Section 6 Reflected Light

What Do You See?

Learning Outcomes

In this section, you will

- **Observe** the reflection of light by a mirror.
- **Identify** the normal of a plane mirror.
- **Measure** angles of incidence and reflection for a plane mirror.
- **Collect** evidence for the relationship between the angle of incidence and the angle of reflection for a plane mirror.
- **Observe** changes in the reflections of letters.
- **Identify** patterns in multiple reflections.

What Do You Think?

Astronauts placed a mirror on the Moon in 1969 so that a light beam sent from Earth could be reflected back to Earth. By timing the return of the beam, scientists found the distance between Earth and the Moon. They measured this distance to within 30 cm.

- **How are you able to see yourself in a mirror?**
- **If you want to see more of yourself in the mirror, what can you do?**

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 section, you will investigate the reflection of light from a plane mirror. You will also make measurements to find the relationship between the angle of incidence and angle of reflection.

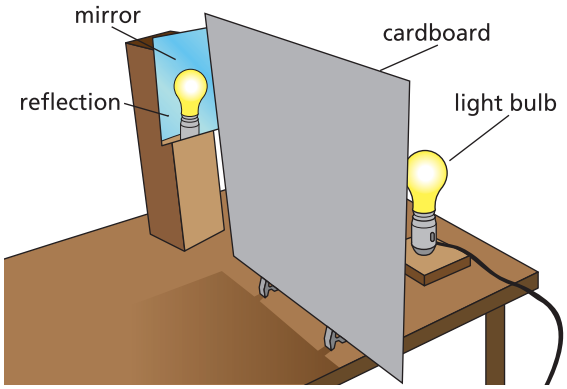
1. Look at your face in a small mirror. Keeping the mirror vertical and close to your face, note how much of your face you can see (for example, from your eyebrows to the top of your lips).

   a) Predict what will happen if you move the mirror further from your face.

b) Observe how much of your face you can see with your arm extended and record your findings.

2. Arrange a large piece of cardboard between you and a light bulb on a table, as shown in the diagram, so you cannot see the light bulb directly.

3. Carefully stand a plane mirror on the table. Then adjust the mirror so that you can see the light bulb.

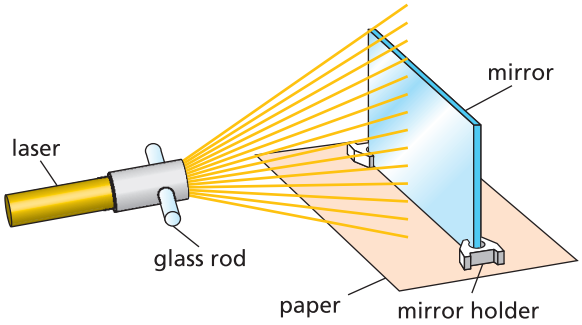


a) Where does the image of the light bulb appear to be located?

b) Place a pencil where the image appears to be. Do all members in your group agree on this location? Record the position of the pencil.

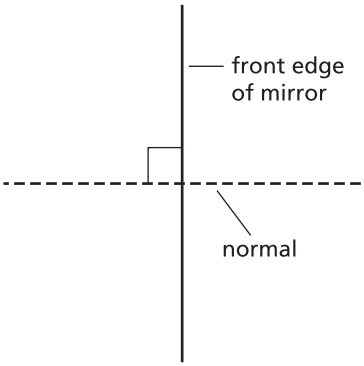
Do not use mirrors with chipped edges. Make sure the ends of the glass rod are polished.

4. Place a piece of paper on your desk. Carefully aim a laser pointer, or the light from a ray box, so the light beam moves horizontally, as shown in the diagram. If you are using a laser, place a glass rod in the path of the light beam so that the beam spreads up and down. The glass rod can be fixed to the laser temporarily with masking tape or by constructing a cylinder that slides over the end of the laser and has two holes in the side for the glass rod. (A small sleeve with two holes is placed around the tip of the laser. The glass rod is inserted through the two holes.)



Never look directly at a laser beam or shine a laser beam into someone's eyes. Always work above the plane of the beam and beware of reflections from shiny surfaces.

5. Carefully stand the plane mirror on your desk in the middle of the piece of paper. It can be held in place with a mirror holder or modeling clay. Draw a line on the paper along the front edge of the mirror. Now remove the mirror and draw a dotted line perpendicular to the first line, as shown, crossing the middle of the first line. In geometry this dotted line is called the *normal*, which means the same as the perpendicular line.



