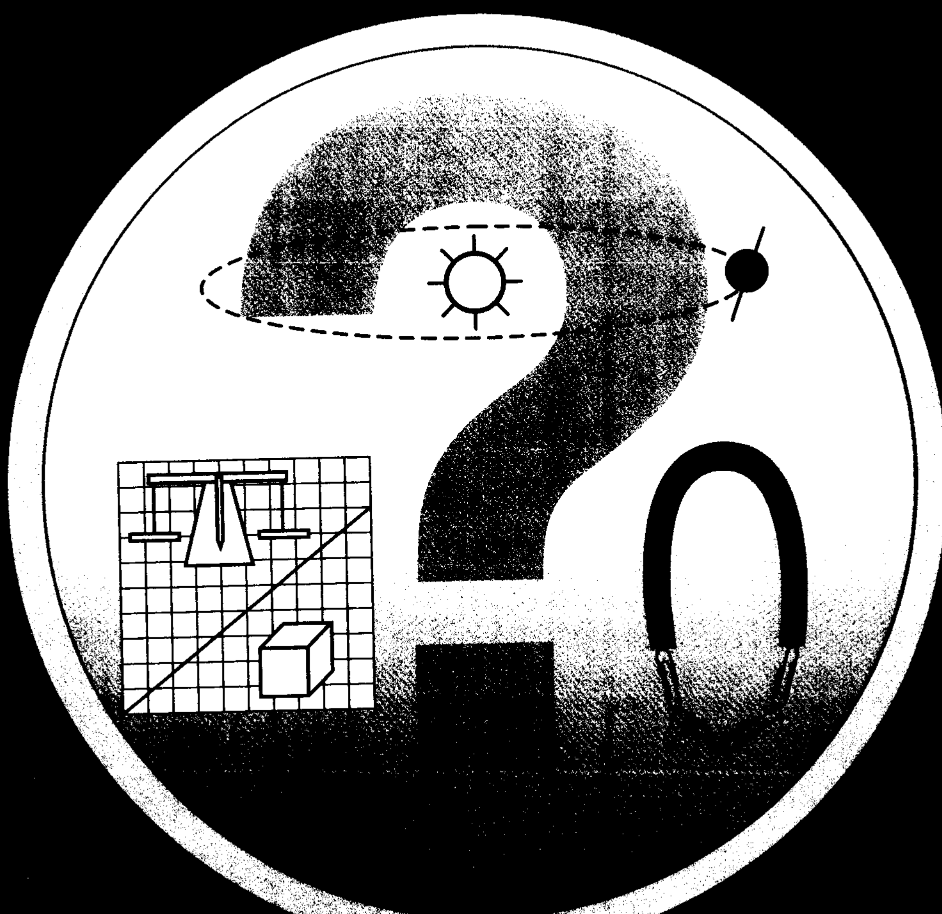
PHYSICS BY INQUIRY

Volume I



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and the
Physics Education Group at the University of Washington

Part A: Light and shadows

We begin our investigation of light by making observations using flashlights, masks, and screens. We use the ideas that we develop in this context to account for more complicated phenomena, such as the formation of images and shadows from extended sources.

Section 1. Introduction to light

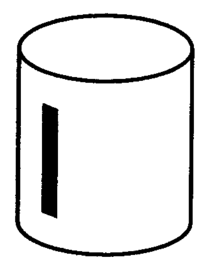
Experiment 1.1

This experiment should be performed in a darkened room.

You will need a small bulb, a socket, two batteries, connecting wires, and some black construction paper. A staff member can show you how to connect the bulb to two batteries in series so that the bulb shines brightly.

A. Look at the lighted bulb. Note that you can see it from many places.

Make a cover for the bulb, as shown at right, by rolling a piece of construction paper into a tube just large enough to fit over the socket. Cut a narrow slit in the paper (about 3 mm wide), then place the tube over the bulb. Place another piece of paper over the top of the tube.



Can you still see the bulb from many different places? If not, where must you place your eye to see the bulb?

Rotate the cover. Now where must you place your eye to see the bulb?

Draw a top view diagram (a picture of what someone would see when looking down from above) to show where you need to place your eye in order to see the bulb. Do this for at least two different positions of the slit.

Describe the arrangement of bulb, slit, and your eye that is necessary for you to be able to see the lighted bulb.

B. Obtain a chalkboard eraser that has chalk dust on it. Have your partner hold the eraser near the slit in the tube and strike the eraser several times with a ruler. What do you observe?

C. People often speak of a *beam* of light. Why do you think people use this word to describe light?

Experiment 1.2

This experiment should be performed in a darkened room.

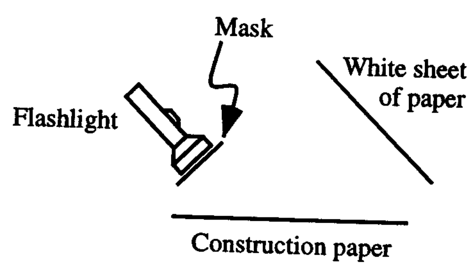
You will need several sheets of colored construction paper, a white sheet of paper, a flashlight, and a mask for the flashlight. Make the mask by cutting a small slit (approximately 25 mm long and 5 mm wide) in an index card or thick piece of paper. Tape the mask to the front of the flashlight.

A. Shine the flashlight through the mask onto various flat surfaces, including colored pieces of construction paper.

Describe what you observe as you vary the angle between the flashlight and the flat surfaces.

