

# Optics

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CONCEPT **1**

# Optics

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## Lesson Objectives

- Outline how light is reflected.
- Describe how mirrors reflect light and form images.
- Explain the refraction of light.
- Describe how lenses refract light and form images.
- Explain how mirrors and lenses are used in optical instruments.

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## Lesson Vocabulary

- concave
- convex
- image
- laser
- law of reflection
- lens
- optics

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## Introduction

Did you ever see trees or other objects reflected in the still waters of a lake, like the one in **Figure 1.1**? The water in the lake is so calm that it reflects visible light almost as clearly as a mirror. A mirror is one of many devices that people use to extend their ability to see. Mirrors allow people to see themselves as other people see them and also to see behind their back. Mirrors are also used in instruments such as telescopes, which you will read about in this lesson. The use of light in devices such as these is possible because of optics. **Optics** is the study of visible light and the ways it can be used to extend human vision and do other tasks.

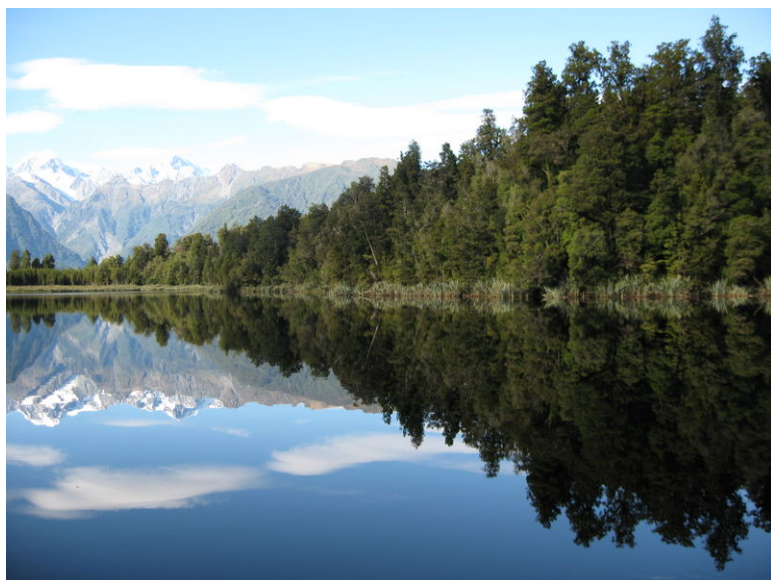
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## Reflection of Light

Almost all surfaces reflect some of the light that strikes them. The still water of the lake in **Figure 1.1** reflects almost all of the light that strikes it. The reflected light forms an image of nearby objects. An **image** is a copy of an object that is formed by reflected or refracted light.

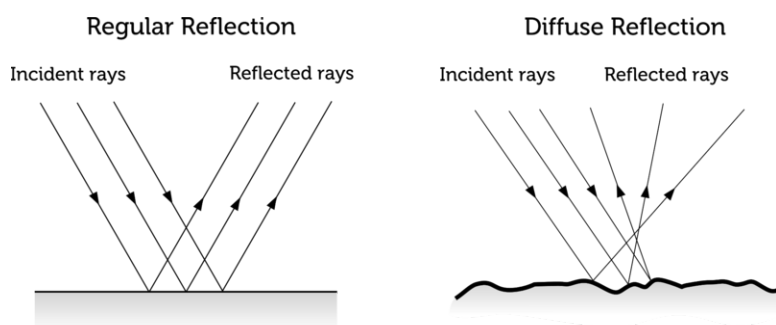
### Regular and Diffuse Reflection

If a surface is extremely smooth, like very still water, then an image formed by reflection is sharp and clear. This is called regular reflection. If the surface is even slightly rough, an image may not form, or if there is an image, it is blurry or fuzzy. This is called diffuse reflection. Both types of reflection are represented in **Figure 1.2**. You can

**FIGURE 1.1**

Still waters of a lake create a mirror image of the surrounding scenery.

also see animations of both types of reflection at this URL: <http://toolboxes.flexiblelearning.net.au/demosites/series5/508/laboratory/studynotes/snReflectionMirrors.htm> .

