Topic 4.6 What are lenses and what are some of their applications?

Key Points

- Lenses have at least one curved surface and refract light in predictable ways.
- Converging lenses can be used to produce different types of images.

Key Skills

Inquiry

Key Terms

lens
converging lens
diverging lens

Photos like this one clearly demonstrate that lenses can change the appearance of objects. Lenses can make images that appear larger or smaller than the object, upside down, or even misshapen. Most of the time, though, you probably don't give much thought to the lenses that are in use all around you. For example, everyone has lenses in their eyes. You may also use lenses on your eyes, in the form of contact lenses, or in front of your eyes, in the form of glasses, to help you see more clearly. Nearly all cell phones have very tiny lenses. Your teacher probably uses a projector in your classroom occasionally. Projectors also have lenses. Lenses can focus light because of refraction. Light refracts once when entering the lens and again when leaving. The result is a change in the direction of the light rays.

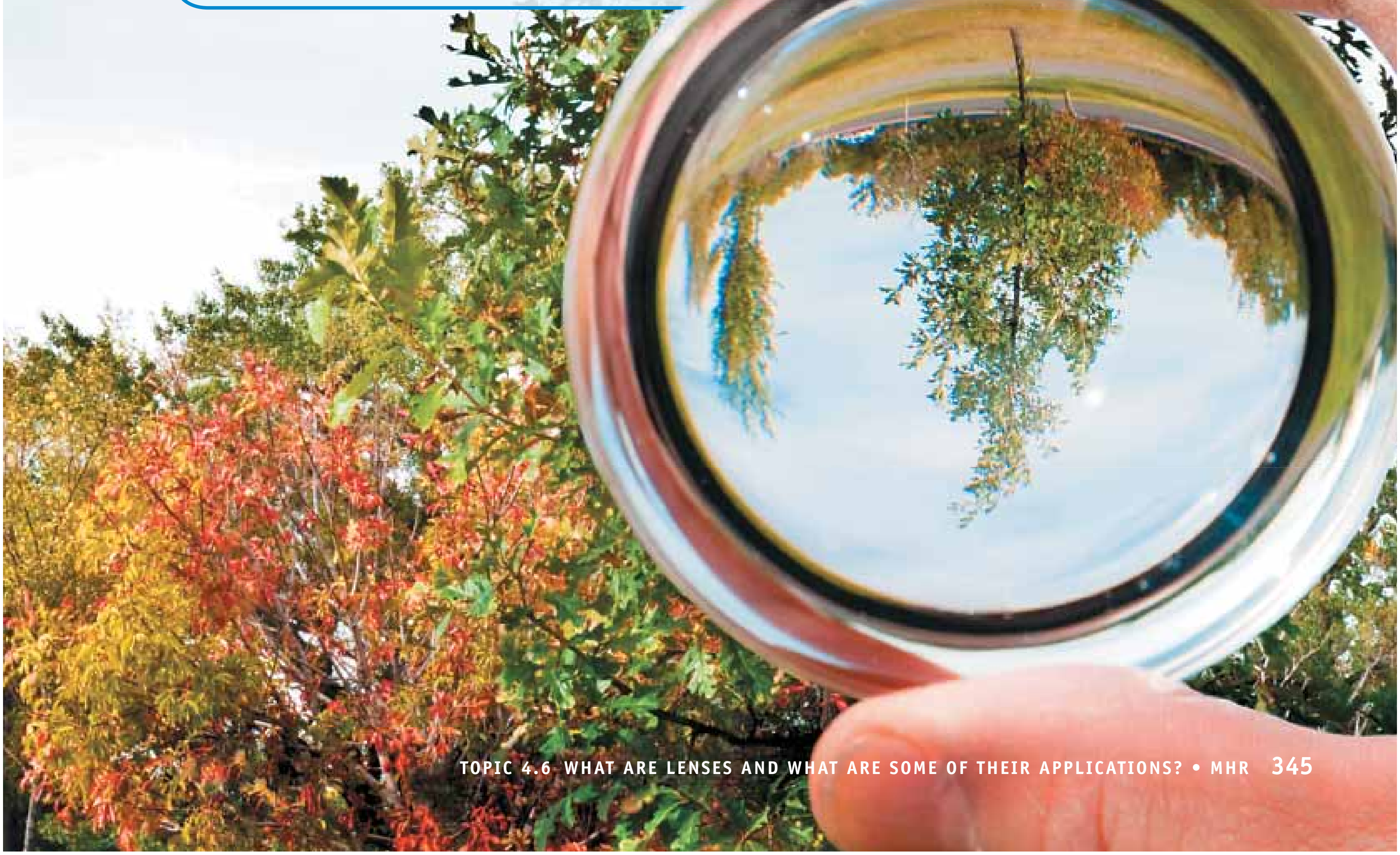
Starting Point Activity

What To Do

1. Obtain a 10 cm by 10 cm piece of waxed paper, newspaper (about half of a page), a medicine dropper, and some water.
2. Lay the waxed paper on the newspaper.
3. With the medicine dropper, place one drop of water on the waxed paper.
4. Observe the shape of the drop of water.
5. Look at the newspaper through the drop of water while you move the waxed paper around on the newspaper.
6. Choose a letter, such as an e and place the waxed paper over the newspaper so the drop of water is directly over the letter you chose. Compare the appearance of the letter through the drop with its appearance when nothing is on the newspaper.