Compare what happens when you shine the flashlight on the following types of surfaces: dark-colored surfaces, light-colored surfaces, rough surfaces, and smooth surfaces. Try other types of surfaces as well. Describe the similarities and differences in the results when the different surfaces are used.

B. Hold a piece of white paper above a sheet of white construction paper as shown. Aim the flashlight at the construction paper, not at the white sheet of paper.



How does the appearance of the white paper that you are holding change when the flashlight is turned on and off? How might you account for your observations?

Leave the flashlight on and replace the white construction paper by a piece of red construction paper. Does this change make a difference in the appearance of the sheet of white paper you are holding?

Try other colors of construction paper. How does the color of the construction paper affect what you see on the white sheet of paper?

Experiment 1.3

A. Look at an unlighted bulb. Notice that even though the bulb is not lighted, you can still see it.

Suppose you took the bulb into a very dark closet. Would you still be able to see it? Explain.

B. Place the cover that you used in Experiment 1.1 over the unlighted bulb.

Where do you have to place your eye to see the bulb?

Use a flashlight with a mask to produce a beam of light.

How do you have to aim the flashlight to make the bulb inside the cover more easily visible?

C. When you are not aiming a flashlight at the bulb, does light from anywhere else strike the bulb? Explain.

✔ Discuss this experiment and Experiment 1.2 with a staff member.

Exercise 1.4

A. Consider the following statement by a student:

"At night it is dark, but during the day it is bright because the sun lights up objects. When objects are lit up I can see them."

Do you agree with the statement by this student? Would you change the statement in any way to make it more correct?

B. Summarize the conditions necessary for you to be able to see an object.

The observations that you have made thus far are consistent with the following way of thinking about light: An observer sees an object when light travels from that object to the observer's eye. In some cases, the object generates light (e.g., a lighted bulb, the sun, etc.). In other cases, the object (e.g., an unlighted bulb, a piece of paper, etc.) cannot be seen unless it is illuminated by light from another source. Light from the source reaches the object and then travels from the object to the observer's eye. We say that light from the source is *reflected* from the object.

Exercise 1.5

A. Discuss how the experiments that you have performed thus far are consistent with the way of thinking about the motion of light outlined above. Give specific examples.

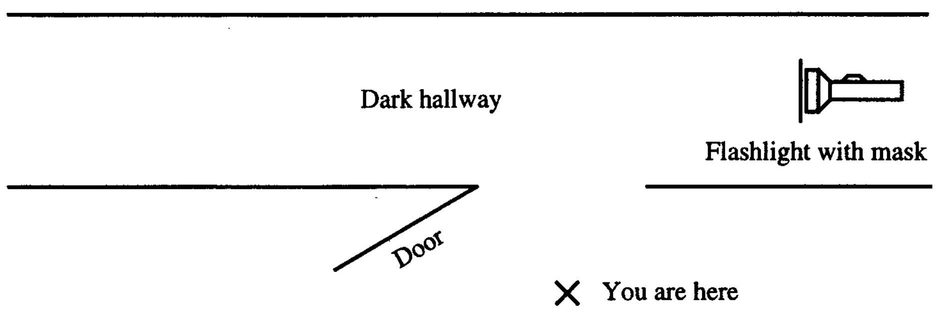
B. Examine your responses to Exercise 1.4. Do you still agree with your answers to that exercise? If not, modify your answers to make them more complete.

C. In Experiments 1.1 and 1.3 you were able to see the bulb both when it was lighted and when it was not. Describe, both in words and in a diagram, the path that light follows in each of these two cases. On your diagram, use an arrow to indicate the direction that light moves along the path.

Experiment 1.6

Imagine that your partner is in a dark hallway, and you are by a doorway that enters into the hall. You are facing the hallway and no other lights are on. Your partner aims a flashlight with a mask at the far end of the hall.

Would you be able to tell whether the flashlight is on or off? If so, how could you tell? What would you see? If not, explain why not.



Discuss your ideas with your partner, then carry out the experiment, if possible. If your prediction was incorrect, try to resolve any inconsistencies.

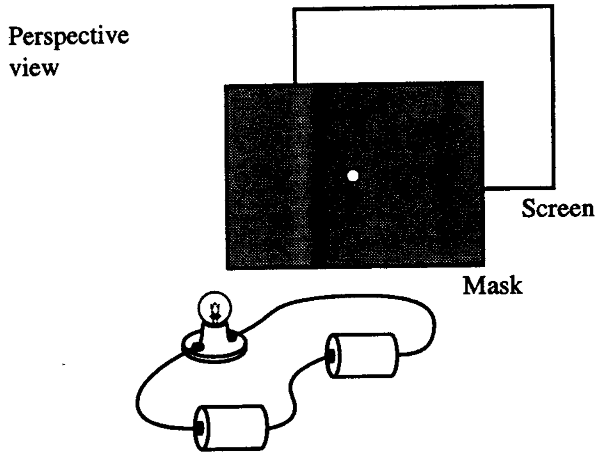
✔ Discuss this experiment and the preceding exercise with a staff member.

Section 2. Light sources, masks, and screens

Experiment 2.1

This experiment should be performed in a darkened room.

