence of Understanding
Observe that light rays travel in straight lines.	***Investigate*** Steps 3-8	Students note that holes in the cardboard pieces must fall along the same line as the light from the bulb for them to see the light. Students observe what happens to light rays when they are blocked by a puppet. Students draw correct ray diagrams.
Analyze shadow patterns.	***Investigate*** Steps 5-9 ***Checking Up*** Questions 2 and 3	Students record what happens to the shadow of a puppet when it is moved about. Students correctly answer questions.
Explain the size of shadows.	***Investigate*** Steps 5 and 7 ***Physics Essential Questions*** ***Physics to Go*** ***What Do You Think Now?***	Students correctly answer questions. Students describe how shadows are formed using ray diagrams to show how changing an object's position changes the size of the shadow.

Section 5 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Scissors	1 per group	
Ruler, metric, in./cm	1 per group	
Mirror support	2 per group	
Light bulb socket with switch and 40W bulb	1 per group	
Posterboard, 11" x 14", white screen	1 per group	
Cardboard, 14" x 14"	2 per group	
Card, unlined index, 3" x 5" pkg 100		4 per class
Access to an electrical outlet*	1 per group	

*Additional items needed not supplied

Time Requirement

- Allow one class period or 45 minutes for students to complete the *Investigate*, and an additional class period or 45 minutes to complete all the other parts of the section from the *Pacing Guide*.

Teacher Preparation

- A white screen is the best to clearly show the edge of the shadows. The penumbra will fade from being quite dark to white near the umbra as it approaches its edge.
- A laser can be used to demonstrate the straight-line propagation of light. Shining a helium–neon laser across the classroom away from students and illuminating the beam with either mist from a humidifier or chalk dust from erasers allows students to see the beam traveling in a straight line. After students have performed the *Investigate*, you may choose to shine the beam through the holes in the screens to reinforce the straight-line concept.

Safety Requirements

- If a 110-volt source is used for the light bulb, make certain that the terminal connections to the bulb are covered and inaccessible to students.
- It is preferable to use a hole-punch to make the holes in the cards rather than students making a hole with a sharp instrument.

NOTES

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Scissors		1 per class
Ruler, metric, in./cm	1 per group	
Mirror support		2 per class
Light bulb socket with switch and 40W bulb		1 per class
Posterboard, 11" x 14", white screen		1 per class
Cardboard, 14" x 14"		2 per class
Card, unlined index, 3" x 5" pkg 100		4 per class
Access to an electrical outlet*	1 per group	

*Additional items needed not supplied

Time Requirement

- Allow one class period or 45 minutes for students to complete the *Investigate*, and an additional class period or 45 minutes to complete all the other parts of the section from the *Pacing Guide*.

Teacher Preparation

- Note the teacher preparation items from *Plan A*.
- Have the equipment set up in a position easily seen by the class. Hand puppets should be already cut out, and screens with holes prepared beforehand.
- Prepare transparencies of the diagrams for *Steps 8* and *9* from the *Student Edition* to show the path of the light rays.

Safety Requirements

- If a 110-volt source is used for the light bulb, make certain that the terminal connections to the bulb are covered and inaccessible.
- Use a hole-punch to make the holes in the cards.

NOTES

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Recording a series of observations	***Investigate*** Steps 4-8	**Augmentation** • Students with executive-function, organization, and attention issues may struggle to complete the *Investigate* and record meaningful observations at the same time. Before beginning *Steps 4-8,* allow 5-10 minutes for students to play with their puppets and talk about the shadows they are creating. Then give students time limits such as 5-8 minutes for completing each step and recording their observations. Check in with students who struggle to make meaningful observations or who have weak writing skills. **Accommodation** • Provide students with a recording sheet for observations to complete and tape into their logs.
Drawing straight lines	***Investigate*** Step 7.a)	**Augmentation** • Students with graphomotor issues struggle to draw straight lines. Provide students with a ruler or straightedge to draw the light rays for this step. **Accommodation** • Provide students with a drawing that already has the light rays included.
Reading comprehension	***Physics Talk***	**Augmentation** • Students who struggle with reading may have never been explicitly taught the strategies that good readers use (utilizing headings, captions, and pictures to support the text, rereading difficult passages, and so on). Provide direct instruction of reading strategies for nonfiction sources such as textbooks. • This section provides many diagrams to support the explanations. Explicitly teach students to look at and study pictures and diagrams, read the captions, and compare their concept understanding to the graphic representations in the section.

Strategies for Students with Limited English-Language Proficiency

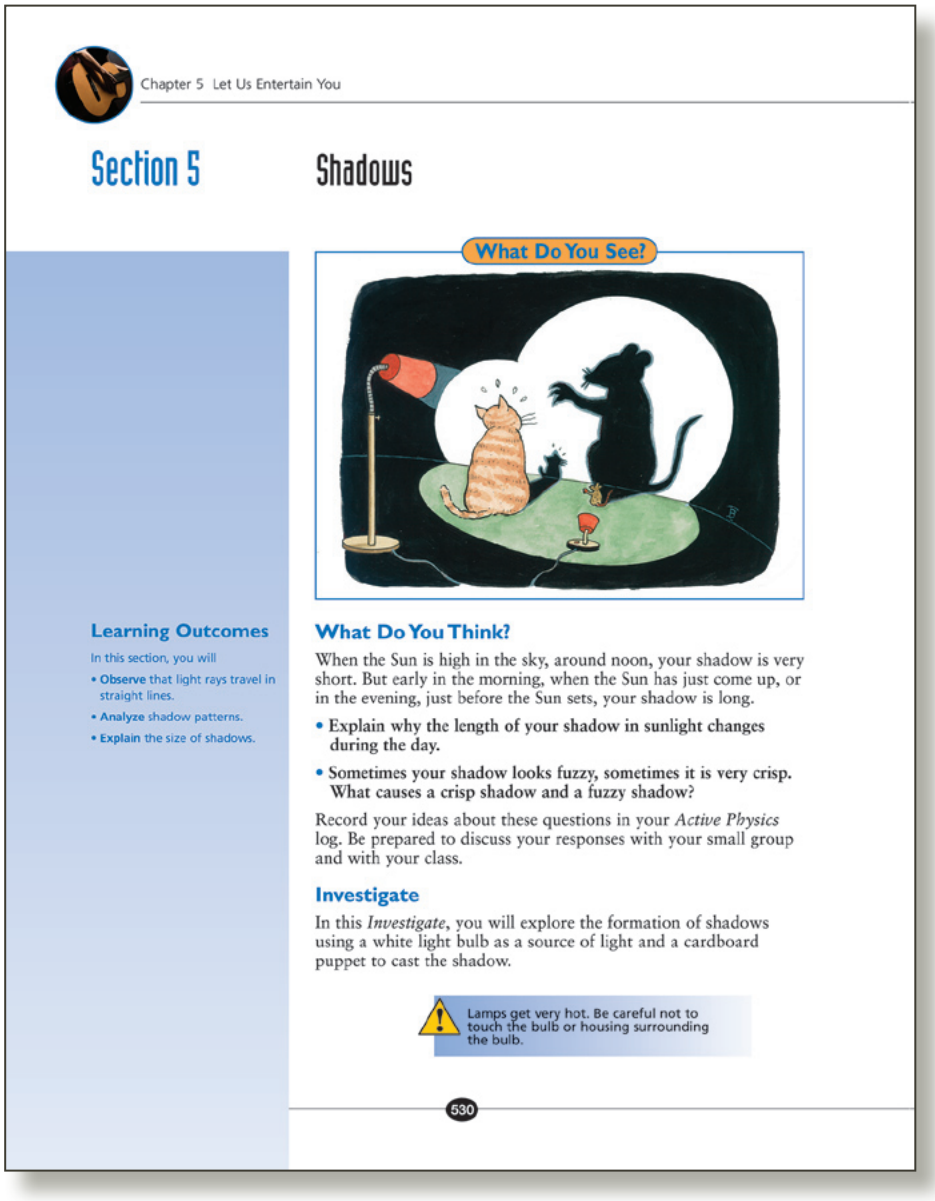
Learning Issue	Reference	Augmentation
Vocabulary comprehension	***What Do You Think?***	Help students understand fuzzy and crisp in context. A "fuzzy" image is not clear; it looks blurry. A "crisp" image is clear, sharp, and well-defined.
Reading comprehension Understanding concepts	***Investigate*** Steps 5.a) and 6	Check students' drawings. Be sure all elements are included and each is in its proper position. It is important that students show light rays as straight lines. Also, the rays should be shown going out from the light in all directions, not just directly toward the puppet. (Note: For the purposes of investigating and understanding shadows, the light rays shining away from the puppet do not need to be represented. However, students may benefit from knowing that light rays truly shine in all directions.)
Comprehension	***Investigate*** Steps 5.c) and 6	Students should have noticed that the shadow can be larger than, smaller than, or about the same size as the puppet. Be sure they have determined that the closer the puppet is to the light source, the larger and fuzzier its shadow will be.
Vocabulary comprehension Understanding concepts	***Investigate*** Steps 8.c) and 8.d)	Review umbra and penumbra with your students. The "umbra" is the darkest area of a shadow, where all light is cut off. The "penumbra" is the area of partial shadow, between the umbra and the area fully lit. Check students' understanding of "fuzzy" and "crisp" by asking: "Does the penumbra look fuzzy or crisp?" or "Which area looks fuzzy?"
Understanding concepts	***What Do You Think Now?***	If students are struggling with why shadow length changes over the course of a day, review the cat and mouse illustration on the first page of this section. Be sure they comprehend that the angle at which light strikes an object is one factor that determines the size of the shadow produced.
Understanding concepts	***Physics Talk***	Be sure students can answer these two questions: "What must happen so that you can see?" [light must enter your eye], and "What causes the umbra?" [the absence of light].
Vocabulary comprehension	***Reflecting on the Section and the Challenge***	Help students infer the meaning of "aesthetic" from context [artistic; demonstrating beauty and good taste].