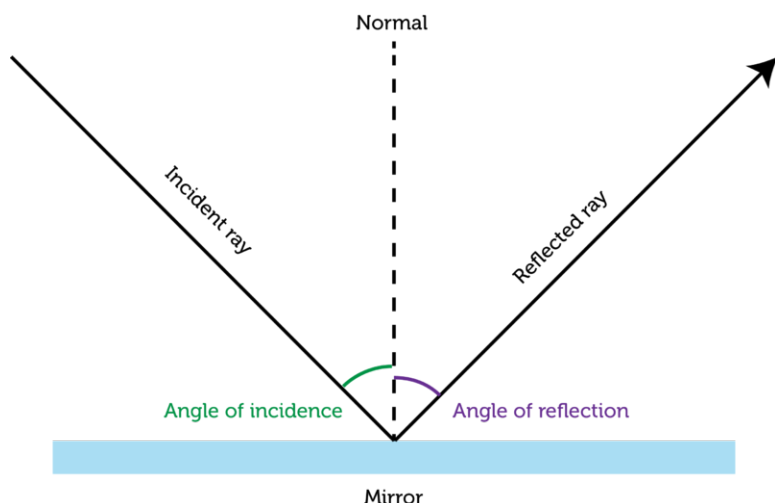
**FIGURE 1.2**

Whether reflection is regular or diffuse depends on the smoothness of the reflective surface.

In **Figure 1.2**, the waves of light are represented by arrows called rays. Rays that strike the surface are referred to as incident rays, and rays that reflect off the surface are known as reflected rays. In regular reflection, all the rays are reflected in the same direction. This explains why regular reflection forms a clear image. In diffuse reflection, in contrast, the rays are reflected in many different directions. This is why diffuse reflection forms, at best, a blurry image.

## Law of Reflection

One thing is true of both regular and diffuse reflection. The angle at which the reflected rays bounce off the surface is equal to the angle at which the incident rays strike the surface. This is the **law of reflection**, and it applies to the reflection of all light. The law is illustrated in **Figure 1.3** and in the animation at this URL: <http://www.physicsclassroom.com/mmedia/optics/lr.cfm> .

**FIGURE 1.3**

According to the law of reflection, the angle of reflection always equals the angle of incidence. The angles of both reflected and incident light are measured relative to an imaginary line, called normal, that is perpendicular (at right angles) to the reflective surface.

## Mirrors

Mirrors are usually made of glass with a shiny metal backing that reflects all the light that strikes it. Mirrors may have flat or curved surfaces. The shape of a mirror's surface determines the type of image the mirror forms. For example, the image may be real or virtual. A real image forms in front of a mirror where reflected light rays actually meet. It is a true image that could be projected on a screen. A virtual image appears to be on the other side of the mirror. Of course, reflected rays don't actually go behind a mirror, so a virtual image doesn't really exist. It just appears to exist to the human eye and brain.

### Plane Mirrors

Most mirrors are plane mirrors. A plane mirror has a flat reflective surface and forms only virtual images. The image formed by a plane mirror is also life sized. But something is different about the image compared with the real object in front of the mirror. Left and right are reversed. Look at the man shaving in **Figure 1.4**. He is using his right hand to hold the razor, but his image appears to be holding the razor in the left hand. Almost all plane mirrors reverse left and right in this way.

### Concave Mirrors

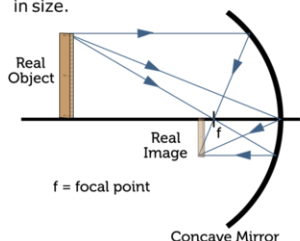
Some mirrors have a curved rather than flat surface. Curved mirrors can be concave or convex. A **concave** mirror is shaped like the inside of a bowl. This type of mirror forms either real or virtual images, depending on where the object is placed relative to the focal point. The focal point is the point in front of the mirror where the reflected rays intersect. You can see how concave mirrors form images in **Figure 1.5** and in the interactive animation at the URL below. The animation allows you to move an object to see how its position affects the image. Concave mirrors are used behind car headlights. They focus the light and make it brighter. They are also used in some telescopes.