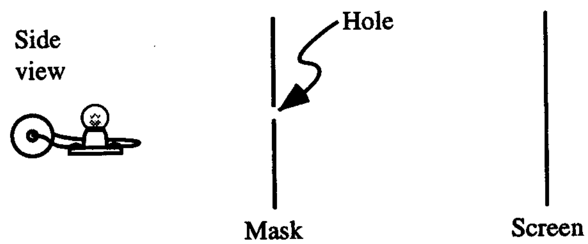
A small bulb, a screen made of white paper, and a mask are arranged as shown. The mask is a sheet of paper with a hole in it that is about 3 mm wide.



A. Predict what you will see on the screen when the bulb is lighted. Explain.

Set up the equipment and check your prediction.

B. Predict how what you see on the screen would change if the bulb were moved upward, downward, or side to side. Explain.



Check your predictions.

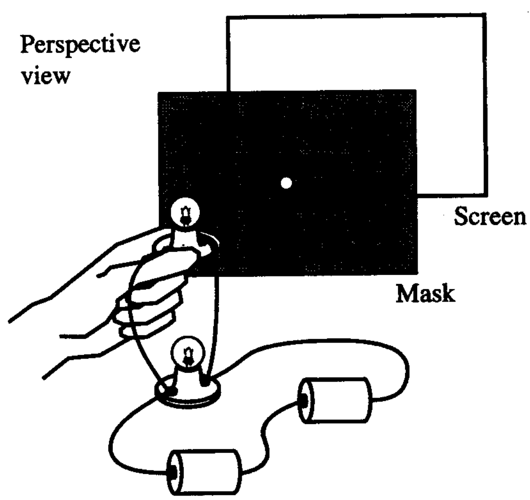
How does the direction that the bright spot moves compare to the direction that the bulb moves?

Draw a diagram to account for what you observe.

C. Predict how placing a second bulb above the first would affect what you see on the screen.

Predict how moving the top bulb upward slightly would affect what you see on the screen.

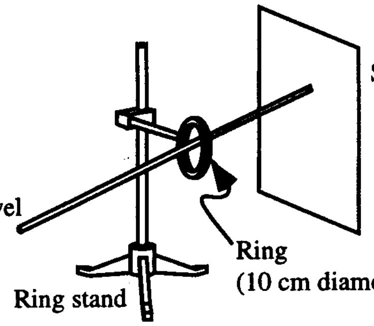
Check your predictions.



D. What do your observations suggest about the path taken by light from the bulb to the screen?

Experiment 2.2

Set up the apparatus shown at right. You will need a long dowel, a ring stand, and a ring that is about 10 cm in diameter.



Demonstrate how you can use this apparatus to help you account for some of the observations that you made in the preceding experiment. The ring represents the hole in the mask.

What did you use the dowel to represent? What property of the dowel makes it a suitable choice for this role?

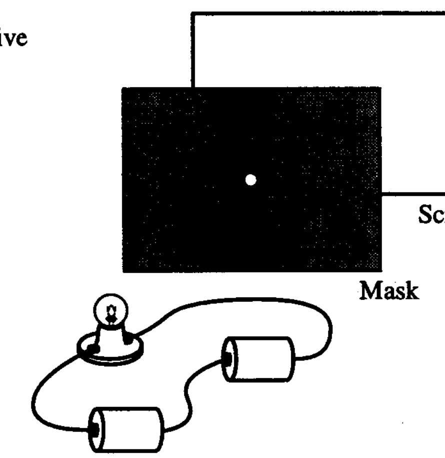
✔ Discuss this experiment and Experiment 2.1 with a staff member.

Experiment 2.3

This experiment should be performed in a darkened room.

In this experiment, you will be asked to make several predictions. If you find that your predictions are incorrect, try to resolve the inconsistencies in your explanation before continuing to the next prediction.

A mask with a circular hole is placed between a small lighted bulb and a screen as shown.



Predict how each of the following changes would affect what you see on the screen. Explain your reasoning and include sketches that support your predictions.

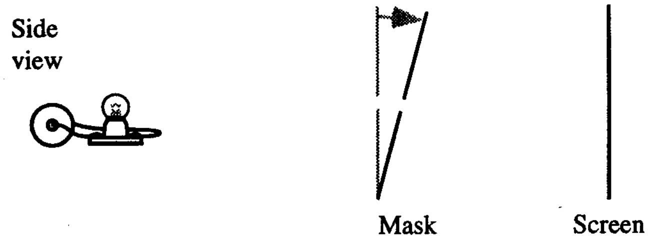
A. The bulb is moved *farther* from the mask.

Check your prediction.

B. The mask is replaced by a mask with a *triangular* hole.

Check your prediction.

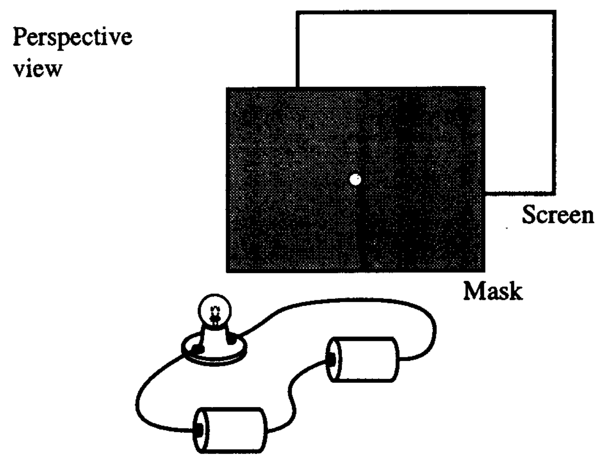
C. The mask is tilted toward the screen as shown in the side view diagram below.