7. Add two or three more drops to the first drop of water so it spreads out a little bit on the waxed paper.
8. Repeat steps 4 through 6 with the larger amount of water.

What Did You Find Out?

1. How did the single drop of water affect the appearance of the letter that you chose?
2. How did the effect caused by the larger amount of water compare to the effect caused by the single drop of water?
3. How do you think that the shape of the drop of water affected the appearance of the print that you saw through the water?



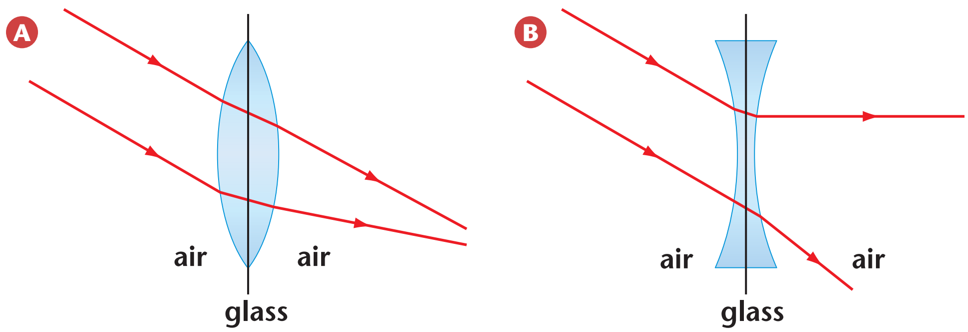
Lenses have at least one curved surface and refract light in predictable ways.

lens: a thin piece of glass or plastic that has at least one curved side

converging lens: a lens that makes parallel light rays come together

diverging lens: a lens that makes parallel light rays move apart

A **lens** is a thin, transparent piece of glass or plastic that has at least one curved side. The sides may be concave, convex, or plane. Lenses (the plural of lens) come in many sizes and shapes and are made for many different purposes. However, Figure 4.43 shows that there are two basic types of lenses. Lenses that make parallel light rays come together (converge) are **converging lenses** (A), and lenses that make parallel light rays move apart (diverge) are **diverging lenses** (B). Two factors determine the extent to which the rays converge or diverge after passing through a lens: the material that the lens is made of and the shape of the lens.



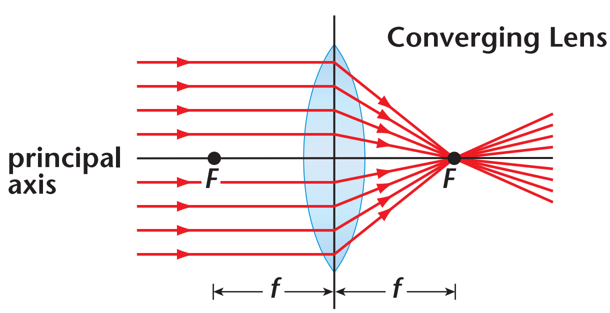
▲ **Figure 4.43** All light rays refract when they enter a lens and when they leave it.