<http://www.splung.com/content/sid/4/page/concavemirrors>

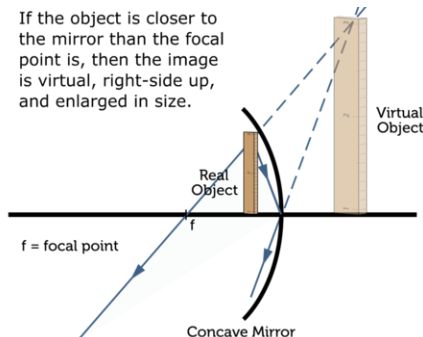
**FIGURE 1.4**

The term “mirror image” refers to how left and right are reversed in the image compared with the real object.

If the object is farther from the mirror than the focal point is, then the image is real, upside down, and reduced in size.



If the object is closer to the mirror than the focal point is, then the image is virtual, right-side up, and enlarged in size.

**FIGURE 1.5**

The image created by a concave mirror depends on how far the object is from the mirror.

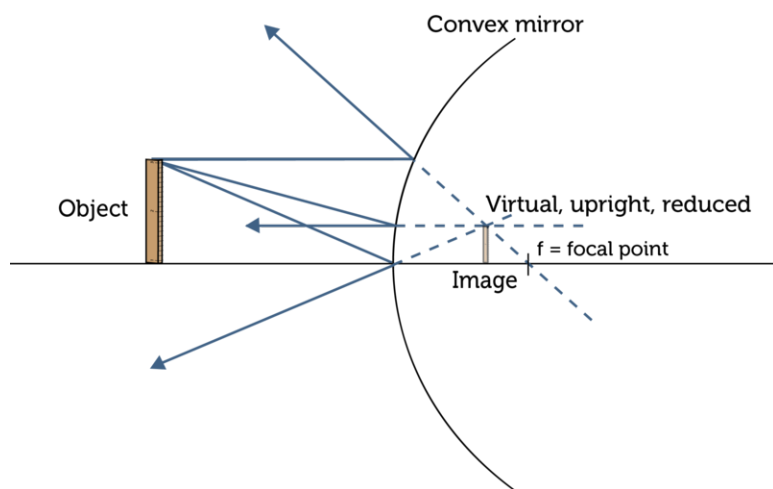
## Convex Mirrors

The other type of curved mirror, a **convex** mirror, is shaped like the outside of a bowl. This type of mirror forms only virtual images. The image is always right-side up and smaller than the actual object, which makes the object appear farther away than it really is. You can see how a convex mirror forms an image in **Figure 1.6** and in the animation at the URL below. Because of their shape, convex mirrors can gather and reflect light from a wide area. This is why they are used as side mirrors on cars. They give the driver a wider view of the area around the vehicle than a plane mirror would.

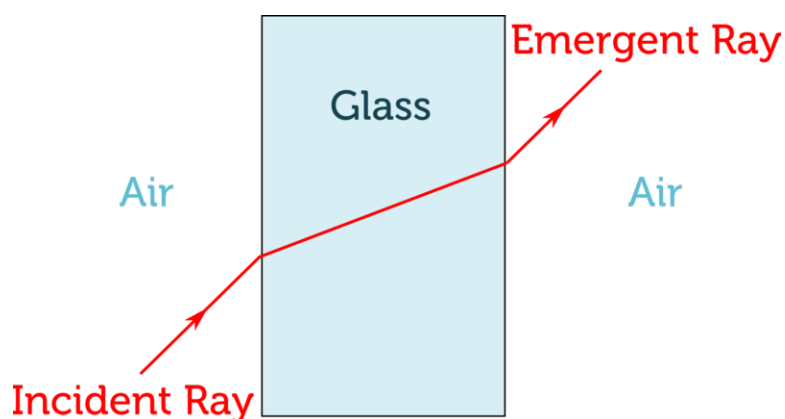
<http://physics.slss.ie/resources/convex%20mirror.swf>