SECTION 5

Teaching Suggestions and Sample Answers

What Do You See?

In this illustration of *What Do You See?* students will most likely notice the difference in the length of shadows. Prompt them with questions that guide them toward the physics they are about to study in the *Investigate*. Consider asking them about the difference in the placement of light sources and what the artist is trying to show. Encourage students to study the illustration carefully and share their ideas with the class. Remind them that their perspective of the illustration will continue to change as they investigate the physics of shadows.


Chapter 5 Let Us Entertain You

Section 5 Shadows

What Do You See?

Learning Outcomes

In this section, you will

- **Observe** that light rays travel in straight lines.
- **Analyze** shadow patterns.
- **Explain** the size of shadows.

What Do You Think?

When the Sun is high in the sky, around noon, your shadow is very short. But early in the morning, when the Sun has just come up, or in the evening, just before the Sun sets, your shadow is long.

- Explain why the length of your shadow in sunlight changes during the day.
- Sometimes your shadow looks fuzzy, sometimes it is very crisp. What causes a crisp shadow and a fuzzy shadow?

Record your ideas about these questions in your *Active Physics* log. Be prepared to discuss your responses with your small group and with your class.

Investigate

In this *Investigate*, you will explore the formation of shadows using a white light bulb as a source of light and a cardboard puppet to cast the shadow.

Lamps get very hot. Be careful not to touch the bulb or housing surrounding the bulb.

530

Students' Prior Conceptions

This section gives students the opportunity to draw diagrams, to model what they see, and to analyze how light travels from a source to a screen when it strikes an object to form shadows. While examining shadow formation, if students use a straight-edged meter stick and/or model light rays with strings from the light source to the edge of a puppet and then to the shadow of the puppet, they can "see" how light rays travel and/or are absorbed and reflected. This assists students in realigning their prior conceptions in accordance with physics concepts.

1. **Students do not have the notion that light travels from one place to another. This leads to difficulties explaining the direction and formation of shadows.** Direct experience with this section and modeling the transmission of light rays and the results will make this prior notion clearer for students, so that they can amend it.
2. **Each point on a luminous object emits light in all directions.** Encourage students to examine other shadows that may exist due to the transmission of light from the bulb in directions other than those that are straight toward the puppet. Extend the *Investigate* so that students experience light traveling from a small hole toward the puppet by placing a card with a series of small holes in front of the light source and covering and uncovering these holes with tape to see what happens to the shadows of the puppet. Recall that *Active Physics* promotes the 7E-model of teaching and learning.

What Do You Think?

The *What Do You Think*? has questions designed to elicit students' curiosity. Generate a discussion to get an idea of how much they know about shadows. Allow them to discuss these questions. You might want to ask students to highlight key words and phrases that provide clues to the answers. Be alert for misconceptions and accept all responses, but do not expect right answers at this point. Point out to students that they will be returning to these questions again, following the *Investigate*.

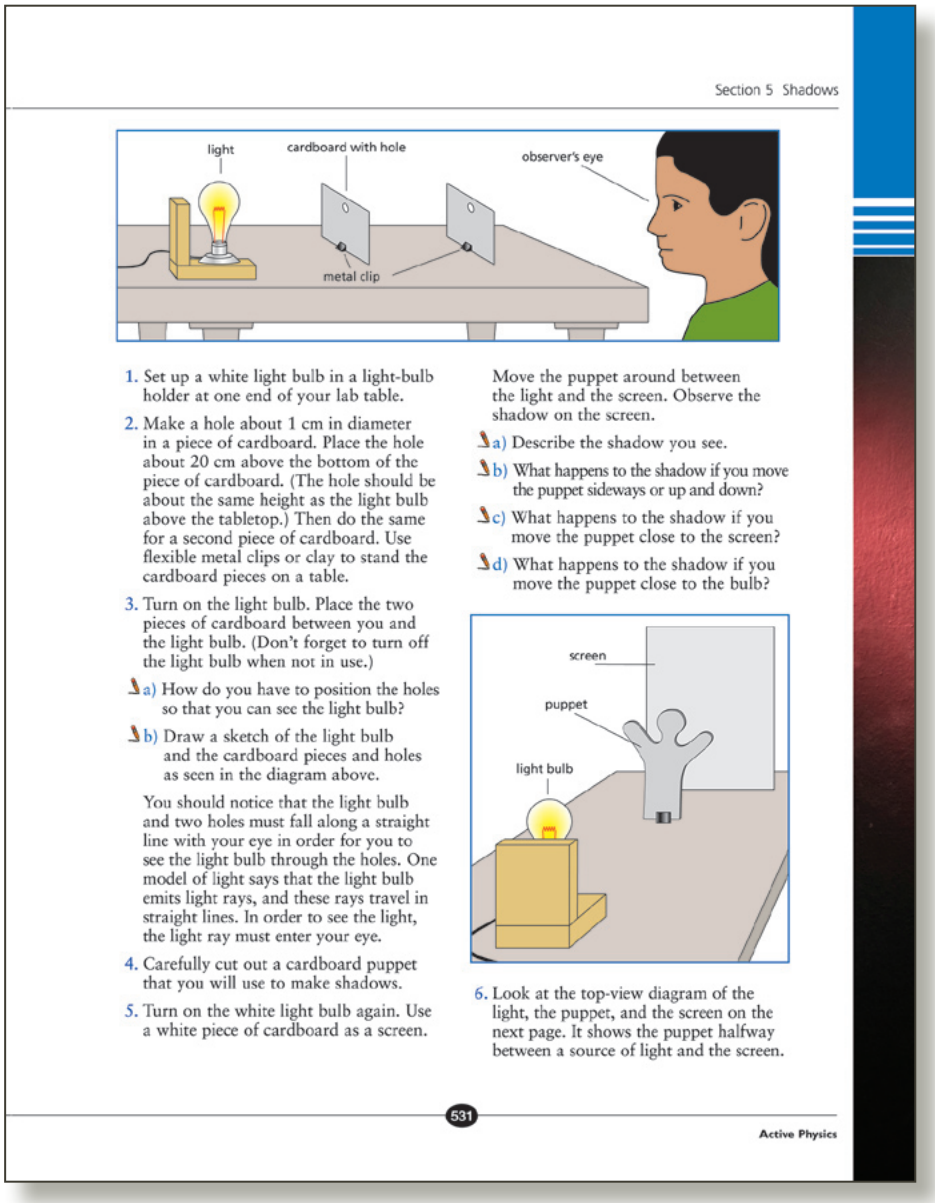
What Do You Think?