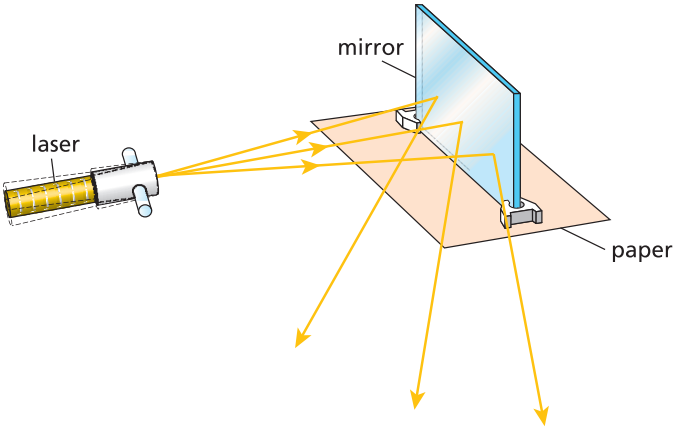
6. Aim the light source so the beam approaches the mirror along the normal. Be sure the glass rod is in place to spread out the beam.

a) What happens to the light after it hits the mirror?

7. Keeping the output end of the light source at the same point, tilt the light source so that the light hits the mirror at a different angle.

a) What happens to the light beam?

b) On the paper, mark three or more dots under the beam to show the direction of the beam as it travels to the mirror. Connect these dots with a ruler and extend the line up to the mirror surface. The line you traced is called the *incident ray*. Also make dots to show the light ray going away from the mirror. This line is called the *reflected ray*. Label this pair of lines to show they go together. Draw the *normal* line where these rays touch the mirror.

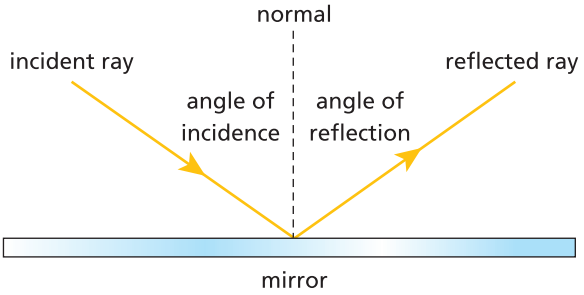


8. Repeat *Step 7* for several different angles.

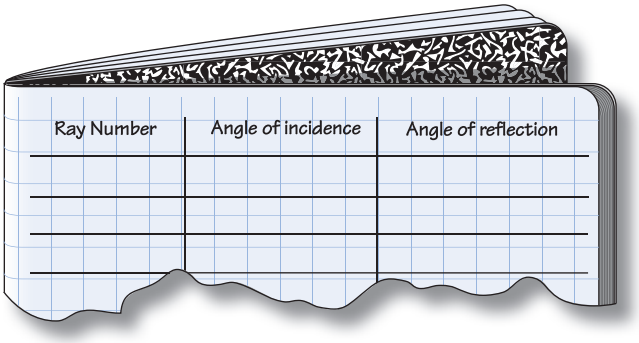
a) For each angle, mark dots on the paper to show the direction of the incident and reflected rays. Also, label each pair of rays. Describe how the direction of the reflected ray changes when you change the direction of the incident ray.

9. Turn off the light source and remove the paper. Look at one pair of rays. Your mirror may have the reflecting surface on the back of the glass. If so, the light bends as it enters and leaves the glass part of the mirror. In your drawing, the incident and reflected rays may not meet on the line drawn at the mirror surface.

The following diagram shows a top view of the mirror, the normal, and an incident and reflected ray. Notice the *angle of incidence*, the angle formed between an incident ray and the normal, and the *angle of reflection*, the angle formed between a reflected ray and the normal in the drawing.



a) Using a protractor, measure the angles of incidence and reflection for all of your pairs of rays. Record your data in your log in a table similar to the following.



Ray Number	Angle of incidence	Angle of reflection

b) What is the relationship between the angles of incidence and reflection?

c) Look at the reflected rays in your drawing. Extend each reflected ray back behind the mirror. What do you notice when you have extended all the rays? The position where the rays meet (at least approximately) is the location of the image of the light source. All of the light rays leave the light source at one point in front of the mirror. The reflected rays all seem to emerge from one point behind the mirror. If you observed the reflected light, you would see the image of the light source at this point behind the mirror.

d) Tape a copy of your diagram in your log.