Check your prediction.

Experiment 2.4

A small bulb is placed 10 cm from a mask with a hole that is 4 cm in diameter. The mask is 15 cm from a screen. The bulb is centered on the hole in the mask.



A. On a piece of graph paper, draw a careful life-size diagram to illustrate this physical situation.

Which of the following types of diagrams do you think will be most useful in helping you to determine the size of the bright region of the screen: a perspective view, a top view, or a side view? Explain.

Since the filament of the bulb is small, you can draw it as a dot. A source of light that is represented as a dot on a diagram is often called a *point source* of light. In this module, treat small bulbs as point sources.

From your diagram, measure the height of the bright region on the screen.

B. Your diagram should contain two triangles: The vertices (corners) of the larger triangle are located at the bulb and at the top and bottom of the bright region on the screen. The vertices of the smaller triangle are located at the bulb and at the top and bottom of the hole in the mask. Outline both triangles on your sketch.

Which features of these triangles are the same and which features are different?

(1) Measure the length of one side of the larger triangle and the length of the corresponding side of the smaller triangle. Calculate the following ratio of the two lengths:

$$\frac{\text{length of side on larger triangle}}{\text{length of corresponding side on smaller triangle}}$$

Make the same calculation as above for each of the two remaining sides of the triangles.

Are the three ratios essentially the same or are they different?

(2) Compare the angles in the two triangles.

How do the corresponding angles of the triangles compare?

What is the ratio of corresponding angles in the two triangles?

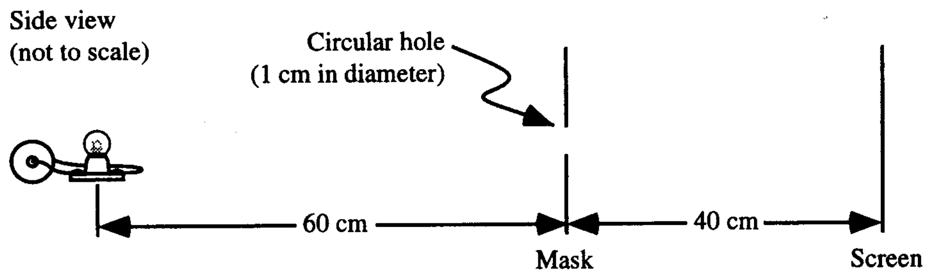
C. Triangles such as the two that you have drawn, where one is a scaled version of the other, are called *similar triangles.*

Suppose that you were given two triangles. Describe a method by which you could determine whether or not the triangles are similar.

It is not always possible to make a full-size diagram of a physical setup. For example, if a bulb and screen are very far apart, it may be necessary to make a sketch that is smaller than life-size. A diagram in which each distance is shown reduced or enlarged by the same multiplicative factor is called a *scale diagram.*

Experiment 2.5

A bulb is placed in front of a mask and screen as shown below.



A. Use the properties of similar triangles to write an equation that you can use to determine the height, *h*, of the bright region on the screen.

Calculate *h*. What are the units of *h?*

Is the height of the bright region on the screen greater than, less than, or equal to the diameter of the hole in the mask? Explain how you can tell from your equation and how you can tell from the diagram.

Set up the apparatus and check your prediction for the height of the bright region on the screen.

B. Write an equation for the height, *h*, of the bright region on the screen in terms of the diameter, *d*, of the hole in the mask.

Check your equation by substituting 1 cm for the diameter of the hole. You should obtain the same answer as in part A.

Suppose that the diameter of the hole in the mask were doubled.

Would the height of the bright region on the screen also double? Explain how can you tell from your equation.

C. Compare the following ratios without making any measurements:

$$\frac{\text{height of bright region on the screen}}{\text{distance from bulb to screen}} \quad \text{and} \quad \frac{\text{height of hole in mask}}{\text{distance from bulb to mask}}$$

D. Suppose the following changes are made to the mask above. In each case, make a rough sketch, and decide whether or not you can use the idea of similar triangles to find the size of the bright region on the screen.

(1) The mask is raised so that the bulb is not even with the center of the hole in the mask.

(2) The top of the mask is tilted toward the screen (as in part C of Experiment 2.3).

Exercise 2.6

A mask with a small circular hole is placed between a bulb and a screen. The hole is 5 cm in diameter. The mask is 45 cm from the bulb and 60 cm from the screen.

Determine the size of the lit area on the screen. Explain your reasoning.

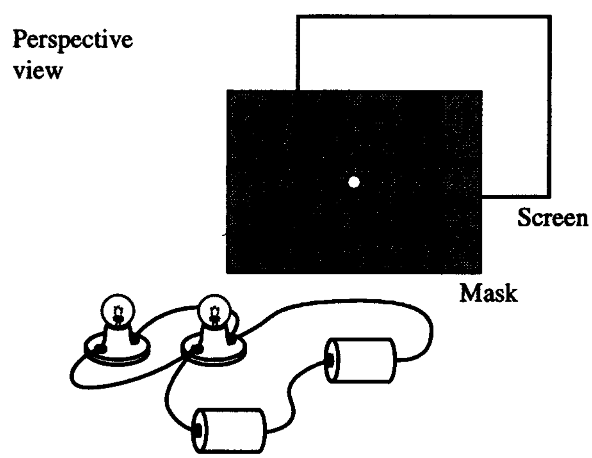
✔ Discuss this experiment and Experiment 2.5 with a staff member.