A Physicist's Response

The change in the size of a shadow is due to the change of geometry in the location of the Sun (low in the sky in the morning and evening and high in the sky at noon). Students need to remember that they are standing vertically. If the surface on which the shadow is formed is close to the object, the penumbra region may be so small that it is hard to see, which makes the edge of the shadow look relatively sharp. If the shadow surface is far away from the object, the umbra and penumbra are both larger and it is easier to see the "fuzzy" penumbra region.

NOTES

NOTES



Section 5 Shadows

1. Set up a white light bulb in a light-bulb holder at one end of your lab table.
2. Make a hole about 1 cm in diameter in a piece of cardboard. Place the hole about 20 cm above the bottom of the piece of cardboard. (The hole should be about the same height as the light bulb above the tabletop.) Then do the same for a second piece of cardboard. Use flexible metal clips or clay to stand the cardboard pieces on a table.
3. Turn on the light bulb. Place the two pieces of cardboard between you and the light bulb. (Don't forget to turn off the light bulb when not in use.)
   a) How do you have to position the holes so that you can see the light bulb?
   b) Draw a sketch of the light bulb and the cardboard pieces and holes as seen in the diagram above.

   You should notice that the light bulb and two holes must fall along a straight line with your eye in order for you to see the light bulb through the holes. One model of light says that the light bulb emits light rays, and these rays travel in straight lines. In order to see the light, the light ray must enter your eye.
4. Carefully cut out a cardboard puppet that you will use to make shadows.
5. Turn on the white light bulb again. Use a white piece of cardboard as a screen. Move the puppet around between the light and the screen. Observe the shadow on the screen.
   a) Describe the shadow you see.
   b) What happens to the shadow if you move the puppet sideways or up and down?
   c) What happens to the shadow if you move the puppet close to the screen?
   d) What happens to the shadow if you move the puppet close to the bulb?

6. Look at the top-view diagram of the light, the puppet, and the screen on the next page. It shows the puppet halfway between a source of light and the screen.

531

Active Physics

Investigate

1.

Students set up the equipment.

2.

Students continue to prepare the equipment for the investigation.

3.a)

Because light travels in a straight line, students will be able to see the light bulb only if the two holes, their eye, and the light bulb all line up in a straight line.

3.b)

A student's sketch should show a straight-line path between the two holes in the cardboard and the light bulb.

4.

A puppet of any size or shape will be fine. Something about 10-15 cm in size is good.

5.a)

The shadow is dark in the center with a gray area around the edges.

5.b)

The shadow moves in the same direction as the puppet.

5.c)

When the puppet is close to the screen, the size of the puppet's shadow decreases and becomes closer in size to the puppet. The fuzzy area around the shadow also decreases, making the shadow appear sharper.

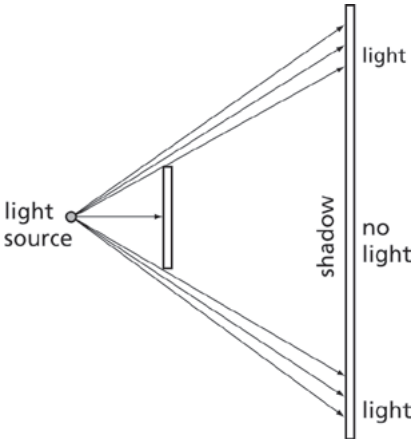
5.d)

As the puppet moves away from the screen and toward the bulb, the shadow gets larger.

CHAPTER 5

6.a)

Students' drawings should appear similar to the one below.



6.b)

i) The part of the screen above and below the puppet receives light.

ii) The part of the screen between the lines receives no light. The part of the screen between the inner and outer lines receives some light (since it is possible to draw a line from some part of the bulb to this part of the screen). No part of the screen receives all the light of the bulb.

6.c)

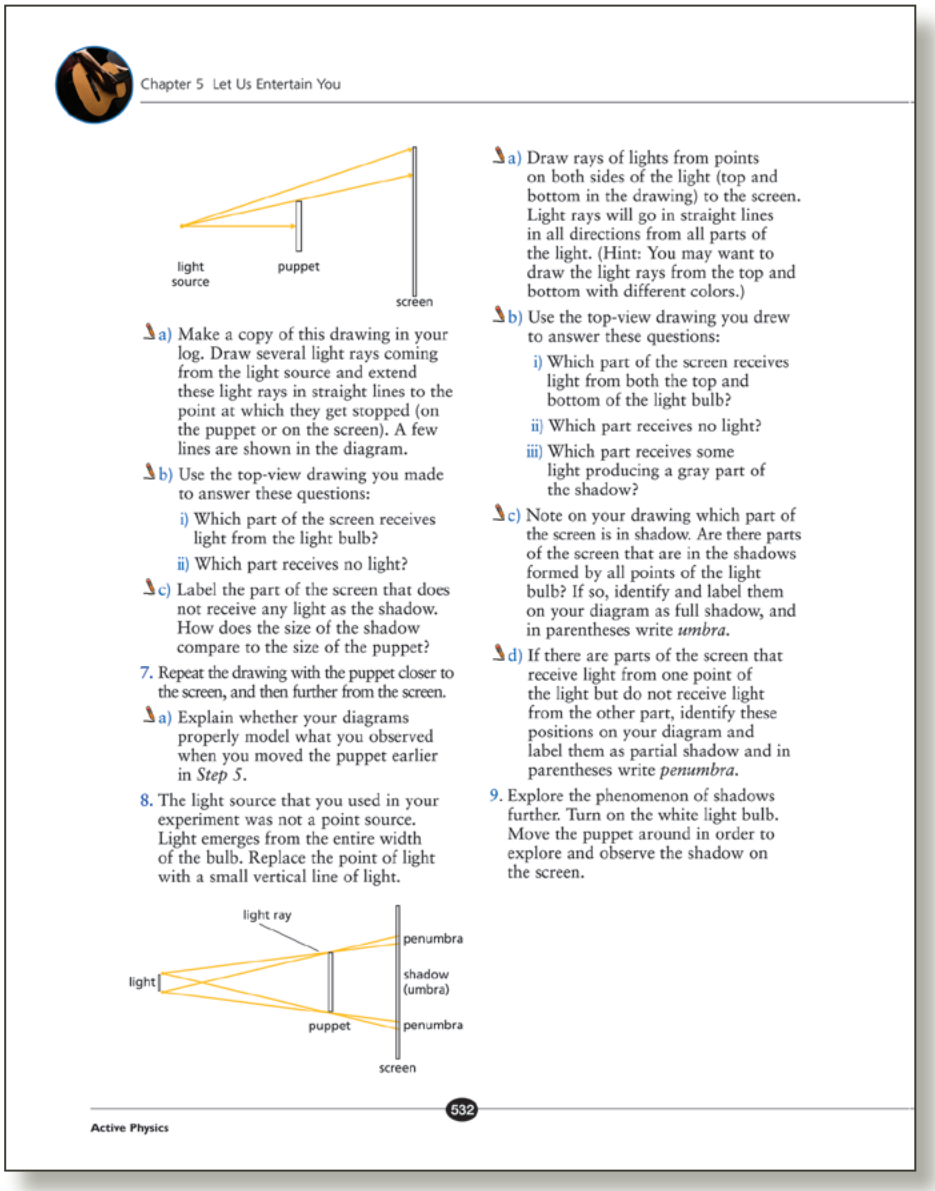
The shadow is larger than the puppet because light from the bulb continues to spread out after it passes the puppet.