## Refraction of Light

Although the speed of light is constant in a vacuum, light travels at different speeds in different kinds of matter. For example, light travels more slowly in glass than in air. Therefore, when light passes from air to glass, it slows down. If light strikes a sheet of glass straight on, or perpendicular to the glass, it slows down but passes straight through. However, if light enters the glass at an angle other than  $90^\circ$ , the wave refracts, or bends. This is illustrated in **Figure 1.7**. How much light bends when it enters a new medium depends on how much it changes speed. The greater the change in speed, the more light bends.

**FIGURE 1.6**

A convex mirror forms a virtual image that appears to be on the opposite side of the mirror from the object. How is the image different from the object?

**FIGURE 1.7**

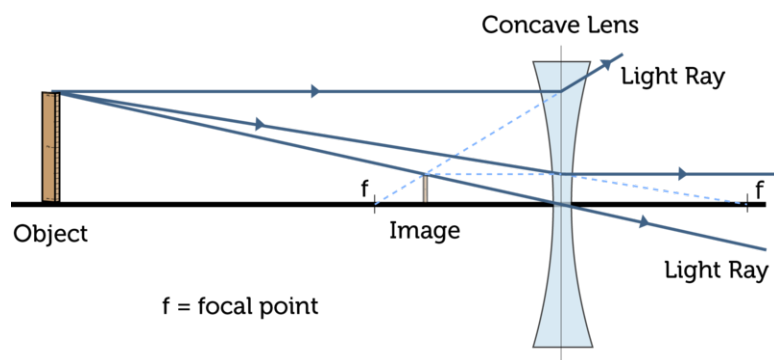
Light refracts when it passes from one medium to another at an angle other than  $90^\circ$ . Can you explain why?

## Lenses

Lenses make use of the refraction of light to create images. A **lens** is a transparent object, typically made of glass, with one or two curved surfaces. The more curved the surface of a lens is, the more it refracts light. Like mirrors, lenses may be concave or convex.

### Concave Lenses

Concave lenses are thicker at the edges than in the middle. They cause rays of light to diverge, or spread apart. **Figure 1.8** shows how a concave lens forms an image. The image is always virtual and on the same side of the lens as the object. The image is also right-side up and smaller than the object. Concave lenses are used in cameras. They focus reduced images inside the camera, where they are captured and stored. You can explore the formation of images by a concave lens with the interactive animation at this URL: [http://phet.colorado.edu/sims/geometric-optics/geometric-optics\\_en.html](http://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html).