Experiment 2.5 and Exercise 2.6 illustrate how an understanding of the properties of similar triangles can allow us to calculate quantities without having to measure them in real life or from a sketch. Even so, it is often still useful to make a sketch of the physical situation. To be useful, however, the sketch must be accurate enough to show which triangles, if any, are similar.

Experiment 2.7

This experiment should be performed in a darkened room.

A mask is placed between two small bulbs and a screen as shown.



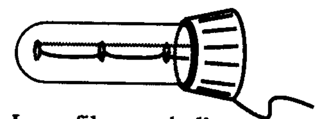
A. Predict what you would see on the screen. Explain your reasoning.

Set up the apparatus, and check your prediction.

B. Predict what you would see on the screen if you were to add a third bulb in line with the other two bulbs.

Check your prediction.

C. Predict what you would see on the screen if you were to replace the three small bulbs by a long filament bulb. Explain your reasoning.



Obtain a bulb with a long filament and check your prediction.

Describe how your observation is consistent with the idea that we can consider a long filament bulb as a string of closely spaced small bulbs.

D. Predict what you would see on the screen when two long filament bulbs are arranged to form a T-shaped light source. Use a diagram to help explain your prediction.

Check your prediction. Draw a side view diagram and a top view diagram to account for your observation.

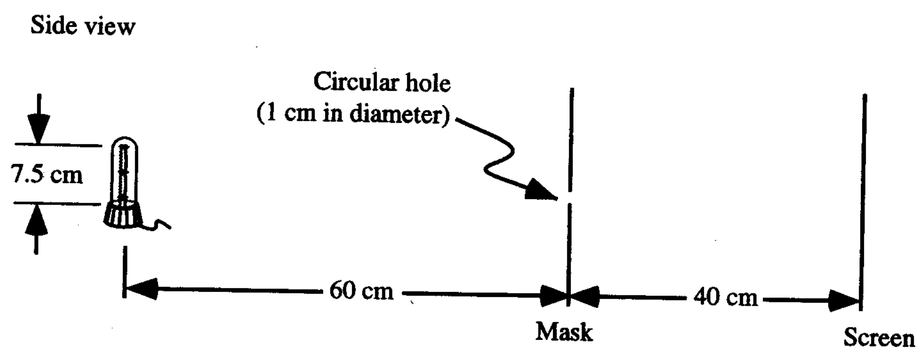
E. Predict what you would see on the screen when two long filament bulbs are arranged to form an L-shaped light source. Use a diagram to help explain your prediction.

Check your prediction. Draw a side view diagram and a top view diagram to account for your observation.

✔ Discuss your results with a staff member.

Experiment 2.8

Consider the situation pictured below. Except for the hole in the mask, the diagram has been drawn to scale.



A. Sketch a diagram illustrating the approximate size of the lit area on the screen. Explain your reasoning.

B. If the diameter of the hole in the mask were halved, would the height of the lit area on the screen also become half as tall? Explain your reasoning both in words and with a sketch.

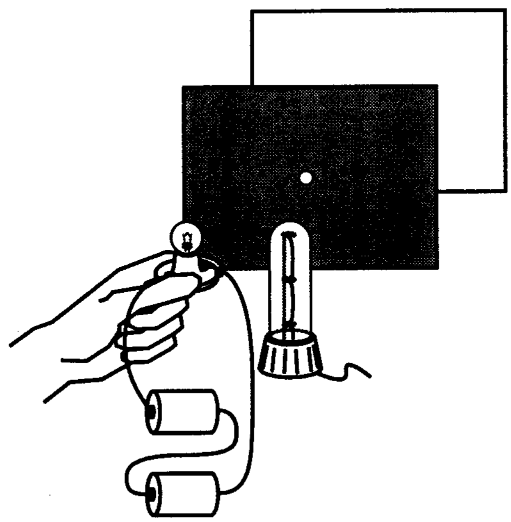
Check your prediction. If your prediction was incorrect, resolve the inconsistency.

C. If the hole were very small, say the size of a pinhole, would the lit region on the screen be taller than, shorter than, or the same height as the filament? Draw a diagram that supports your prediction.

Determine the exact height of the lit region on the screen in this case. (*Hint:* Use the idea of similar triangles developed in Experiment 2.5 and Exercise 2.6.)

Check your prediction.

D. Sketch what you think you would see on the screen when both a small bulb and a long filament bulb are held in front of the mask as shown below. The bulbs are the same distance from the mask and the bulb is held level with the top of the long filament bulb.



If the diameter of the hole in the mask were halved, would the *height* of each bright region on the screen also halve? Explain your reasoning.

If the diameter of the hole in the mask were halved, would the *width* of each bright region on the screen also halve? Explain your reasoning.

Check your predictions. If any of your predictions were incorrect, resolve the inconsistency.

✔ Discuss your results with a staff member.