7.a)

The diagrams will be variations on the one shown in *Step 6.a)*. In all cases the shadow is larger than the puppet.

8.a)

The student diagram should resemble the one at the right.



Chapter 5 Let Us Entertain You

a) Make a copy of this drawing in your log. Draw several light rays coming from the light source and extend these light rays in straight lines to the point at which they get stopped (on the puppet or on the screen). A few lines are shown in the diagram.

b) Use the top-view drawing you made to answer these questions:

i) Which part of the screen receives light from the light bulb?

ii) Which part receives no light?

c) Label the part of the screen that does not receive any light as the shadow. How does the size of the shadow compare to the size of the puppet?

7. Repeat the drawing with the puppet closer to the screen, and then further from the screen.

a) Explain whether your diagrams properly model what you observed when you moved the puppet earlier in *Step 5*.

8. The light source that you used in your experiment was not a point source. Light emerges from the entire width of the bulb. Replace the point of light with a small vertical line of light.

a) Draw rays of lights from points on both sides of the light (top and bottom in the drawing) to the screen. Light rays will go in straight lines in all directions from all parts of the light. (Hint: You may want to draw the light rays from the top and bottom with different colors.)

b) Use the top-view drawing you drew to answer these questions:

i) Which part of the screen receives light from both the top and bottom of the light bulb?

ii) Which part receives no light?

iii) Which part receives some light producing a gray part of the shadow?

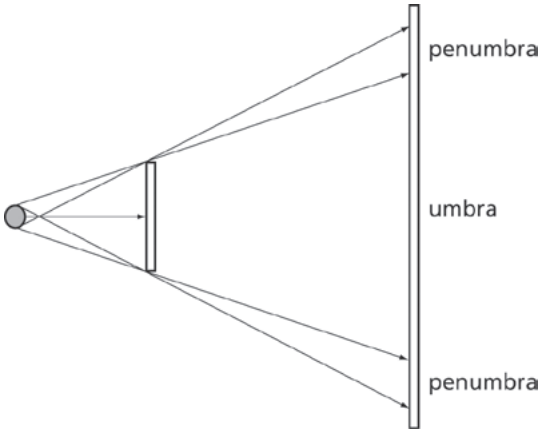
c) Note on your drawing which part of the screen is in shadow. Are there parts of the screen that are in the shadows formed by all points of the light bulb? If so, identify and label them on your diagram as full shadow, and in parentheses write *umbra*.

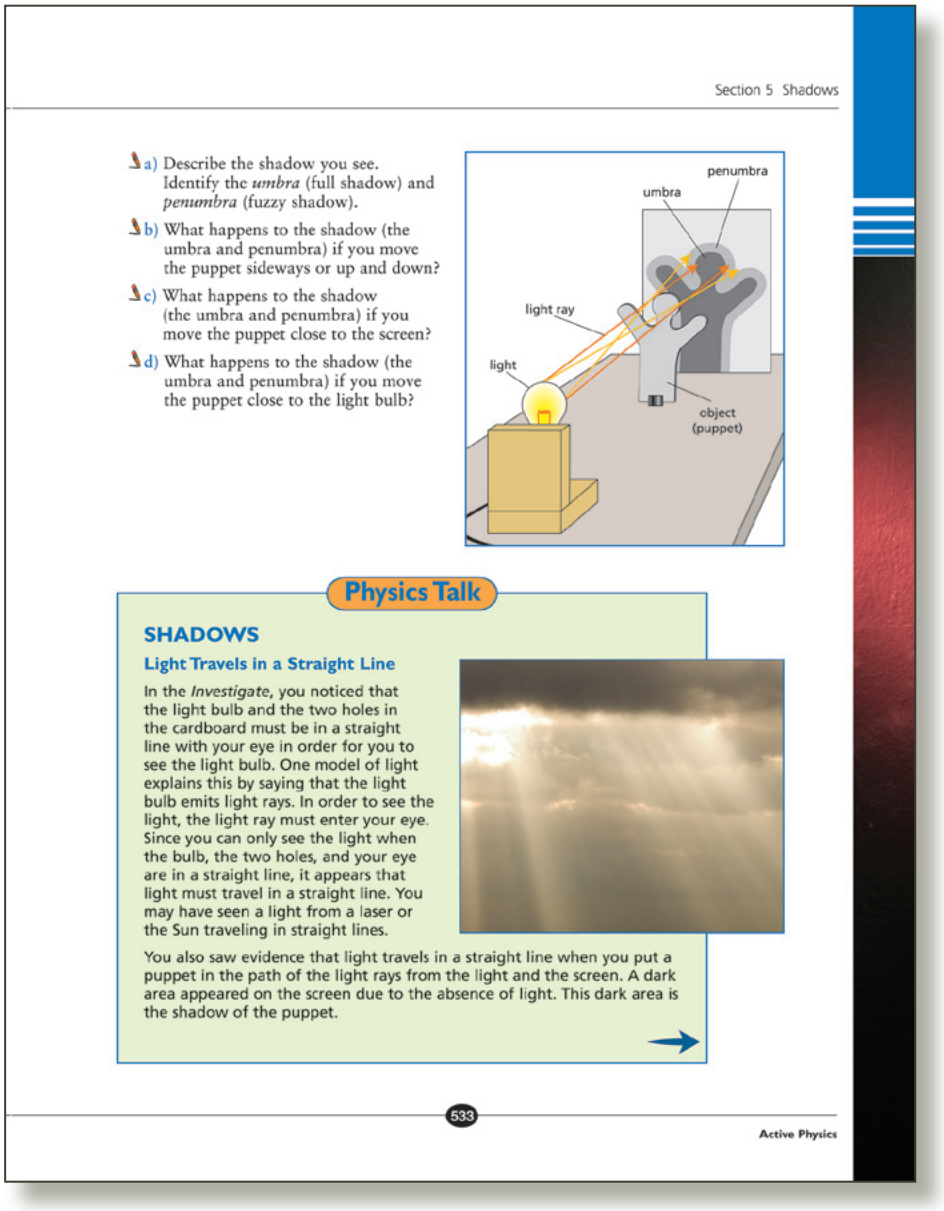
d) If there are parts of the screen that receive light from one point of the light but do not receive light from the other part, identify these positions on your diagram and label them as partial shadow and in parentheses write *penumbra*.

9. Explore the phenomenon of shadows further. Turn on the white light bulb. Move the puppet around in order to explore and observe the shadow on the screen.

532

Active Physics





8.b)

i) The part of the screen between the inner and outer lines receives some light (since it is possible to draw a line from some part of the bulb to this part of the screen). No part of the screen receives light from the entire bulb.

ii) The part of the screen between the inner lines receives no light.

iii) The part of the screen between the inner and outer lines receives some light.

8.c)

The parts of the screen between the inner lines are in full shadow and should be marked umbra.

8.d)

The parts of the screen between the inner and outer lines should be marked penumbra.

9.a)

Students should see the penumbra area as an area starting at the shadow, and getting lighter as it moves away until moving into full illumination. The umbra will be the fully dark region.

9.b)

The umbra and penumbra move in the same direction as the puppet.

9.c)

Moving the puppet closer to the screen decreases the size of both the umbra and penumbra.

9.d)

Moving the puppet closer to the light source increases the size of both the umbra and penumbra.

Physics Talk

Students connect the *Investigate* to the theory of light traveling in straight lines. The discussion in the *Physics Talk* leads to an understanding of why shadows are formed. It also illustrates how the size of a shadow is related to the relative positions of the light source, the object, and the screen. The light of the Sun traveling through a dusty atmosphere or the light from a laser are examples of light traveling in a straight line.