10. Hold the light source, or some other object, near the mirror and look at the image of the object reflected in the mirror. Now hold the object far away and again look at the reflection.

a) How is the size of the image related to the size of the object?

b) Since things far away appear smaller to your eyes, how does the position of the image appear to change as the object is moved away from the mirror?

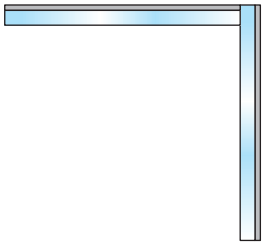
11. Set up a mirror on another piece of paper, and draw the normal to the mirror on the paper. Print your name in block capital letters along the normal (the line perpendicular to the mirror). Observe the reflection of your name in the mirror.

a) How can you explain the reflection you see?

b) Which letters in the image are closest to the mirror? Which are farthest away?

c) In your log, make a sketch of your name and its reflected image.

12. Carefully stand up two flat mirrors so they meet at a right angle. Be sure they touch each other, as shown.



13. Place an object in front of the mirrors.

a) How many images do you see?

b) Slowly change the angle between the mirrors. Make a general statement about how the number of images you see changes as the angle between the mirrors changes.

Physics Talk

REFLECTION OF IMAGES IN A PLANE MIRROR

Locating an Image in a Plane Mirror

People look in a mirror every day, yet few people know how a mirror works. Most people think that if they step away from a mirror that they will see more of themselves. Your investigation disproved this. As the mirror was moved farther from your face, you could not see any more of your face (unless you tilted the mirror).

Mirrors are important for many reasons. They are used in personal grooming and are also used in automobile safety, telescopes, cameras, CD players, and many more technologies.

Understanding mirrors begins with an understanding that when a light ray hits a mirror, the **angle of incidence** is equal to the **angle of reflection**. You observed this in the investigation. The ray of light that strikes a surface is called the **incident ray**, while the ray of light that reflects off a surface is called the **reflected ray.**

The angle of incidence and angle of reflection are shown in the diagram at the top of the next page.

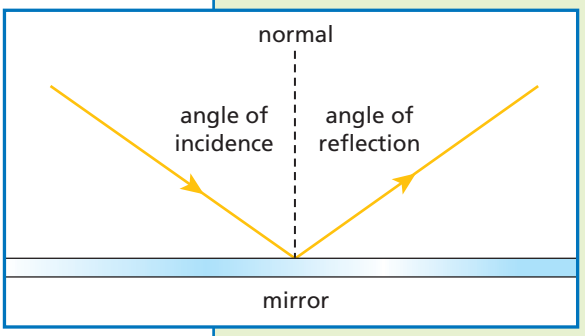
Physics Words

angle of incidence: the angle formed between an incident ray and the normal.

angle of reflection: the angle formed between a reflected ray and the normal.

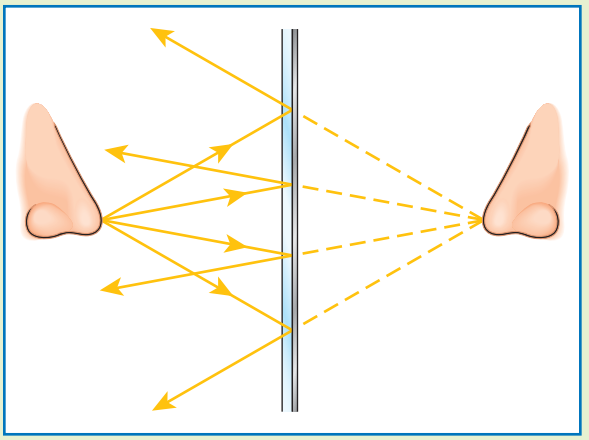
incident ray: the ray of light that strikes a surface.

reflected ray: the ray of light that reflects off a surface.



The angle of incidence is the angle between the incident ray and the **normal** (line drawn perpendicular to the mirror — as shown as a dotted line). The angle of reflection is the angle between the reflected ray and the normal.

Most objects do not reflect light like a mirror. An object like the tip of a nose reflects the light of the incident ray in all directions. That is why everybody in a room can see the tip of the nose.