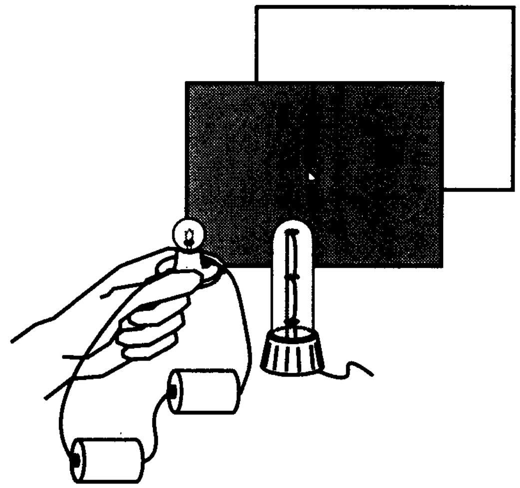
Experiment 2.9

This experiment should be performed in a darkened room.

In this experiment, you will be making several predictions. If you find that your predictions are incorrect, try to find the error in your explanation before continuing to the next prediction.

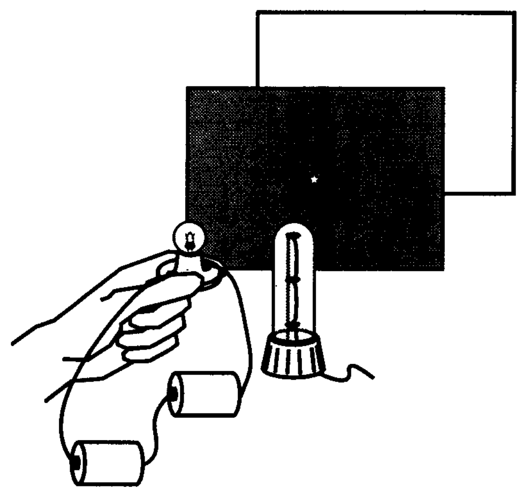
A. Predict what you would see on the screen when a small bulb is held near the top of a long filament bulb, and both are held in front of a mask with a *triangular* hole as shown at right. Explain your reasoning.

   Check your prediction.



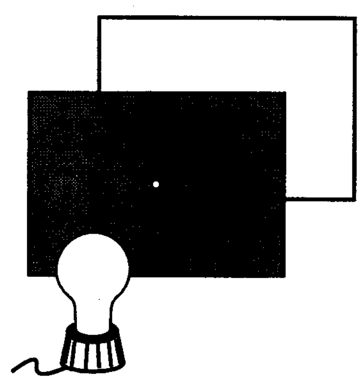
B. Predict what you would see on the screen if instead the hole in the mask were star-shaped. Explain your reasoning.

   Check your prediction.



C. Predict what you would see on the screen if an ordinary frosted bulb were placed in front of a mask with a circular hole. Explain.

   Check your prediction.

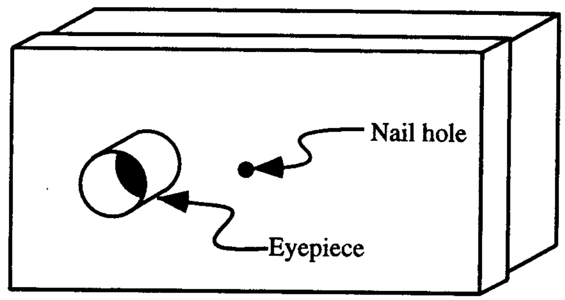


Section 3. Pinhole cameras

The ideas developed in the preceding sections can be used as the basis for explaining many phenomena involving light. In this section, we apply these ideas to help us understand a simple type of camera.

Experiment 3.1

For this experiment you will need a box about the size of a shoe box, a knife, some tape, a pair of scissors, and a piece of cardboard tubing about 3 cm long.



A. On one of the largest sides of the box, cut a hole for an eyepiece. The hole should be off-center as shown. Make the hole small enough that the cardboard tube fits snugly inside. Secure the tube in the hole with about one-half centimeter of the tube extending into the box.

Inside the box, on the wall opposite the hole, tape a piece of plain white paper. The paper should cover the entire side of the box.

The box should not have any holes other than the one that you just cut; it must be completely dark inside when the eyepiece is covered. To check the box for holes, hold the eyepiece to one of your eyes and cup your hands around that eye to block light from the sides. Then close your other eye and peer into the box. Wait a few moments for your eye to adjust to the darkness. If the inside of the box is lit, find the holes and cover them with black tape.

On the same side of the box as the eyepiece, use a nail to punch a hole about 4 cm from the eyepiece. Make the edges of the nail hole as smooth as possible.

B. Stand with your back to a window or another bright spot in the room. Look into the box through the eyepiece. You may need to cup your hands around your eye to block the light from the sides. Describe what you see in the box.

Note: Wait a few moments to allow your eyes to adjust to the darkness. If you do not see anything, move the box slightly from side to side or ask your partner to help block the light on the sides of your eye. If you still do not see anything, ask the staff for help.

C. Move toward and away from the object that you are viewing with the box.

    How does changing your distance from what you are viewing affect what you see inside your box?

D. Make two more holes close to the first nail hole: one larger than the original hole; the other, smaller.

    Use your fingers to cover two of the three holes and view an object with the box. Then repeat twice more, each time leaving a different hole uncovered.

    How does the size of the uncovered nail hole affect what you see inside the box?

The device you constructed in the preceding experiment is called a *pinhole camera.*

The "picture" you observed on the side of the box opposite the hole is called an *image.*

In the following experiments, we examine how an image is formed in a pinhole camera.

Experiment 3.2

This experiment should be performed in a darkened room.

A. Use tape to cover all but one of the holes in your pinhole camera. View a small lighted bulb through your pinhole camera.

    Describe what you observe.