The *Physics Talk* also explains how shadows change length. Students should note why the Sun's position determines the change in the size of the shadow and not the distance of the object from the Sun. Point out that the size of a shadow depends on how much light an object is able to block.

The physics concepts of umbra and penumbra, illustrated by the ray diagrams, help students understand why shadows are full or partial. Draw attention to the difference between the two ray diagrams that are formed by light

CHAPTER 5

emitted from a point source and light emitted from an extended source. Consider asking students why an extended light source was used to illustrate the formation of shadows, and why it is needed to form a penumbra. Also, ask them why a point source can only form an umbra.

5-5a Blackline Master

Checking Up

1.

Light travels in straight lines.

2.

A dark shadow is formed when all light from the light source is blocked and the shadow does not get any light from the light source.

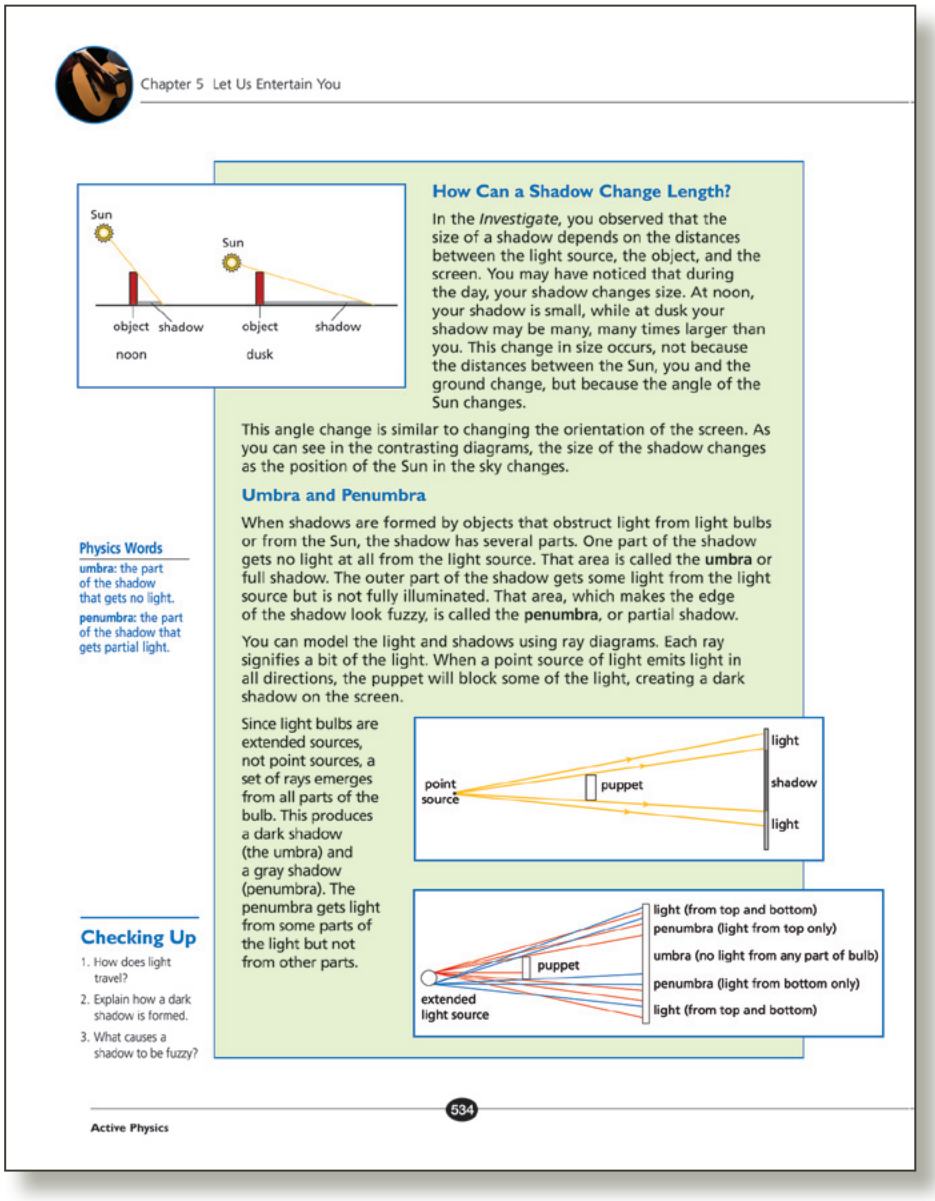
3.

A shadow is fuzzy when light from some parts of the light source illuminate the surface, but light from other parts of the light source is blocked.

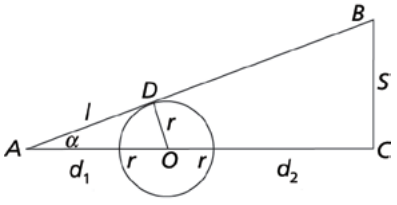
Active Physics Plus

Students calculate the size of a shadow by using the ratio of a similar triangle formed by ray diagrams. They also calculate the difference in the size of a shadow when the angles formed by the object or the wall are varied.

Questions 1-3 can all be solved simply by making scale diagrams. First, students choose a suitable scale (and size of paper). They then draw to scale the rod or basketball and their distances to the light and screen. Finally, they measure the size of the shadow directly with a ruler. Motivated students can attempt the math solutions shown.



1.



d_1 = distance from bulb to front of basketball
r = radius of basketball
d_2 = distance from rear of basketball to wall
S = size of top half of shadow

Triangle ABC

$$\tan\alpha = \frac{S}{d_1 + 2r + d_2}$$

Triangle AOD

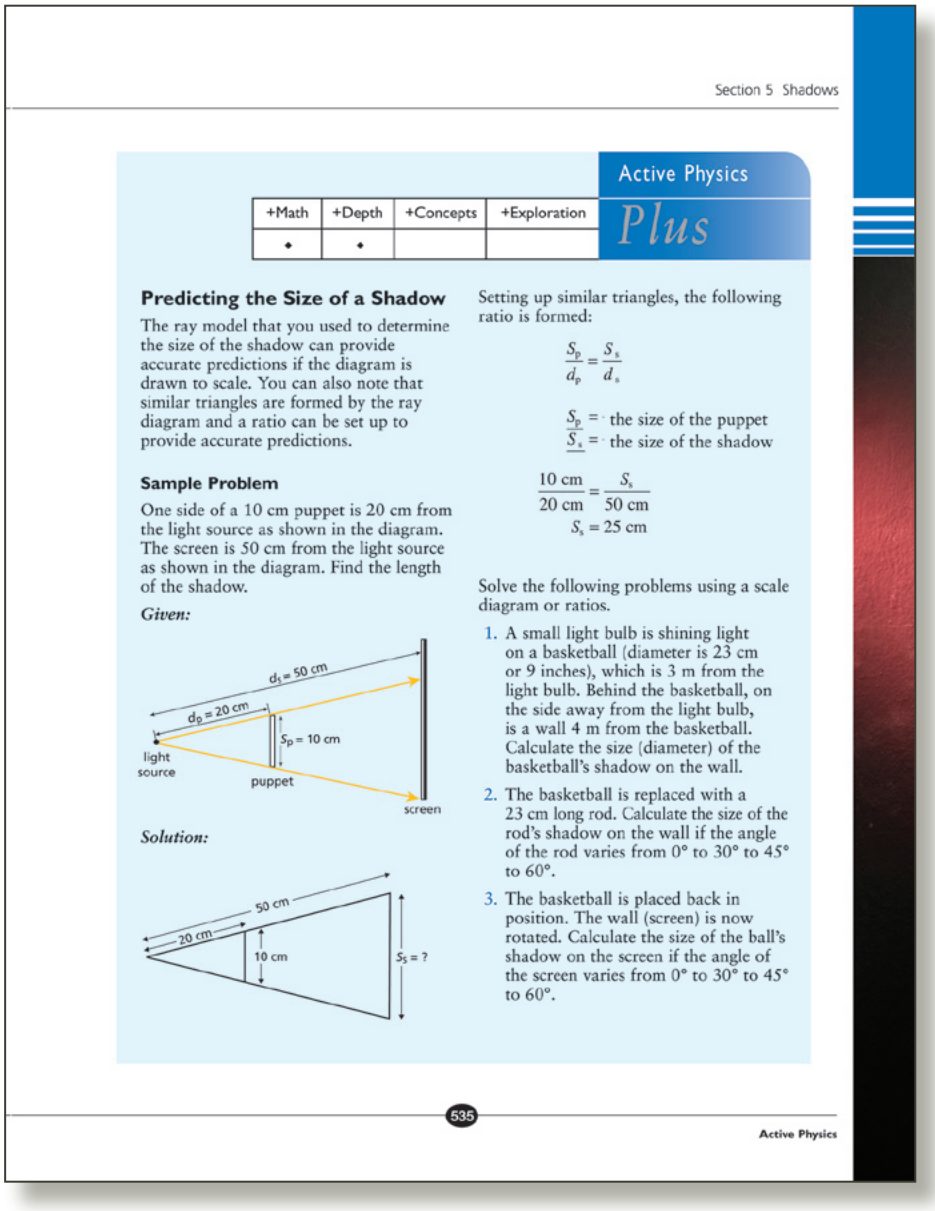
$$\tan\alpha = \frac{r}{l} = \frac{r}{\sqrt{(d_1 + r)^2 - r^2}}$$