Converging Lenses

ACTIVITY LINK

Activity 4.20 on page 352.

Finding the focal point for lenses is similar to finding it for mirrors. But lenses have two sides, so light can pass through in both directions. As a result, a lens has two focal points—one on each side of the lens. Figure 4.44 shows that, when parallel rays, close to the principal axis, pass through a converging lens, the rays all meet at one point on the other side of the lens. The point at which the rays meet is the focal point, *F*. The distance between the lens and the focal point is the focal length, *f*. Notice also that the rays are drawn so they appear to refract only once at the centre of the lens. The rules for how to draw rays for lenses are designed to fit this model.



▶ **Figure 4.44** If you shine parallel rays from the right side of the lens, they will meet at *F* on the left side of the lens.

Rules for Drawing Ray Diagrams for Converging Lenses

You can draw ray diagrams to find an image formed by a lens. With lenses you can use three rays. If all three rays do not meet at the same point, one of the rays was drawn incorrectly. The rules for drawing rays for converging lenses are as follows.

- Any ray that enters the lens parallel to the principal axis will pass through the focal point on the other side of the lens.
- Any ray that travels through the centre of the lens will keep travelling in the same direction.
- Any ray that enters the lens from the focal point will leave the lens parallel to the principal axis.

You might wonder why the ray passing through the centre of the lens at the principal axis does not change direction. The explanation is shown in **Figure 4.45**. Near the principal axis, the lens is nearly flat on both sides. When a light ray travels into the lens near the principal axis, it does refract. However, when it leaves the lens on the other side, it refracts by the same amount in the opposite direction. As a result, the light is slightly shifted to the side but still travels in the same direction. Lenses are usually quite thin so the amount of shifting sideways is extremely small and can be ignored.

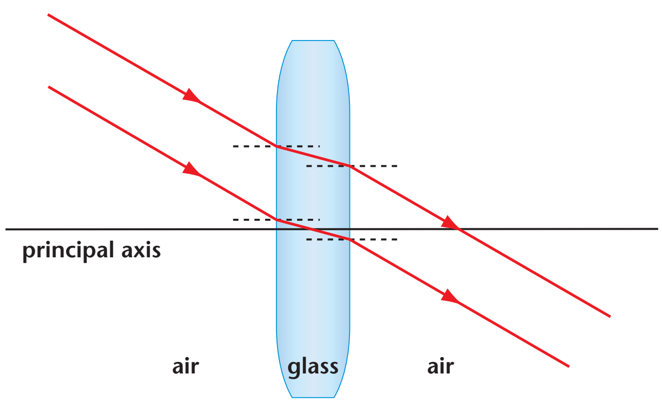


Figure 4.45 Near the principal axis of a lens, the normals are horizontal. Light rays refract by the same amount on both sides. Rays that enter parallel will leave parallel.

Similar to the case of concave mirrors, converging lenses can produce very different images, depending on the location of the object. **Table 4.6** on the next page shows you how to draw ray diagrams for converging lenses when the object is farther from the lens than the focal length.

LEARNING CHECK

1. A mirror has one focal point but a lens has two. Explain why.
2. Make a Venn diagram to compare converging and diverging lenses.
3. Explain why a ray passing through the lens at the principal axis does not change in direction.

