Section 5 Shadows

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 See?

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.

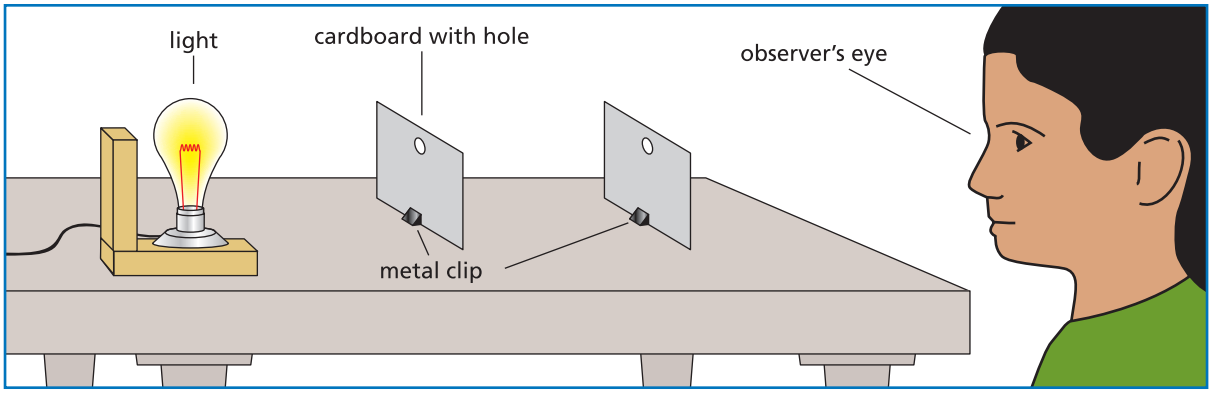
- **Explain why the length of your shadow in sunlight changes during the day.**
- **Sometimes your shadow looks fuzzy, sometimes it is very crisp. What causes a crisp shadow and a fuzzy shadow?**

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.



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.

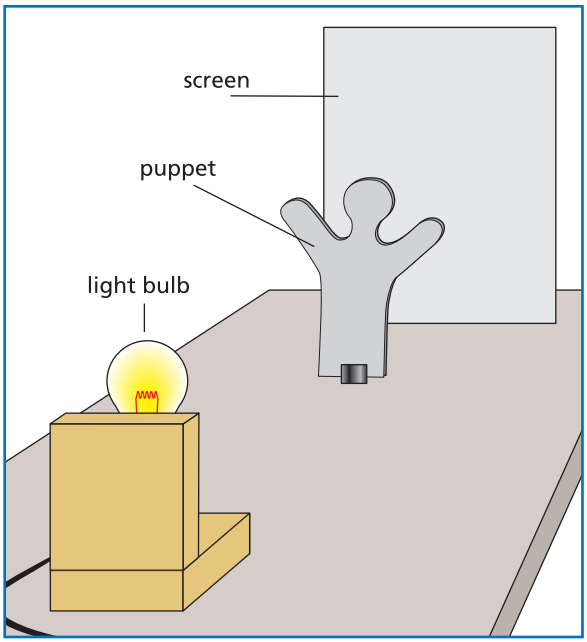
4. Carefully cut out a cardboard puppet that you will use to make shadows.
5. Turn on the white light bulb again. Use a white piece of cardboard as a screen. Move the puppet around between the light and the screen. Observe the shadow on the screen.

a) Describe the shadow you see.

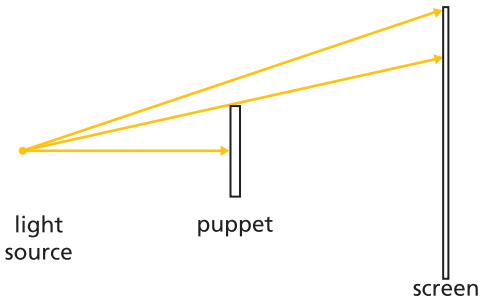
b) What happens to the shadow if you move the puppet sideways or up and down?

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.



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?