You can look at the light leaving the tip of a nose and hitting a mirror to see how an image is produced and where it is located. Each ray of light leaves the nose at a different angle. Many of these rays of light then hit the mirror. The **law of reflection** for mirrors states that the angle of incidence for a ray equals the angle of reflection for that ray. There are now a set of rays diverging from the mirror. If you assume that the light always travels in straight lines, you can extend these rays behind the mirror and find from where they seem to emerge. That is the location of the image. The mirror does such a good job of reflecting that it looks as if there is a tip of a nose (and all other parts of the face) behind the mirror. That is how a mirror works.

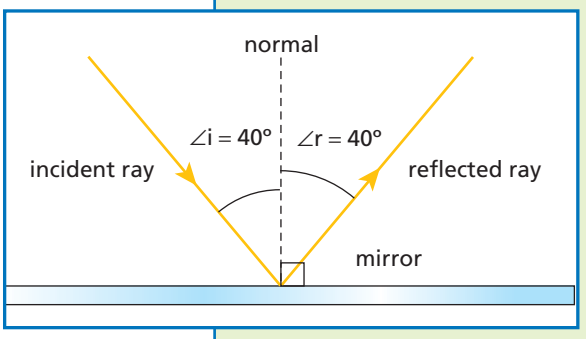
If you measure the distance of the image behind the mirror, you will find that it is equal to the distance of the nose (object) in front of the mirror. This can also be proved using geometry.

Physics Words

normal: a line that is perpendicular.

law of reflection: a law for mirrors that states that the angle of incidence is equal to the angle of reflection.

Sample Problem 1



Light is incident upon the surface of a mirror at an angle of 40°. Sketch the reflected ray. What is the angle between the incident ray and the reflected ray?

Strategy: The angles of incidence and reflection are always measured from the normal. The law of reflection states that the angle of incidence is equal to the angle of reflection. Since the angle of incidence is equal to 40°, the angle of reflection is also 40°.

Given:

$\angle i = 40°$

Solution:

The angle of incidence and the angle of reflection are measured from the normal. As the two angles are equal, the angle between the incident ray and the reflected ray is twice the angle of incidence. In this case the angle between the incident ray and the reflected ray is 40°+ 40°, or 80°.

Sample Problem 2

Suppose that the mirror is turned clockwise (as viewed from above) 10° so the angle of incidence is now 50°. How much has the angle between the incident ray and the reflected ray changed?

Strategy: Since the angle of incidence is now 50°, the angle of reflection is also 50° according to the law of reflection.

Given:

$\angle i = 50°$

Solution:

The angle of incidence and the angle of reflection are measured from the normal, the line perpendicular to a surface. So, the angle between the incident ray and reflected ray is now 100°. It has increased by 20°, or twice the angle through which the mirror was rotated.

Light Waves

As you begin to study the reflection of light rays, it is worthwhile to recognize that light is a wave and has properties similar to sound waves.

In studying sound waves, you learned that sound waves are compressional or longitudinal. The disturbance is parallel to the direction of motion of the wave. In sound waves, the compression of the air is left and right as the wave travels to the right. You saw a similar compressional wave using the compressed coiled spring.

Light waves are transverse waves. They are similar to the transverse waves of the coiled spring. In a transverse wave, the disturbance is perpendicular to the direction of the wave. In the coiled spring, the disturbance was up and down as the wave traveled to the right. In light, the fields that make up light (the disturbance) are perpendicular to the direction of motion of the waves. Unlike the transverse waves of a coiled spring, the transverse light waves do not need a medium to travel. Light waves can travel in a vacuum.

Light waves also carry energy. You know that when you are in full sunlight, you feel warmed by the light. Light waves are transferring energy from the Sun to you.

Checking Up

1. Explain the law of reflection.
2. Define the angle of incidence.
3. Describe the behavior of light waves hitting a mirror.