B. Predict how the bright spot in your pinhole camera would change if the bulb were moved upward, downward, or side to side. Check your predictions.

    How does the direction that the light spot moves compare to the direction that the bulb moves?

    Have your partner move the bulb while you are viewing it in your pinhole camera. Try to infer the direction in which your partner is moving the bulb.

    Draw diagram(s) to account for your observations.

C. Predict how the image in your pinhole camera would change if the light bulb were moved toward or away from the pinhole camera. Check your predictions.

    Draw diagram(s) to account for your observations.

Experiment 3.3

This experiment should be performed in a darkened room.

A. Set up two small bulbs side by side on a table. Predict what you will see when you look at the bulbs through your pinhole camera, then check your prediction.

B. Replace the two small bulbs by a long-filament bulb. Predict what you will see when you look at the long-filament bulb through your pinhole camera. Check your prediction.

Imagine that the long filament bulb is oriented vertically. Predict what you would see in the box if your partner were to cover the top half of the long filament bulb. Check your prediction.

C. For this part of the experiment, you will need an overhead projector to project a large lighted area in the shape of the letter *L* on the wall.

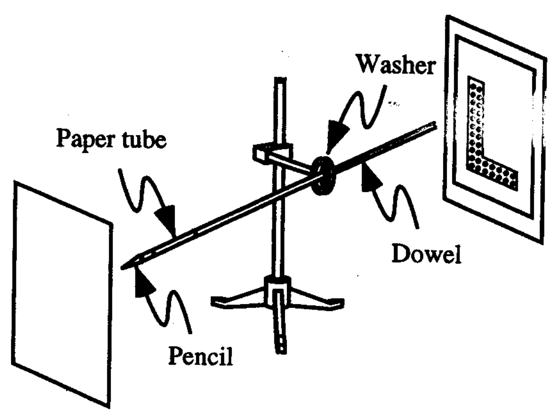
Sketch what you think you will see inside your pinhole camera when you view the letter *L* through your pinhole camera. Explain your reasoning.

Check your prediction.

How does the image in your camera differ from what is projected on the wall? Use the ideas that you have developed thus far to account for any differences.

✔ Explain your reasoning to a staff member.

Experiment 3.4



The equipment you used in Experiment 2.2 can help you to visualize how a pinhole camera works. Set up a ring stand, a washer and a dowel as shown. The diameter of the dowel should be slightly less than that of the washer.

Fasten a pencil to the dowel by wrapping paper around both the dowel and the pencil and then taping the paper to the dowel. The pencil should slide freely in and out of the paper tube.

Draw a large letter *L* on a sheet of paper. Tape the *L* and a blank sheet of paper to pieces of cardboard. Support each piece of cardboard vertically in the locations shown.

We can imagine that the *L* is made up of many small dots, spaced very close to one another. Draw some dots on your letter *L* as shown.

A. Hold the end of the dowel without the pencil in the middle of one of the dots in the *L*. While holding that end in place, mark the blank piece of paper with the pencil. Make the mark as large as the hole in the washer allows.

   Predict the shape you will obtain after making a mark on the blank paper for each of the dots on the pattern. Sketch your prediction. Check your answer by repeating the procedure above for each of the dots that make up the *L*.

   How does the orientation of the diagram that you generated compare to the orientation of the original diagram?

B. Describe how the activity you performed in part A of this experiment can help you to account for the observations you made while using the pinhole camera in part C of the preceding experiment.

C. Predict how the "image" that you generated in part A would change if the paper containing the original pattern were moved closer to the ring stand and washer.

   What would be the analogous change for someone looking at an image in a pinhole camera?

   Check your prediction using a pinhole camera and the projection of a transparency of the letter *L*.

D. Predict how the diagram that you generated in part A would change if the size of the washer hole were enlarged.

   What would be the analogous change for someone looking at an image in a pinhole camera?

   Check your prediction by replacing the washer by one with a larger hole and repeating the procedure of part A.

✔ Discuss this experiment with a staff member.

Experiment 3.5

This experiment should be performed in a darkened room.

Obtain transparencies of various letters and words from your instructor. Use an overhead projector to project the transparencies on a wall or screen.

A. Project one of the transparencies and predict what you would see in the camera when looking at the projection. Explain your reasoning. Draw a sketch of your prediction, then check your answer.

B. Look in your pinhole camera and have your partner project a different transparency for you. Try to determine what is being projected on the wall only on the basis of what you see in your camera.

C. View one of the projected letters through your pinhole camera. Change the size of the hole in the camera and describe how the image changes. Explain this effect using the ideas about light that you have developed thus far. (See part D of Experiment 3.4.)

D. Look at a building or other large object in your camera. Explain the formation of the image using the ideas about light that you have developed thus far.

Section 4. Shadows

Experiment 4.1

This experiment should be performed in a darkened room.

A. Place a nail on its head so it stands upright on your table. (A small piece of clay will hold the nail in place.) Use a small lighted bulb to cast a shadow of the nail on a sheet of white paper held vertically behind the nail. Experiment with the equipment as you try to answer the following questions:

(1) How can you make the shadow of the nail larger? How can you make the shadow smaller? What factors affect the size of the shadow?

(2) Does the shadow "fill up" space in the way that a light beam does, or is it a flat thing? Would it make sense to speak of a "shadow beam" as we speak of a light beam?