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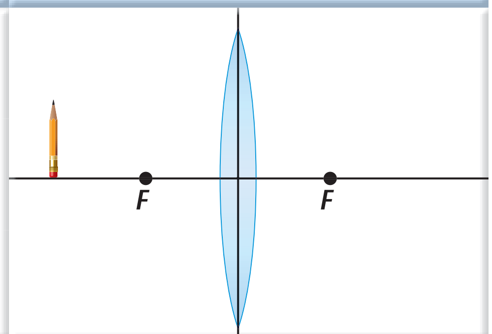
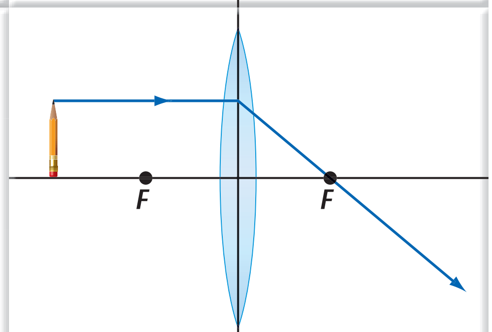
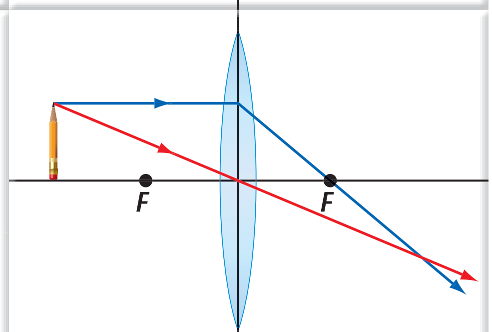
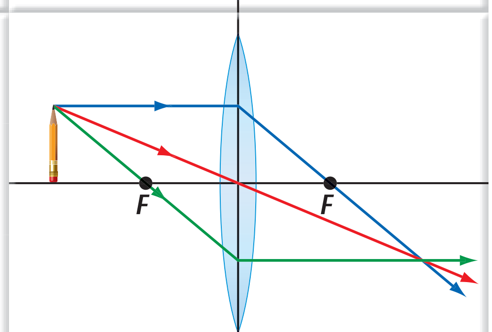
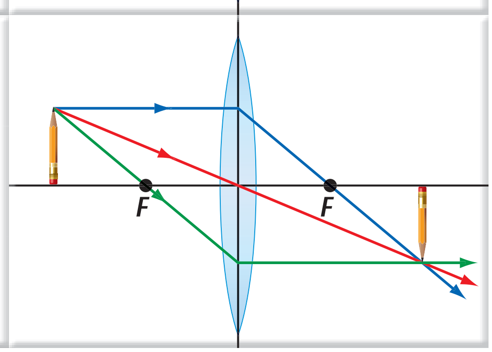
Table 4.6 **Ray Diagram for Converging Lens with Object beyond F**

Directions	Example
Step 1 • Draw a principal axis and a vertical line through the axis to represent the centre of the converging lens. • Draw focal points on both sides of the lens at the same distance from the centre of the lens. • Add an object that is farther from the lens than the focal point.	
Step 2 • Draw the first ray (shown in blue). It starts at the top of the object and runs parallel to the principal axis until it reaches the centre of the lens. It leaves the lens and passes through the focal point on the far side of the lens.	
Step 3 • Draw the second ray (shown in red). It starts from the top of the object and goes directly through the point where the centre of the lens meets the principal axis. It continues in the same direction.	
Step 4 • Draw the third ray (shown in green). It goes from the top of the object, through the focal point on the same side of the lens as the object. It leaves the lens running parallel to the principal axis.	
Step 5 • Draw the image. The top of the image is at the point where the three rays meet. The bottom of the image is on the principal axis. The image is real and inverted.	

Inquiry Focus

Activity 4-21

DRAWING AND ANALYZING RAY DIAGRAMS FOR CONVERGING LENSES

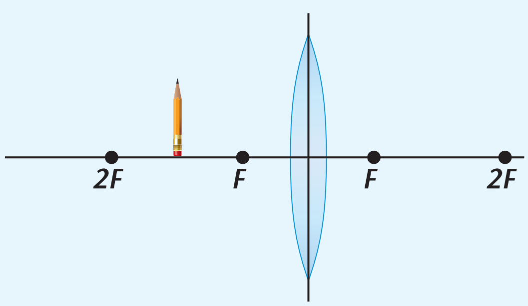
In this activity, you will be drawing a ray diagram for images formed by converging lenses. In the first diagram, the object will be between one and two focal lengths from the lens. In the second diagram, the object will be farther than two focal lengths from the lens. You will analyze the images and compare them to each other.