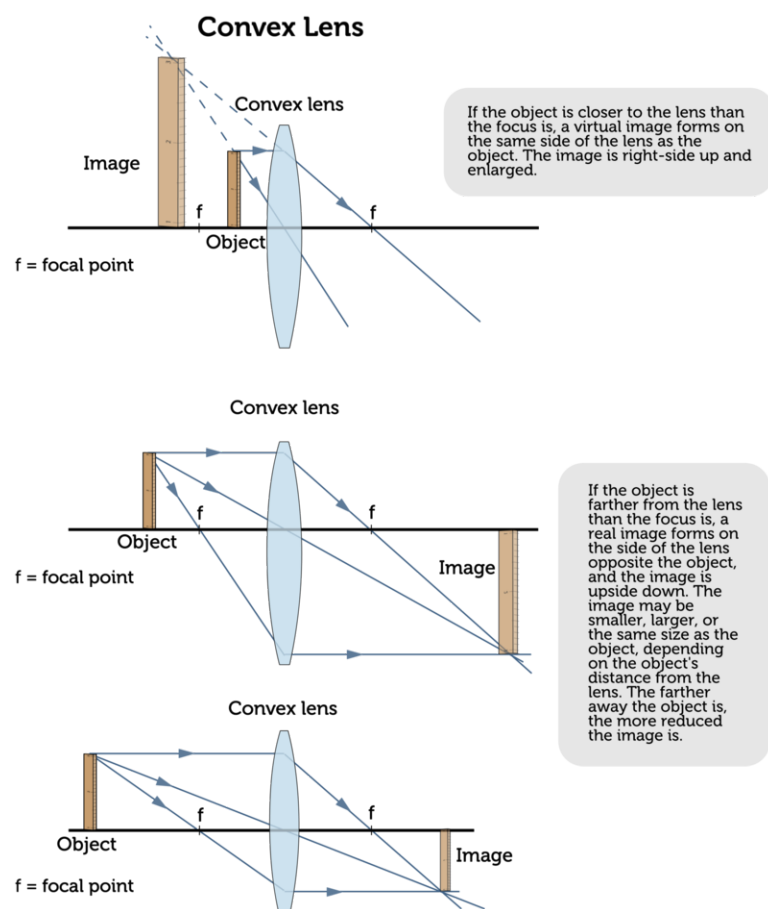
**FIGURE 1.8**

The image formed by a concave lens is a virtual image.

## Convex Lenses

Convex lenses are thicker in the middle than at the edges. They cause rays of light to converge, or meet, at a point called the focus (F). Convex lenses form either real or virtual images. It depends on how close an object is to the lens relative to the focus. **Figure 1.9** shows how a convex lens works. You can also interact with an animated convex lens at the URL below. An example of a convex lens is a hand lens.

<http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=1395.msg5241#msg5241>

**FIGURE 1.9**

The type of image made by a convex lens depends on how close the object is to the lens. Which diagram shows how a hand lens makes an image?



## Optical Instruments

Mirrors and lenses are used in optical instruments to reflect and refract light. Optical instruments include microscopes, telescopes, cameras, and lasers.

### Light Microscopes

A light microscope is an instrument that uses lenses to make enlarged images of objects that are too small for the unaided eye to see. A common type of light microscope is a compound microscope, like the one in **Figure 1.10**. A compound microscope has at least two convex lenses: one or more objective lenses and one or more eyepiece lenses. The objective lenses are close to the object being viewed. They form an enlarged image of the object inside the microscope. The eyepiece lenses are close to the viewer's eyes. They form an enlarged image of the first image. The magnifications of all the lenses are multiplied together to yield the overall magnification of the microscope. Some light microscopes can magnify objects more than 1000 times! For more on light microscopes and the images they create, watch the video at this URL: <http://www.youtube.com/watch?v=Xo7mr90GYLA> (7:29).



#### MEDIA

Click image to the left for more content.

### Telescopes

Like microscopes, telescopes use convex lenses to make enlarged images. However, telescopes make enlarged images of objects—such as distant stars—that only appear tiny because they are very far away. There are two basic types of telescopes: reflecting telescopes and refracting telescopes. The two types are compared in **Figure 1.11**. You can learn more about telescopes and how they evolved in the video at this URL: <http://www.videojug.com/film/how-does-a-telescope-work>.

### Cameras

A camera is an optical instrument that records an image of an object. The image may be recorded on film or it may be detected by an electronic sensor that stores the image digitally. Regardless of how the image is recorded, all cameras form images in the same basic way, as demonstrated in **Figure 1.12** and at the URL below. Light passes through the lens at the front of the camera and enters the camera through an opening called the aperture. As light passes through the lens, it forms a reduced real image. The image focuses on film (or a sensor) at the back of the camera. The lens may be moved back and forth to bring the image into focus. The shutter controls the amount of light that strikes the film (or sensor). It stays open longer in dim light to let more light in. For a series of animations showing how a camera works, go to this URL: <http://www.shortcourses.com/guide/guide1-3.html>.