(3) Can an object have more than one shadow? If so, describe the circumstances under which it can have more than one. If not, explain why it cannot.

B. Place the sheet of paper underneath the nail and hold the bulb above the table so that the shadow is on the paper.

What factors affect the shape and size of the shadow now?

Experiment 4.2

This experiment should be performed in a darkened room.

A. Imagine that a small light bulb is placed 8 cm from a nail and a vertical screen is placed 15 cm beyond the nail. Let h represent the height of the nail. Draw a scale diagram of this arrangement and predict the length of the shadow of the nail.

Set up the equipment and check your prediction.

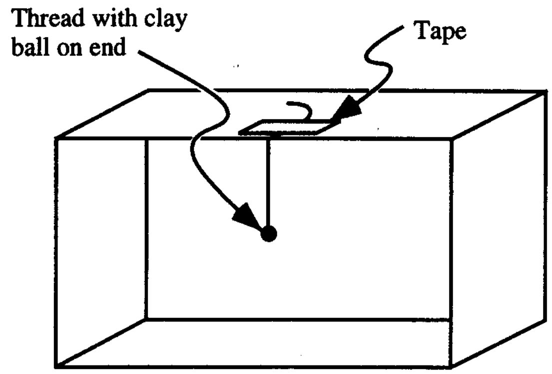
B. Suppose the bulb is held 20 cm above the tabletop and 15 cm horizontally from the nail. Predict the length of the shadow that is cast on the table by the nail.

Set up the equipment and check your prediction.

✔ Check your results with a staff member.

Experiment 4.3

In this experiment, you will make a shadow box. You will need clay, thread, tape, white paper, and a box with a removable lid (or flaps that can be folded out of the way or removed). If you are working near a window, turn your box so that the open side of the box faces away from the window.



Tape white paper to the back of the box to serve as a screen. Suspend a small ball of clay, about 1 cm in diameter, from thread as shown below.

This experiment should be performed in a darkened room.

A. Hold a small lighted bulb in front of the clay ball.

Describe what you observe. Draw a diagram to help you account for your observation.

B. For each of the following situations, first predict how the shadow will change, then check your prediction. Use diagrams and the ideas developed thus far to explain your predictions and observations.

(1) The clay ball is made larger.

(2) The clay ball is made smaller.

(3) The clay is formed into a triangular shape.

C. Sketch what you expect to see on the screen at the back of the box if two small lighted bulbs are held side-by-side in front of the ball.

How do you expect what you see on the screen to change as the bulbs are moved closer together? Explain.

Check your predictions and try to resolve any inconsistencies.

D. Discuss the following student's statement.

"A shadow is formed when no light reaches a certain portion of a screen or wall."

✔ Discuss your results with a staff member.

Experiment 4.4

Perform this experiment in a darkened room. You will need a long filament bulb and a shadow box with a clay ball about 1 cm in diameter.

A. *Predict* what you would see in the box if the long filament bulb were held vertically in front of the clay ball. Explain your reasoning.

Check your prediction. Try to resolve any inconsistencies between your prediction and observation.

B. *Predict* how the shadow would change if the long filament bulb were brought closer to the clay ball. How would the shadow change if the bulb were moved farther from the clay ball?

Check your predictions. Draw a diagram to help explain your observations.

C. Use your hand or a piece of dark paper to cover the top half of the long filament bulb.

How does the shadow change? How can you account for your observations?

D. In Section 2, we treated the long filament bulb as though it consisted of a line of point sources. Explain how that idea can be used to explain your observations in this experiment.

Experiment 4.5

Perform this experiment in a darkened room. In this experiment, you will be making several predictions. If you find that a prediction is incorrect, try to resolve any inconsistencies before continuing to the next prediction.

A. *Predict* what you will see in your shadow box when two long filament bulbs are used to make a T-shaped light source. Use diagrams to explain your prediction.

Check your prediction.

B. *Predict* what you will see in your shadow box when two long filament bulbs are used to make an L-shaped light source.

Check your prediction.

C. *Predict* what you will see in your shadow box when the clay is made into a triangular shape (the light source is still L-shaped).

Check your prediction. If your prediction is incorrect, try to resolve the inconsistency.

✔ Discuss your results with a staff member.

Part B: Pigments and colored light

In Part B of this module, we conduct experiments with colored paints and colored light. We determine how to mix paints of different colors to obtain a particular color of paint and how to combine light of different colors to obtain a particular color of light. On the basis of our observations, we construct a model that helps us to predict the color an object will be when viewed under light of different colors.

Section 5. Pigments

Experiment 5.1

Obtain a large sheet of paper, a paintbrush, a container of water, and the following colors of paint: blue, cyan (turquoise), green, magenta (purplish-pink), red, and yellow. Before you begin the experiment, make sure that you can associate each color with its name.

A. Explore what happens when you mix two or more colors together. Record your results. Experiment with mixing the colors in various proportions. Continue to mix paints until you know the color that will result when you mix any two colors. (You may find it useful to make a table to record your results.)

B. Can you make a mixture of two of your original colors that is the same color as one of the other colors that you were given?

   Is it possible to reproduce each of your original colors by mixing two of the other colors? Make a list of those that you can reproduce and another list of those that you cannot.

C. How can you make gray or black from the colors you have been given?

   Can you make gray or black by mixing only two colors of paint? If so, how?

D. What is the smallest number of different paint colors that you would need to make all of the other colors that you have been given? Which colors could you use?