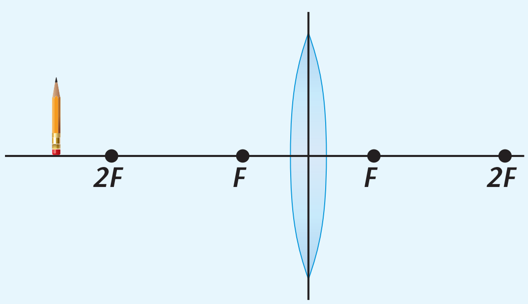
What You Will Need

- paper
- pencil
- ruler

What To Do

1. Copy the following diagrams on a piece of paper. Leave plenty of space for drawing rays. Be sure that all sizes and focal lengths are the same in both diagrams. The only feature that should be different in the two diagrams is the distance between the object and the lens.





2. Draw the rays according to the directions in Table 4.6. Draw carefully so you will be able to accurately analyze your images.
3. Make a table to record your data. You will be measuring the object and image heights and the object and image distances for two ray diagrams.
4. When you have completed drawing your diagram, make the following measurements for each diagram.
   a) the image height
   b) the object height
   c) the image distance
   d) the object distance
5. Summarize your results by stating the following characteristics of the image relative to the object.
   a) location
   b) orientation
   c) size
   d) type

What Did You Find Out?

1. Based on an analysis of your data, complete the following sentences.
   a) As the object distance becomes greater, the image distance becomes ____________.
   b) b) As the object height becomes larger, the image height becomes ___________.
2. What would you predict about the relationship between the object and image heights when the object is located at 2*F* of a converging lens?

LEARNING CHECK

1. If a ray travels toward a converging lens parallel to the principal axis, where will it be directed when it leaves the lens?
2. You need only two rays to locate an image of an object. Why it is helpful to draw three rays in a ray diagram?

Converging lenses can produce different types of images.

The first known lens ever used was a converging lens called a reading stone. As shown in **Figure 4.46**, it was placed directly on the page of a book and magnified the print. The image formed by a reading stone is upright and larger than the object. On the previous page, you saw that a converging lens formed an inverted image. How can a converging lens produce both upright and inverted images? The ray diagram developed in **Table 4.7** shows how this happens.

▶ **Figure 4.46** Reading stones date back to about 1000 CE. They were used mostly by monks and scholars because they were the only people who could read.

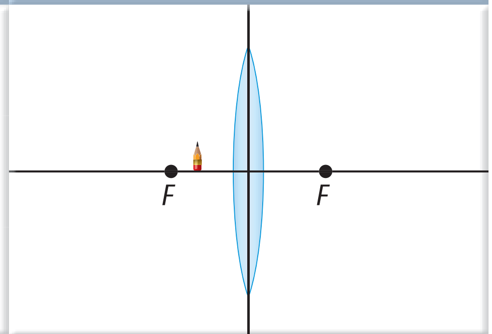
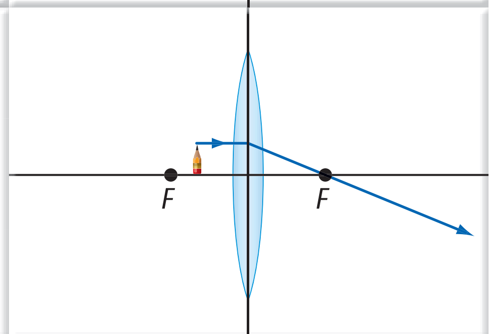
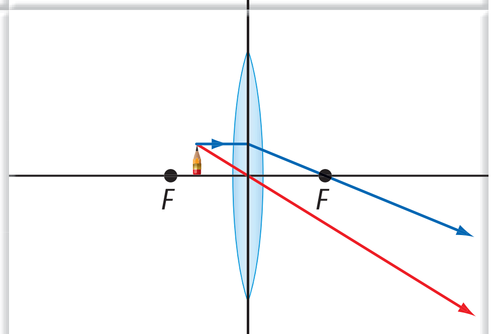
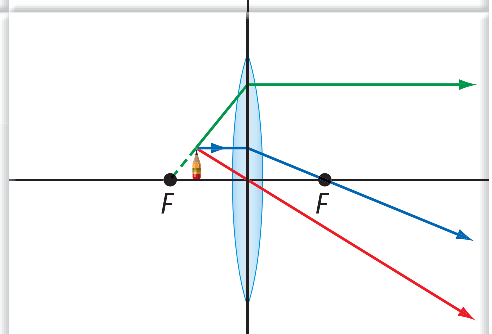
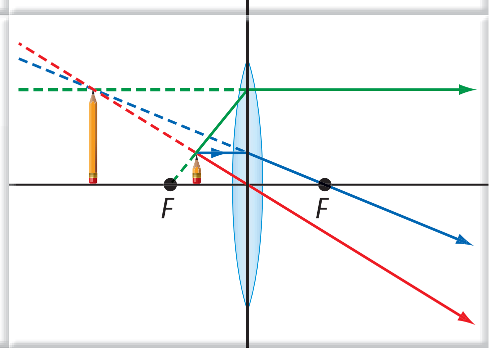
INVESTIGATION LINK