Using ratio of side from similar triangle to exclude the need for tangent

$$\frac{S}{d_1 + 2r + d_2} = \frac{r}{\sqrt{(d_1 + r)^2 - r^2}}$$

$$S = r(d_1 + 2r + d_2)\Big/\sqrt{(d_1 + r)^2 - r^2} = 0.2671 \text{ m}$$

total height, $S_t = S + S = 0.53$ m



Section 5 Shadows

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
•	•		

Predicting the Size of a Shadow

The ray model that you used to determine the size of the shadow can provide accurate predictions if the diagram is drawn to scale. You can also note that similar triangles are formed by the ray diagram and a ratio can be set up to provide accurate predictions.

Sample Problem

One side of a 10 cm puppet is 20 cm from the light source as shown in the diagram. The screen is 50 cm from the light source as shown in the diagram. Find the length of the shadow.

Given:

Solution:

Setting up similar triangles, the following ratio is formed:

$$\frac{S_p}{d_p} = \frac{S_s}{d_s}$$

S_p = the size of the puppet
S_s = the size of the shadow

$$\frac{10\text{ cm}}{20\text{ cm}} = \frac{S_s}{50\text{ cm}}$$
$$S_s = 25\text{ cm}$$

Solve the following problems using a scale diagram or ratios.

1. A small light bulb is shining light on a basketball (diameter is 23 cm or 9 inches), which is 3 m from the light bulb. Behind the basketball, on the side away from the light bulb, is a wall 4 m from the basketball. Calculate the size (diameter) of the basketball's shadow on the wall.
2. The basketball is replaced with a 23 cm long rod. Calculate the size of the rod's shadow on the wall if the angle of the rod varies from 0° to 30° to 45° to 60°.
3. The basketball is placed back in position. The wall (screen) is now rotated. Calculate the size of the ball's shadow on the screen if the angle of the screen varies from 0° to 30° to 45° to 60°.

535

Active Physics

Inserting the values for θ of 0°, 30°, 45°, and 60° gives values for S_t of 0.5367 m, 0.4647 m, 0.3798 m, and 0.2686 m.

3.

To find the length of the shadow when the wall is tilted at an angle φ, first find angle α.

$\sin\alpha = r/(d_1 + r)$

$\alpha = \sin^{-1}(0.115\text{ m}/3.115\text{ m}) = 2.1°$

To find the length of the tilted wall shadow, use the law of sines on triangles *X*, *Y*, *Z* and *A*, *B*, *X*. Also, find the value for the vertical wall shadow length (*S*).

For triangle *X*, *Y*, *Z* (where $S/2$ = one-half the vertical wall shadow)

$(\sin A)/A = (\sin B)/B$ or

$\sin\theta/(S/2) = \sin(90 + \alpha)/W_2$

$W_2 = S\sin(90 + \alpha)/(2\sin\theta)$

and $\theta = 180 - 90 - \alpha - \varphi$

For triangle *A*, *B*, *X*

$(\sin A)/A = (\sin B)/B$ or

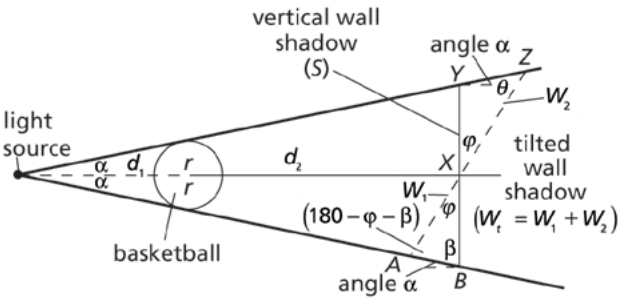
$\sin(180 - \varphi - \beta)/(S/2) = \sin(\beta)/W_1$

$W_1 = (S\sin\beta)/(2\sin(180 - \varphi - \beta))$

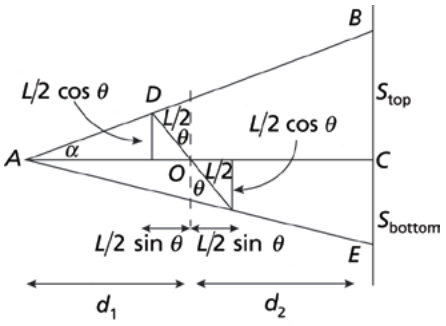
and angle $\beta = 90° - \alpha$

The length of the shadow on the tilted wall is then $W_t = W_1 + W_2$

Inserting the values for φ of 30°, 45° and 60° gives values for W_t of 0.62 m, 0.754 m and 1.09 m.



2.