Active Physics Plus

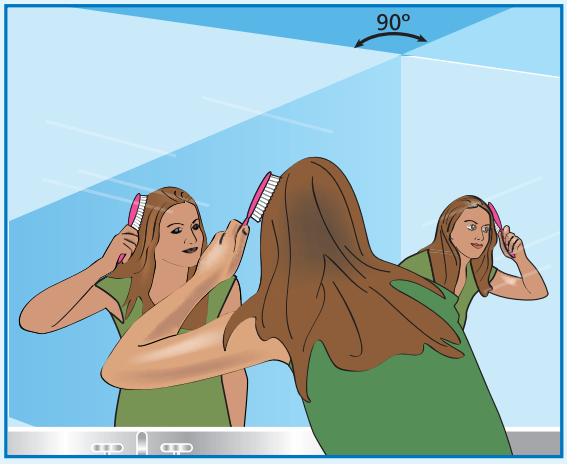
+Math	+Depth	+Concepts	+Exploration
◆		◆	◆

Reflection of a Reflection

Have you ever found yourself between two mirrors? If the mirrors are not quite parallel to one another, you can see hundreds of images of yourself. The first mirror creates an image. The second mirror creates an image of the image. The first mirror then creates an image of the image of the image.

Carefully tape together one edge of two mirrors so they can move like a hinge, with the mirrored surfaces facing each other.

1. Place a small object between the mirrors. When the angle between the mirrors is 90°, you should see three images.



a) Draw a ray diagram that shows how the first image is created by a reflected light from the object to the first mirror and into your eye.

b) Draw a ray diagram that shows how the second image is created by a reflected light from the object to the second mirror and into your eye.

c) Draw a ray diagram that shows how the third image is created by a reflected light from the first image to the second mirror and into your eye.

d) Draw a ray diagram that shows how the third image is also created by a light reflected from the second mirror to the first mirror and into your eye.

2. Investigate how the number of images you see depends on the angle between the mirrors. You will need a protractor to measure this angle. (If you have polar coordinate paper available, you will not need a protractor.)

a) Plot a graph of the number of images versus the angle between the two mirrors.

b) What mathematical relationship can you find between the angle and the number of images?

What Do You Think Now?

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

- **How are you able to see yourself in a mirror?**
- **If you want to see more of yourself in the mirror, what can you do?**

Now that you have completed this section, how would you answer these questions? Compare your answers now to those you wrote in your log at the beginning of the section. If they are different, what evidence did you see in the *Investigate* that made you change your answers?

Physics

Essential Questions

What does it mean?

In this section, you learned that light travels in straight lines until it interacts with materials such as mirrors where light can be reflected. Then light travels in straight reflected lines until it interacts with another material or object. In order to talk about the reflection of light, scientists use angles of incidence and angles of reflection. How are these angles defined?

How do you know?

Physicists prefer to find quantitative relationships among properties. These relationships should be based on observations and experiments. How are the angle of incidence and the angle of reflection related? What evidence do you have for this from your investigations?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Waves and interactions	* Interactions of matter, energy, and fields	Experimental evidence is consistent with models and theories

* When scientists observe new phenomena, they often have to modify previously stated general principles. Does light always travel in straight lines? How does what you learned about reflection in this section modify how you would express the general principle about light traveling in straight lines?

Why should you care?

You use mirrors every day. Make a list of some of the ways that mirrors are used in your everyday life. Compare your list with those of your classmates. Suggest two ways that mirrors can be used in creative ways in your sound and light show.

Reflecting on the Section and the Challenge

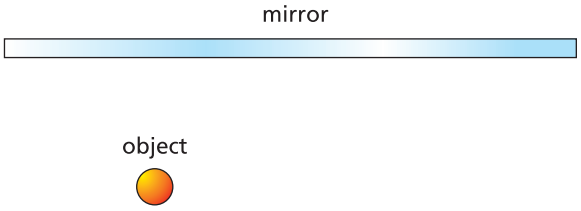
In this section, you aimed light rays at mirrors and observed the reflections. From your investigation, you discovered that the angle of incidence is equal to the angle of reflection. Therefore, you can now predict the path of a reflected light beam. You also experimented with reflections from two mirrors. When you observed the reflection in two mirrors, you found many images of one object that made interesting patterns.

This section has given you experience with many interesting effects that you can use in your sound and light show. For instance, you may want to show the audience a reflection in one mirror or two mirrors placed at angles. You can probably build a kaleidoscope using the directions supplied in *Inquiring Further*. You will also be able to explain the physics concepts you use in terms of reflected light.