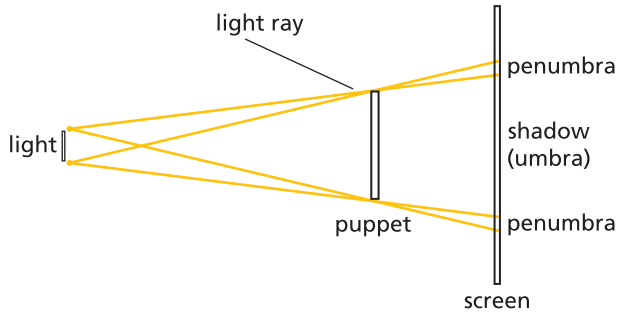
ii) Which part receives no light?

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*.

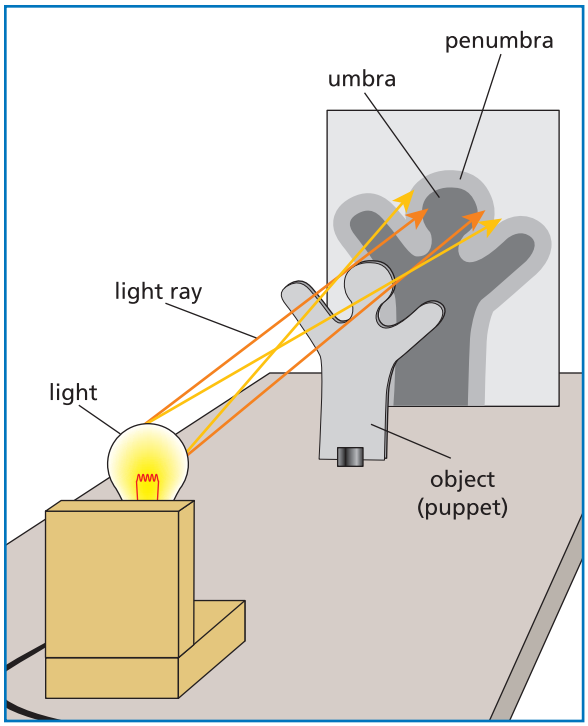
9. Explore the phenomenon of shadows further. Turn on the white light bulb. Move the puppet around in order to explore and observe the shadow on the screen.

a) Describe the shadow you see. Identify the *umbra* (full shadow) and *penumbra* (fuzzy shadow).

b) What happens to the shadow (the umbra and penumbra) if you move the puppet sideways or up and down?

c) What happens to the shadow (the umbra and penumbra) if you move the puppet close to the screen?

d) What happens to the shadow (the umbra and penumbra) if you move the puppet close to the light bulb?



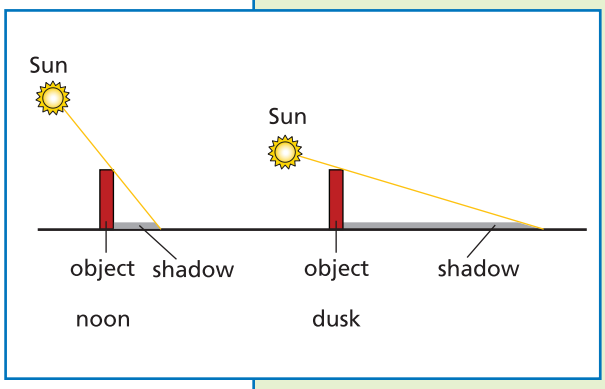
Physics Talk

SHADOWS

Light Travels in a Straight Line

In the *Investigate*, you noticed that the light bulb and the two holes in the cardboard must be in a straight line with your eye in order for you to see the light bulb. One model of light explains this by saying that the light bulb emits light rays. In order to see the light, the light ray must enter your eye. Since you can only see the light when the bulb, the two holes, and your eye are in a straight line, it appears that light must travel in a straight line. You may have seen a light from a laser or the Sun traveling in straight lines.

You also saw evidence that light travels in a straight line when you put a puppet in the path of the light rays from the light and the screen. A dark area appeared on the screen due to the absence of light. This dark area is the shadow of the puppet.



How Can a Shadow Change Length?

In the *Investigate*, you observed that the size of a shadow depends on the distances between the light source, the object, and the screen. You may have noticed that during the day, your shadow changes size. At noon, your shadow is small, while at dusk your shadow may be many, many times larger than you. This change in size occurs, not because the distances between the Sun, you and the ground change, but because the angle of the Sun changes.