$$\frac{L/2\cos\theta}{d_1 - L/2\sin\theta} = \frac{S_{top}}{d_1 + d_2}$$

$$S_{top} = \frac{(d_1 + d_2)(L/2\cos\theta)}{d_1 - L/2\sin\theta}$$

$$\frac{L/2\cos\theta}{d_1 + L/2\sin\theta} = \frac{S_{bottom}}{d_1 + d_2}$$

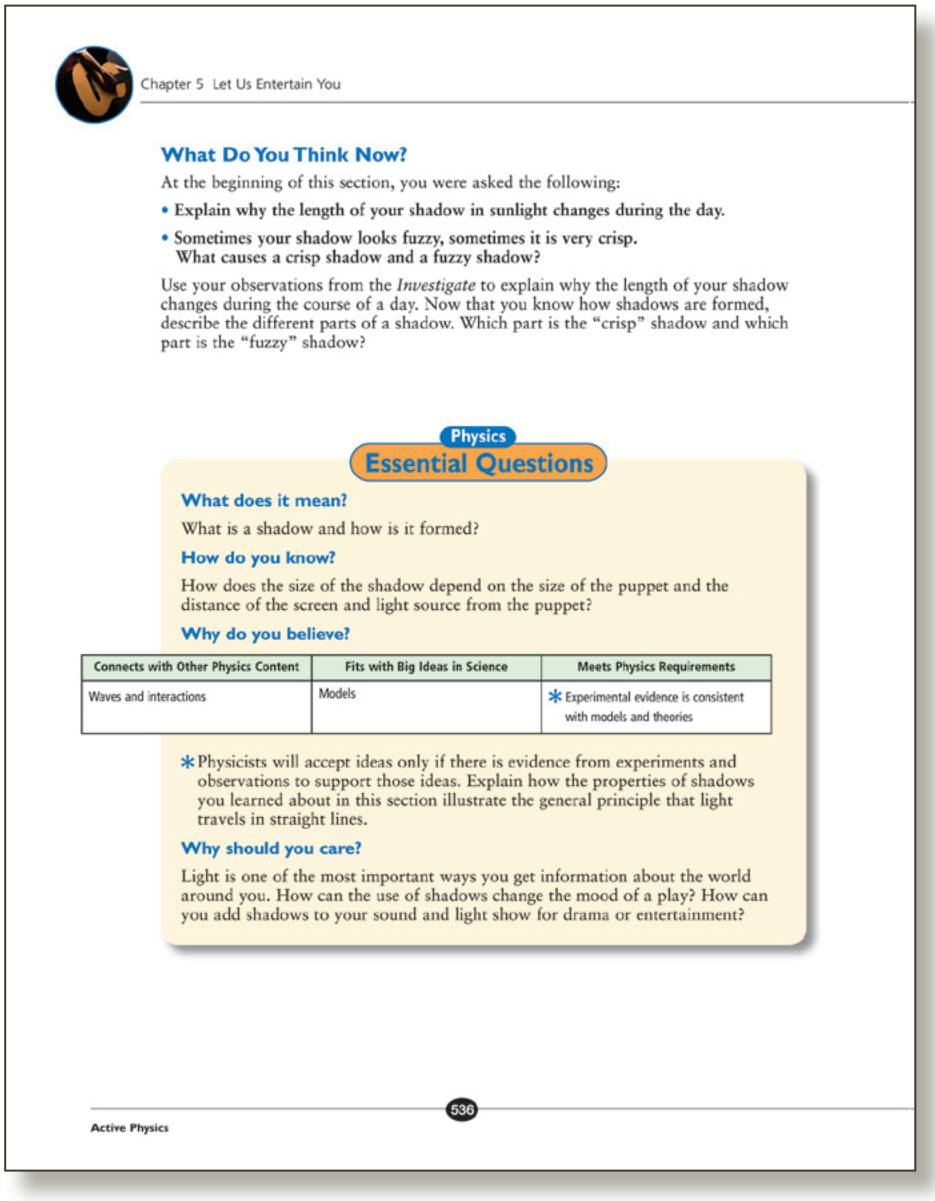
$$S_{bottom} = \frac{(d_1 + d_2)(L/2\cos\theta)}{d_1 + L/2\sin\theta}$$

$$S_t = S_{top} + S_{bottom}$$

CHAPTER 5

What Do You Think Now?

Ask students to refer to their previous answers to the *What Do You Think?* questions. They should be able to explain with confidence why shadows are formed. Discuss *A Physicist's Response* with your class and share your understanding of how light travels and what happens when its path is obstructed. Encourage students to revise and update their answers in the *Active Physics* logs, and to review the *What Do You See?* illustration. They should now be able appreciate how their understanding of shadows has evolved.



Chapter 5 Let Us Entertain You

What Do You Think Now?

At the beginning of this section, you were asked the following:

- **Explain why the length of your shadow in sunlight changes during the day.**
- **Sometimes your shadow looks fuzzy, sometimes it is very crisp. What causes a crisp shadow and a fuzzy shadow?**

Use your observations from the *Investigate* to explain why the length of your shadow changes during the course of a day. Now that you know how shadows are formed, describe the different parts of a shadow. Which part is the "crisp" shadow and which part is the "fuzzy" shadow?

Physics
Essential Questions

What does it mean?

What is a shadow and how is it formed?

How do you know?

How does the size of the shadow depend on the size of the puppet and the distance of the screen and light source from the puppet?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Waves and interactions	Models	✻ Experimental evidence is consistent with models and theories

✻ Physicists will accept ideas only if there is evidence from experiments and observations to support those ideas. Explain how the properties of shadows you learned about in this section illustrate the general principle that light travels in straight lines.

Why should you care?

Light is one of the most important ways you get information about the world around you. How can the use of shadows change the mood of a play? How can you add shadows to your sound and light show for drama or entertainment?

536

Active Physics

Physics Essential Questions

What does it mean?

A shadow is an area behind an object which blocks the light that is illuminating it. If the source of light is not a point, then the shadow has two parts—an umbra and a penumbra.

How do you know?

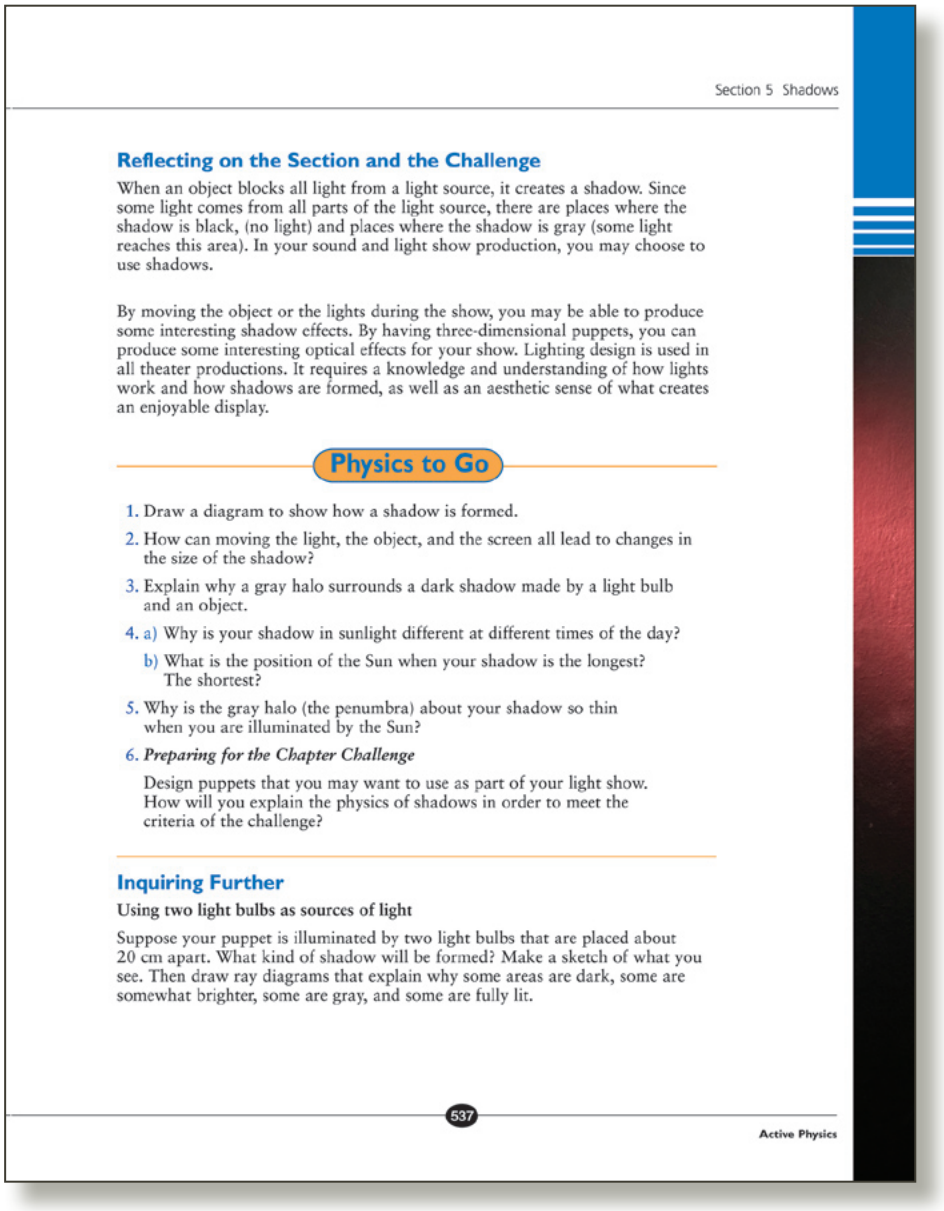
The size of the shadow increases as the size of the puppet increases. The size of the shadow decreases as the distance between the light source and the puppet increases. The size of the shadow increases as the distance between the puppet and screen increases. The edges of the shadow are fuzzy if the light source is spatially extended.