### Lasers

Did you ever see a cat chase after a laser light, like the one in **Figure 1.13**? A **laser** is a device that produces a very focused beam of light of just one wavelength and color. Waves of laser light are synchronized so the crests and troughs of the waves line up (see **Figure 1.13**).

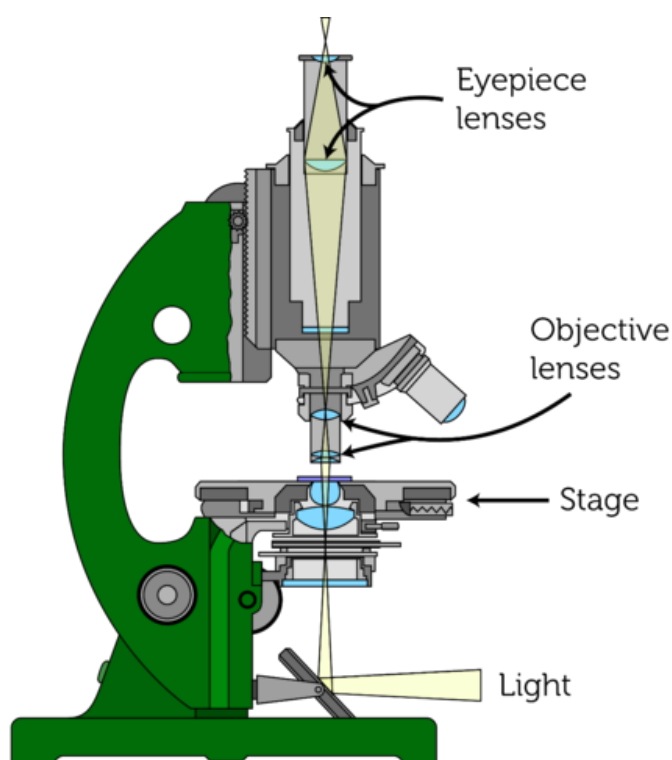
## How a Compound Microscope Works

The object to be viewed is placed on a glass platform called the stage.

Bright light reflects off a small plane mirror, and shines upward through the stage and the objective lenses above it.

The viewer looks through eyepiece lenses to see the magnified image of the object.

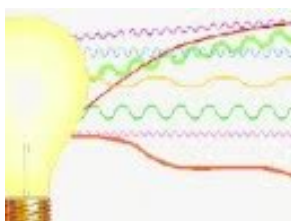
Knobs on the side of the microscope allow the viewer to move the lenses up or down in order to bring the image into focus.



**FIGURE 1.10**

A compound microscope uses convex lenses to make enlarged images of tiny objects.

Laser light is created in a tube like the one shown in **Figure 1.14**. Electrons in a material such as a ruby crystal are stimulated to radiate photons of light of one wavelength. At each end of the tube is a concave mirror. The photons of light bounce back and forth in the tube off the mirrors. This focuses the light. The mirror at one end of the tube is partly transparent. A constant stream of photons passes through the transparent part, forming the laser beam. You can see an animation showing how a laser works at this URL: <http://www.youtube.com/watch?v=gUbBzEXIEho> (1:12).



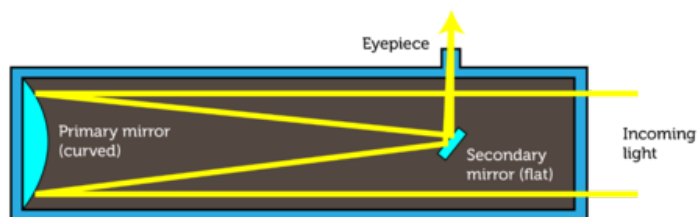
### MEDIA

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Besides entertaining a cat, laser light has many other uses. It is used to scan bar codes, for example, and to carry communication signals in optical fibers. Optical fibers are extremely thin glass tubes that are used to guide laser light (see **Figure 1.15**). Sounds or pictures are encoded in pulses of laser light, which are then sent through an optical fiber. All of the light reflects off the inside of the fiber, so none of it escapes. As a result, the signal remains strong even over long distances. More than one signal can travel through an optic fiber at the same time, as you can see in **Figure 1.15**. Optical fibers are used to carry telephone, cable TV, and Internet signals.