Investigation 4C on page 353
Investigation 4D on page 354

LEARNING CHECK

1. Explain how the same converging lens can produce an image that is upright and one that is inverted.
2. In **Table 4.7**, you see rays that are spreading out after leaving the lens. This appears to contradict the statement that when parallel rays pass through a converging lens, they come together, or converge, after leaving the lens. Explain why rays can spread out after passing through a converging lens.
3. List the four characteristics of an image produced by a converging lens when the object is between the lens and the focal point.

Table 4.7 Ray Diagram for Converging Lens with Object between the lens and *F*

Directions	Example
Step 1 • Draw a principal axis and a vertical line through the axis to represent the centre of the converging lens. • Draw focal points on both sides of the lens at the same distance from the centre of the lens. • Add an object that is between the lens than the focal point.	
Step 2 • Draw the first ray (shown in blue). It starts at the top of the object and runs parallel to the principal axis until it reaches the lens. It then leaves the lens and passes through the focal point on the far side of the lens.	
Step 3 • Draw the second ray (shown in red). It starts from the top of the object and goes directly through the centre of the lens at the principal axis. It continues in the same direction.	
Step 4 • Draw the third ray (shown in green). It appears to come from the focal point on the same side of the lens as the object as shown by the dotted green line. It continues from the top of the object to the lens. It leaves the lens and travels parallel to the principal axis.	
Step 5 • The rays are spreading apart and will never meet. Therefore, extend the rays backwards until they meet, as shown with dashed lines. Draw the top of the image at the point where the extended rays meet. The bottom of the image is on the principal axis.	

Inquiry Focus

Activity 4.20

FINDING THE FOCAL LENGTH OF A CONVERGING LENS

When working with lenses, you often want to know the focal length of the lens. To measure the focal length, you need parallel rays of light. When an object is at a very long distance from the lens, the rays are very nearly parallel when they reach the lens. You can use a light source such as a window on the far side of the room as an object.

What You Need

- several different converging lenses (roughly similar in diameter)
- sheet of paper
- metric ruler

What To Do

1. In your notebook, make a table for recording your results. The table should have the headings, Description of Lens, Maximum Thickness of Lens (mm), and Focal Length (cm).
2. Find a location where you can use a distant bright light source, such as an open window on the far side of the classroom. Work in pairs. One partner should hold a converging lens while the other partner holds a sheet of paper to act as a screen.
3. Point the lens toward the light source, and hold the paper screen on the other side of the lens. Move the screen back and forth until you see the smallest possible, focused image of the light source.
4. Measure the distance from the centre of the lens to the paper screen. Record this measurement in your table.
5. Measure the thickness of the centre of the lens and record it in your table.
6. In your table, describe the lens by indicating how it differs from the other lenses.
7. Repeat steps 3 to 6 for other converging lenses.

What Did You Find Out?

1. How does the thickness of a converging lens affect its focal length?

Investigation 4C

Investigating Converging Lenses

How many different sizes and shapes of images can one single converging lens form?