This angle change is similar to changing the orientation of the screen. As you can see in the contrasting diagrams, the size of the shadow changes as the position of the Sun in the sky changes.

Umbra and Penumbra

Physics Words

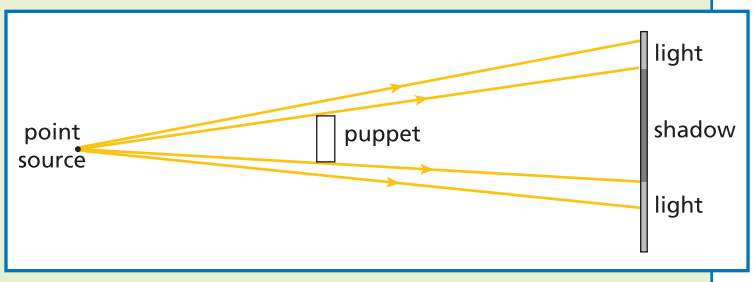
umbra: the part of the shadow that gets no light.

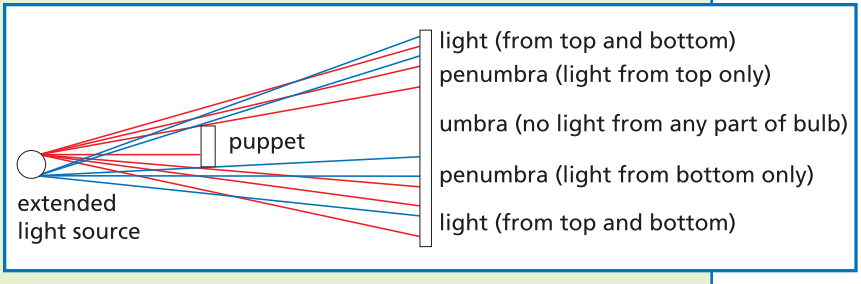
penumbra: the part of the shadow that gets partial light.

When shadows are formed by objects that obstruct light from light bulbs or from the Sun, the shadow has several parts. One part of the shadow gets no light at all from the light source. That area is called the **umbra** or full shadow. The outer part of the shadow gets some light from the light source but is not fully illuminated. That area, which makes the edge of the shadow look fuzzy, is called the **penumbra**, or partial shadow.

You can model the light and shadows using ray diagrams. Each ray signifies a bit of the light. When a point source of light emits light in all directions, the puppet will block some of the light, creating a dark shadow on the screen.

Since light bulbs are extended sources, not point sources, a set of rays emerges from all parts of the bulb. This produces a dark shadow (the umbra) and a gray shadow (penumbra). The penumbra gets light from some parts of the light but not from other parts.





Checking Up

1. How does light travel?
2. Explain how a dark shadow is formed.
3. What causes a shadow to be fuzzy?

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
◆	◆		

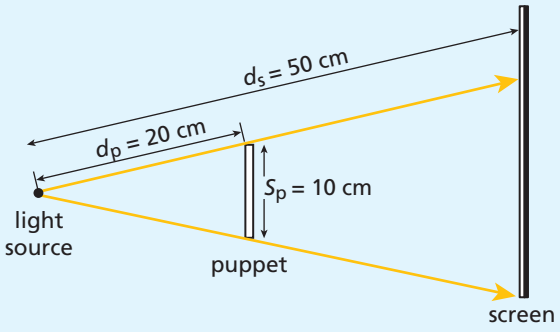
Predicting the Size of a Shadow

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.

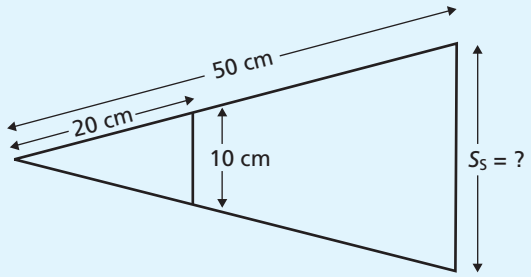
Sample Problem

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). The light bulb is 3 m from the closest side of the basketball. 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°. The rod is pivoted at its center, with the top tilted toward the light source.
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°. The screen is pivoted at its center, with the bottom tilted away from the light source.

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?

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.