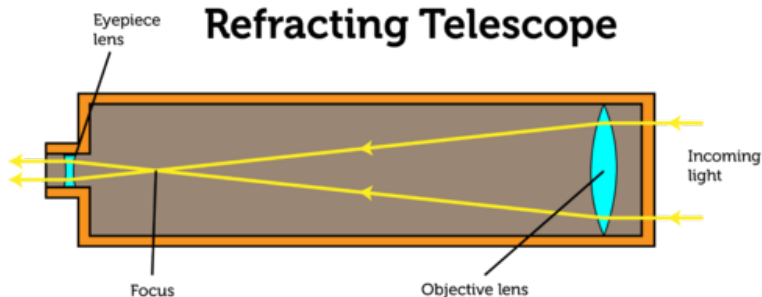
## Reflecting Telescope

A reflecting telescope uses a concave mirror to collect and focus light. The light then strikes a smaller plane mirror, which reflects the light into the eyepiece at the side of the telescope. (The eyepiece is on the side so it doesn't block incoming light.) A convex lens in the eyepiece enlarges the image.



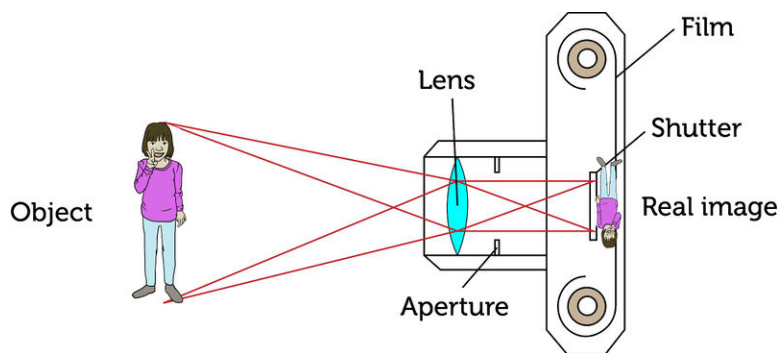
## Refracting Telescope

A refracting telescope uses a convex lens to collect and focus light. It uses another convex lens in the eyepiece to enlarge the image made by the first convex lens.



**FIGURE 1.11**

These telescopes differ in how they collect light, but both use convex lenses to enlarge the image.

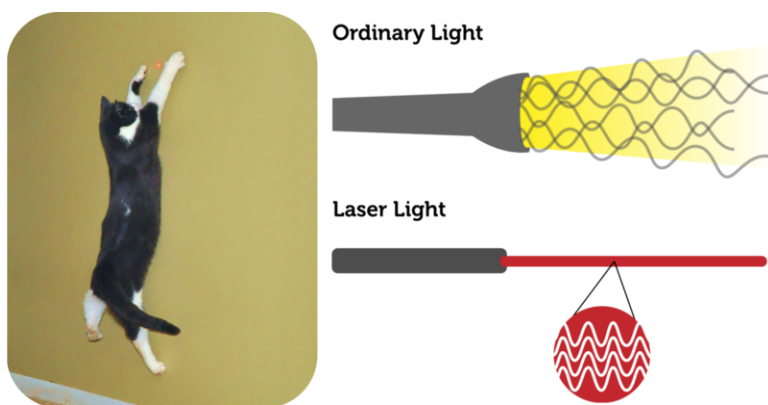


**FIGURE 1.12**

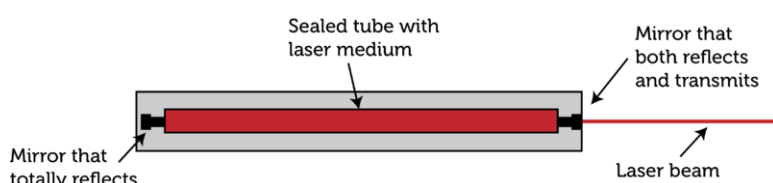
A camera uses a convex lens to form an image on film or a sensor.