Why do you believe?

The model of light rays traveling in straight lines is able to accurately predict the size of the shadow as the distances between the puppet and the light source or the puppet and the screen change.

Why should you care?

Shadows are often associated with deep woods, darkened interiors, and other situations that create a mysterious or gloomy mood. People in shadows add suspense. In the light and sound show, shadows can produce all sorts of effects as the shadows change in size.



Section 5 Shadows

Reflecting on the Section and the Challenge

When an object blocks all light from a light source, it creates a shadow. Since some light comes from all parts of the light source, there are places where the shadow is black, (no light) and places where the shadow is gray (some light reaches this area). In your sound and light show production, you may choose to use shadows.

By moving the object or the lights during the show, you may be able to produce some interesting shadow effects. By having three-dimensional puppets, you can produce some interesting optical effects for your show. Lighting design is used in all theater productions. It requires a knowledge and understanding of how lights work and how shadows are formed, as well as an aesthetic sense of what creates an enjoyable display.

Physics to Go

1. Draw a diagram to show how a shadow is formed.
2. How can moving the light, the object, and the screen all lead to changes in the size of the shadow?
3. Explain why a gray halo surrounds a dark shadow made by a light bulb and an object.
4. a) Why is your shadow in sunlight different at different times of the day?
   b) What is the position of the Sun when your shadow is the longest? The shortest?
5. Why is the gray halo (the penumbra) about your shadow so thin when you are illuminated by the Sun?
6. *Preparing for the Chapter Challenge*

   Design puppets that you may want to use as part of your light show. How will you explain the physics of shadows in order to meet the criteria of the challenge?

Inquiring Further

Using two light bulbs as sources of light

Suppose your puppet is illuminated by two light bulbs that are placed about 20 cm apart. What kind of shadow will be formed? Make a sketch of what you see. Then draw ray diagrams that explain why some areas are dark, some are somewhat brighter, some are gray, and some are fully lit.

537

Active Physics

Reflecting on the Section and the Challenge

Reflecting on this section should generate an interesting discussion on how shadows can be used in the *Chapter Challenge*. Prompt students to think of how they could use shadows to produce optical effects in their show. Encourage them to cut out three-dimensional puppets, which obstruct light at different angles. This is an excellent opportunity for students to use their creative talents in designing an entertaining display of lights.

Physics to Go

1.

Students' diagrams should look similar to the one in *Step 6* in the *Investigate*.

2.

The shadow becomes larger when light can spread out more after it passes the object. Light can spread out more when the screen is moved away from the light source, the object is moved toward the light source, or the light source is moved toward the object.

3.

The gray halo (penumbra) is a region of intermediate brightness at the edge of the shadow. The effect is to make the shadow edge appear fuzzy. The gray halo occurs when the light bulb is frosted (an "extended" source). Because the light comes from different places on the bulb, the area at the edge of the shadow is illuminated by light from only a part of the bulb.

4.a)

The length of the shadow is determined by the altitude of the Sun (the angle between the horizon and the Sun). Because the light rays of sunlight are approximately parallel, the orientation of your body and also the orientation of the ground determine the length of the shadow.

4.b)

Your shadow is longest at sunrise and sunset. It is shortest at noon.

5.

The gray halo is thin because the Sun, although quite large and so far away, becomes closer to a point source.

6.

Preparing for the Chapter Challenge

Students design puppets and explain the physics of shadows in order to meet the criteria of the challenge.

Inquiring Further

Using two light bulbs as sources of light

Here students are asked to use two light sources to form shadows. They need to realize that light rays from both sources illuminate the object and hence, two shadows can be formed. This is easiest to see when the light bulbs are reasonably far apart but about the same distance from the puppet. Encourage the students to understand what happens when the two light bulbs are brought closer together.

NOTES

NOTES

SECTION 5 QUIZ

5-5b Blackline Master

1. A dark shadow is formed when a solid object is placed in the path of light from a point source. The reason the shadow is completely dark is

   a) light is made of waves.

   b) light travels in straight lines.

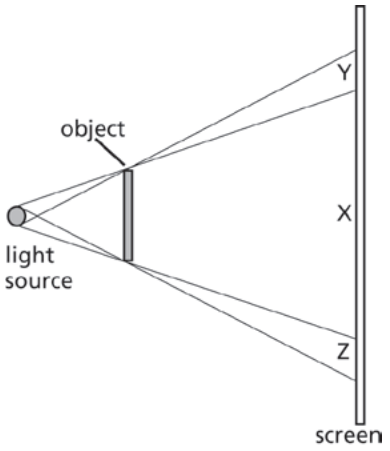
   c) light from different parts of the bulb causes shadows of different shapes.

   d) only laser light can penetrate into shadows.

2. The diagram at the right shows an object between a light source and a screen. The area where the shadow will have no light striking the screen (the umbra) is

   a) X. b) Y.

   c) Z. d) X, Y, and Z.



3. In *Question 2*, as the size of the light source is made larger, what happens to the size of the umbra?

   a) The umbra increases in size.

   b) The umbra decreases in size.

   c) The umbra remains the same size but gets darker.

   d) The umbra remains the same size but gets lighter.

4. In *Question 2*, as the object is moved closer to the screen, what happens to the size of the penumbra?

   a) The penumbra increases in size.

   b) The penumbra decreases in size.

   c) The penumbra remains the same size.

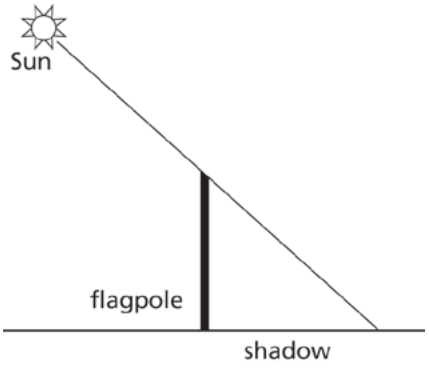
5. A flagpole is casting a shadow as shown in the diagram. Which of the following would make the length of the shadow shorter?

   a) Increasing the height of the flagpole.

   b) Moving the Sun further away from the pole.

   c) Making the Sun brighter.

   d) The Sun moving closer above the flagpole.



SECTION 5 QUIZ ANSWERS

1. b) Light travels in almost straight lines and sharp shadows are formed, since no light can penetrate the area that is blocked. The fact that light is a wave, as in choice *a)*, is not important, except that it will very slightly fill in the dark shadows due to diffraction. Laser light is irrelevant to the shadow, as in choice *d)*, as are the shadows of different shapes in choice *c)*.

2. a) Only region X is completely blocked from receiving light from any portion of the bulb. All the other regions could have a light ray drawn from some portion of the bulb to the screen.

3. b) A larger source will allow light to encroach into the umbra. A sufficiently large source would cause the umbra to disappear completely. Because the umbra by definition is the point where there is no light, choices *c)* and *d)* have no meaning.

4. b) As the object moves closer to the screen, both the umbra and the penumbra decrease in size. This is easily seen if the object is placed right next to the screen, in which case, the umbra is the size of the object, and the penumbra decreases to zero if the object is extremely thin.

5. d) When the Sun is directly overhead, the shadow length is zero, so moving the Sun closer above the flagpole will decrease the shadow length. Making the Sun brighter, choice *c)*, or moving it further away, as in choice *b)*, will not change the shadow length if the relative position of the Sun in the sky is unchanged. Increasing the flagpole height, choice *a)*, will increase the shadow length.