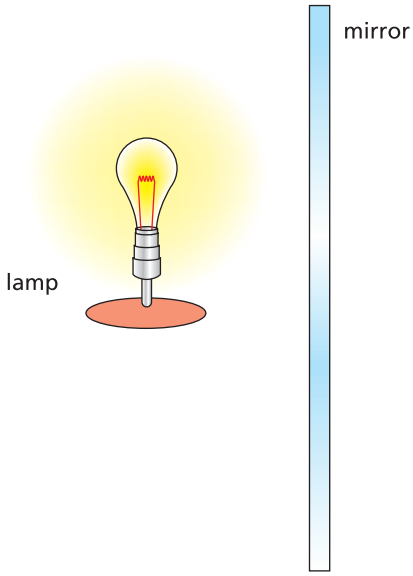
Physics to Go

1. How is light reflecting from a mirror similar to a tennis ball bouncing off a wall?
2. a) What is the normal to a plane mirror?
   b) When a light beam reflects from a plane mirror, how do you measure the angle of incidence?
   c) How do you measure the angle of reflection from a plane mirror?
   d) What is the relationship between the angle of incidence and the angle of reflection?
3. Make a top-view drawing to show the relationships among the normal, the angle of incidence, and the angle of reflection.
4. Suppose you are experimenting with a mirror mounted vertically on a table, like the one you used in this section. Make a top-view drawing. Use a heavy line to represent the mirror and a dotted line to represent the normal.
   a) Show light beams that make angles of incidence of 0°, 30°, 45°, and 60° to the normal.
   b) For each of the above beams, draw the reflected ray. Add a label if necessary to identify each of the rays or use colored pencils for individual sets of incident and reflected rays.
5. Stand in front of a mirror.
   a) Move your hand toward the mirror. Which way does the reflection move?
   b) Move your hand away from the mirror. Which way does the reflection move?
   c) Use what you learned about the position of the mirror image to explain your answers.
6. Suppose you printed the whole alphabet in block (upper case) letters along the normal to a mirror in the way you printed your name in *Step 11* of the *Investigate*.
   a) Which letters would look just like their reflections?
   b) Write three words that would look just like their reflections.
   c) Write three words that would look different from their reflections.
   d) Draw the reflection of each letter you gave in 6.*c*).
7. Why is the word *ambulance* written in an unusual way on the front of the ambulance pictured at the right?

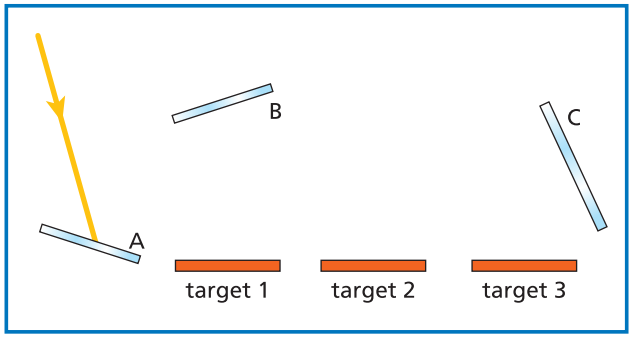
8. Use a ruler and protractor and a ray diagram to locate the image of a small, glowing light bulb placed in front of a plane mirror. Be careful! You must measure as carefully as you can to obtain the most accurate answer.



9. Locate the image of the lamp shown in the diagram at right.



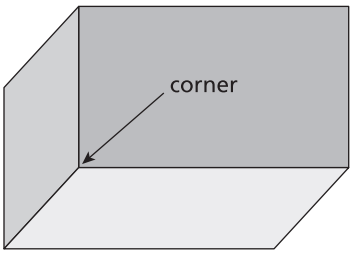
10. After reflecting off the mirrors A, B, and C, which target will the ray of light hit?



Inquiring Further

1. **Reflection from three mirrors**

   Carefully tape together three small, flat mirrors to make a corner reflector. Shine a laser down into the corner. Where does the reflected beam go? Move the laser beam around so that it always strikes all three mirrors. Does the reflected beam change direction?



2. **Building a kaleidoscope**

   Build a kaleidoscope by carefully inserting two mirrors inside a paper-towel holder. You can also use three identical mirrors. Do not force the mirrors into the tube. Tape the edges of the mirrors together, with the mirrored surfaces inside. Describe what you see through your kaleidoscope.

   To make this more interesting, get a small piece of clear plastic tubing and put small pieces of glitter of different colors and baby oil in the tubing. Seal off the ends with sealing wax used when making jellies. This is a safe wax and available in grocery stores. The tubing might be from a spray bottle of window cleaner. Put this filled tube in the center of the paper kaleidoscope tube. Try both the vertical and the horizontal direction and see what the falling pieces of glitter do to make the images produced.