## Lesson Summary

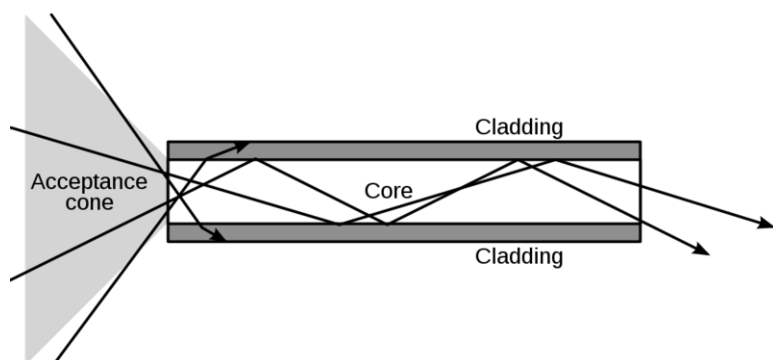
- Objects that reflect or refract light may form images. An image is a copy of an object that is formed by reflected or refracted light. According to the law of reflection, light is reflected at the same angle that it strikes a reflective surface.
- Mirrors reflect all of the light that strikes them and form images. A plane, or flat, mirror forms virtual, life-sized images. A concave mirror forms either enlarged virtual images or reduced real images. A convex mirror forms only reduced virtual images.
- Refraction, or bending, of light occurs when light passes from one medium to another at an angle other than

**FIGURE 1.13**

A very focused beam of bright laser light moves around the room for the cat to chase. The diagram shows why the beam of laser light is so focused compared with ordinary light from a flashlight.

**FIGURE 1.14**

A laser light uses two concave mirrors to focus photons of colored light.

**FIGURE 1.15**

An optical fiber carries pulses of laser light. The outer cladding and inner core refract light by different amounts, so that all of the light is reflected back into the core. The optical fiber in the diagram is much larger than a real optical fiber, which is only about as wide as a human hair.

90° and the speed of light changes in the new medium. The greater the change in speed, the more light bends.

- Lenses are transparent objects with curved surfaces that refract light and form images. Concave lenses form only reduced virtual images. Convex lenses form either enlarged virtual images or real images that may be enlarged or reduced.
- Mirrors and lenses are used in optical instruments to reflect or refract light. Optical instruments include microscopes, telescopes, cameras, and lasers.

## Lesson Review Questions

### Recall

1. Define optics.

2. State the law of reflection.
3. What type of images does a convex mirror form?
4. What type of images does a concave lens form?
5. Choose an optical instrument described in this lesson and state how it uses lenses and/or mirrors to focus visible light.

### Apply Concepts

6. Assume that a light shines upward through the water of a swimming pool. Create a diagram to show what happens to the light when it passes from the water to the air above the water's surface. The light should enter the air at an angle other than  $90^\circ$ . Explain your diagram to another student.

### Think Critically

7. Compare and contrast regular and diffuse reflection.
8. Explain how concave mirrors form real and virtual images.
9. Relate focus and position of an object to the image formed by a convex lens.

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### Points to Consider

In this lesson, you read how convex and concave lenses refract light. The human eye, which you can read about in the next lesson "Vision," also contains a lens.

- How do you think the lens in the eye works? What is its role in vision?
- Do you think the lens in the eye is a concave lens or a convex lens?

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### References

1. Flickr:p-a-t-r-i-c-k. <http://www.flickr.com/photos/patrickkiteley/2634310565/> . CC BY 2.0
2. Joy Sheng. [CK-12 Foundation](#) . CC BY-NC 3.0
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