Skill Check

Initiating and Planning
✓ **Performing and Recording**
✓ **Analyzing and Interpreting**
✓ **Communicating**

What You Need

- converging lens
- lens holder
- metre stick
- four strips of masking tape
- blank sheet of paper as a screen
- small light source such as a burning candle for an object

What To Do

1. Make a table to record your data. You will be observing and recording the four image characteristics of a lens when the lens is placed at four different object distances. These distances will be: a) greater than $2f$, b) at $2f$, c) between $2f$ and f, and d) less than f
2. Determine the focal length of the lens. (See Activity 4.20.)
3. Mount the lens vertically in the middle of the desk.
4. Using masking tape, mark the points that are one focal length and two focal lengths away from either side of the lens.
5. Place the lighted object more than two focal lengths away from the lens. Locate and describe the image. Record your observations in the table. State image distances in terms of f and $2f$. Describe the size of the image as "larger than", "same size", or "smaller than" the object.
6. Repeat the previous step for the other object distances.

NOTE: For one of these object distances, you will have to look into the lens, from the side away from the object, to see the image.

What Did You Find Out?

1. For which object distances was a real image produced?
2. For which object distance was a virtual image produced?
3. For which object distances was the image larger than the object?
4. Based upon your study of the concave mirror and the convex lens, what is the orientation of the:
   a) real images?
   b) virtual images?
5. How far away was the object when the lens was being used as a "magnifying glass"?

Investigation 4D

Skill Check

- ✓ Initiating and Planning
- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communicating

Safety

Be careful handling sharp objects and objects with sharp edges.

What You Need

- convex lens (with a large curve)
- convex lens (with a small curve)
- cardboard
- scissors
- tape
- ruler

Options for an Optical Device

Using combinations of lenses enables us to make optical devices that magnify small objects, as in a microscope, and observe distant objects, as in a telescope. In this Investigation, you will experiment with different combinations of lenses to construct your own optical device.

What To Do

1. Work in groups. Start by experimenting with the lenses. Look through one, and then both, lenses at different objects in the room. Experiment with different distances between the lenses and the objects and between the lenses and each other.

2. Based on your experiences, decide which type of optical device you would like to make. Use the following criteria:
   - The lenses must be mounted safely and positioned on a flat surface, such as a bench.
   - A microscope device must magnify a nearby object, and a telescope must make a distant object appear to be closer.

3. Plan how to arrange the lenses to get the results that you want to achieve. Think about how to safely mount your lenses.

4. Prepare a sketch to show the arrangement and distances of your lenses. Have your teacher approve your plan.

5. Construct cardboard mounts for your lenses. Create and test your device.

What Did You Find Out?

1. Did your arrangement work as you planned? Explain.

2. Suggest ways to improve your design. This could include how to change the design to have an inverted image appear upright, increase magnification, or have fewer or smaller parts.

Inquire Further

3. Design an optical device that can magnify an object that is behind you and around the corner from you. You will need to include mirrors in your design.

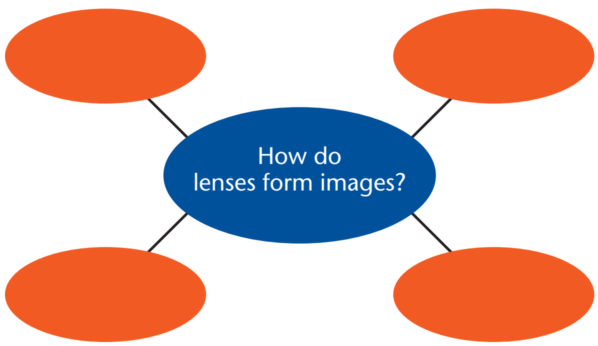
Topic 4.6 Review

Key Concept Summary

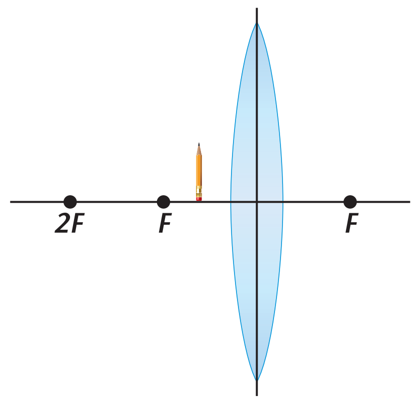
- Lenses have at least one curved surface and refract light in a predictable way.
- Converging lenses can produce different types of images.

Review the Key Concepts

1. K/U Answer the question that is the title of this topic. Copy and complete the graphic organizer below in your notebook. Fill in four examples from the topic using key terms as well as your own words.



2. K/U Explain the difference between converging and diverging lenses.
3. K/U Describe the process for determining the focal length of a converging lens.
4. K/U If a light ray enters a converging lens from the focal point on the same side as the object, how will it travel after it leaves the lens?
5. A Where would an object have to be located, relative to a converging lens, in order to produce a virtual image?
6. K/U Under what conditions will a light ray pass through a lens without changing its direction?
7. T/I Copy the following diagram in your notebook. Complete the ray diagram. List the four characteristics of the image.



8. T/I Draw a ray diagram for a converging lens that produces an image that is real, inverted, and smaller than the object. Where will you place the object?

SCIENCE AT WORK

CANADIANS IN SCIENCE

▲ Victor Tomei is a laserist, a technician who sets up and operates laser light shows.

Laser light shows are a dramatic example of optics in action. Laserists achieve their effects using mirrors to multiply and redirect laser beams. Victor Tomei is operations engineer and head of the laser department for Pyrotech Special Effects Inc. in Markham, Ontario. The company has staged laser shows and pyrotechnics for clients including Jay-Z, Metallica, Usher, Kiss, Justin Timberlake, Green Day, the Toronto Maple Leafs, and the Juno Awards.

What led you to a career as a laserist?

I took an engineering course in electronics at community college, then worked for six or seven years for companies like IBM and DeHavilland aircraft. One of my wife's clients was a producer of laser light shows, and they were looking for someone with a background in control systems so I took the job. From there it was on-the-job training, learning about the effects and the optics involved.

What do you need to know about optics to work as a laserist?

It's important for you to know more about the mechanics of optics and basic colour mixing—how you combine red, blue, and green light. We use laser control software to pick our colours, but you always work with a laser in the room because a colour doesn't always look the same on the computer screen as it does in an actual laser beam. Mirrors are a big part of it. There are two categories of mirrors involved. Internal mirrors are used to generate and maintain the beam and external mirrors are used to steer the beams. You need to understand how the surfaces and coatings of the mirrors react to light.

What was the most challenging job you've ever done?

They've all been somewhat challenging. A couple of years ago we did a Foo Fighters concert at Hyde Park in London, England. The lasers were mounted on two towers hundreds of feet apart so we couldn't run cables. There were 80,000 people in the park, and the design called for us to create a ceiling effect over the whole area and project scanned images into the air.

What is the most rewarding part of your job?

Just getting to work with all these high profile artists. We did the Paul McCartney concert in Kiev in 2008 for 400,000 people. That was pretty cool. I really enjoy working with the designers to come up with something unique every time. Seeing the end result and the audience response is always a thrill. You also get to travel to a lot of exotic destinations, though that can be tiring after awhile and you do put in some long hours.

Put Science To Work

The study of optics contributes to these careers, as well as many more!

OPTICS

- Graphic Designer
- Industrial Painter & Coater
- Interior Designer
- Makeup Artist
- Aesthetic Laser Technician
- Optician
- Laser Welder
- Telecommunications Technician

▲ Opticians work in retail stores, clinics, and doctor's offices with optical dispensing departments. They fit customers with prescription eyeglasses or contact lenses, help them choose frames for glasses, and process eyewear orders.

▲ Medical grade lasers enable aesthetic laser technicians to treat cosmetic and medical conditions including spider veins, cellulite, unwanted body hair, and wrinkles without the use of invasive surgery.

▲ Makeup artists for film, television, and live theatre must understand how skin colour can be enhanced under the intense multi-hued lights of the stage or studio in order to preserve a performer's natural appearance or to create a desired effect.

Over To You

Work Learning Life

1. If you could interview Victor Tomei, what questions would you ask him about his work?
2. Why is it important for a laserist to understand optics?
3. Research a career involving optics that interests you. If you wish, you may choose from the list above. What are the essential skills needed for this career?

Go to **scienceontario** to find out more