25.3 Optics

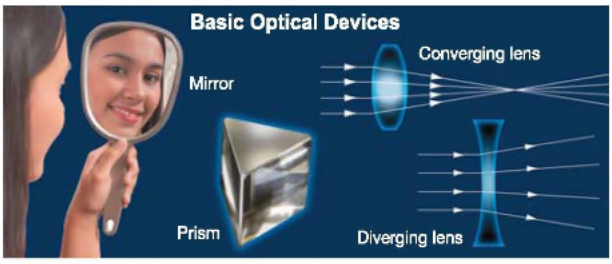
Optics is the science and technology of light. Almost everyone has experience with optics. For example, trying on new glasses, checking your appearance in a mirror, looking through binoculars, or admiring the sparkle from a diamond ring all involve optics.

Basic optical devices

Lenses A **lens** bends light in a specific way. A *converging lens* bends light so that the light rays come together in a point. This is why a magnifying glass makes a hot spot of concentrated light (Figure 25.16). A *diverging lens* bends light so it spreads light apart instead of bringing it together. An object viewed through a diverging lens appears smaller than it would look without the lens.

Mirrors A **mirror** reflects light and allows you to see yourself. Flat mirrors show a true-size image. Curved mirrors distort images. The curved surface of a fun house mirror can make you appear thinner, wider, or even upside down!

Prisms A **prism**, usually a solid piece of glass with flat polished surfaces, can both bend and reflect light. Telescopes, cameras, and laser scanners use prisms of different shapes to bend and reflect light in precise ways. A prism also bends the colors of white light so that you can see that it is made up of a rainbow of colors. A cut diamond is a kind of prism with many flat, polished surfaces. The "sparkle" that makes diamonds so attractive comes from light being reflected many times as it bounces around the gem.



VOCABULARY

lens - an optical device for bending light rays.

mirror - a surface that reflects light rays.

prism - a glass shape with flat, polished surfaces that can both bend and reflect light.

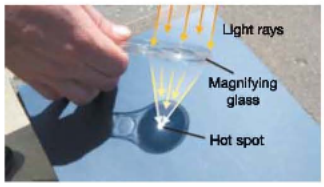


Figure 25.16: *A magnifying glass is a converging lens. This is why a magnifying glass can be used to make a hot spot of concentrated light. You should NOT try this yourself—the science is interesting but can be unsafe.*

Ways that matter affects light

Light's interactions

The following list describes what can happen when light interacts with matter such as glass, wood, or anything else. You can see these interactions illustrated in Figure 25.17.

- Transparency: light passes through almost unchanged
- Translucency: light passes through but is scattered
- Reflection: light bounces off
- Absorption: light transfers its energy

VOCABULARY

transparent - describes matter that allows light rays to pass through without scattering.

translucent - describes matter that allows light rays to pass through but also scatters them in all directions.

Transparency

Materials that allow light to pass through are called **transparent**. Polished glass is transparent, as are some kinds of plastic. Air is also transparent. You can see an image through a transparent material if the material's surface is smooth, like a glass window.

Translucency

An object is **translucent** if it scatters light in many directions as it allows the light to pass through. Tissue paper and frosted glass are translucent materials. Try holding a sheet of tissue paper up to a window. You can't see an image through it.

Reflection and absorption

Almost all surfaces reflect some light. A mirror is a very good reflector, but a sheet of white paper is also a good reflector. The difference is in *how* they reflect. When light is absorbed, its energy is transferred. This is why a black road surface gets hot on a sunny day. A perfect absorber looks black because it absorbs most of the light that falls on it.

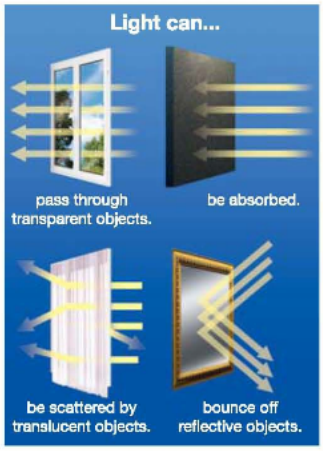


Figure 25.17: *The four interactions of light with matter.*

All interactions at once

When light encounters matter, it can interact in multiples ways. For example, a green shirt both absorbs and reflects colors of light. Although it is mostly transparent, a glass window does absorb some light. Glass also reflects and scatters some light (translucency). A material interacts differently with light depending on how well the surface is polished. For instance, the rough surface of frosted glass makes it translucent.

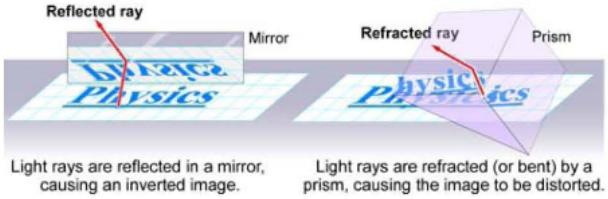
Light rays

What are light rays?

When light moves through a material, it travels in straight lines. Diagrams that show how light travels use straight lines and arrows to represent **light rays**. Think of a light ray as a thin beam of light, like a laser beam. The arrow shows the direction in which the light is moving.

Reflection and refraction

When light rays move from one material into another, the rays might bounce or bend. **Reflection** happens when light bounces off a surface. **Refraction** happens when light bends while crossing a surface or moving through a material. Reflection and refraction cause many interesting changes in the images we see.



Light rays are reflected in a mirror, causing an inverted image.

Light rays are refracted (or bent) by a prism, causing the image to be distorted.

Reflection creates images in mirrors

When you look in a mirror, objects that are in front of the mirror appear as if they are behind the mirror. Light from the object strikes the mirror and reflects to your eyes. The image reaching your eyes appears to your brain as if the object really *was* behind the mirror. This illusion happens because your brain "sees" the image where it would be if the light reaching your eyes had traveled in a straight line.

Refraction changes how objects look

When light rays travel from air to water, they refract. This is why a straw in a glass of water looks broken or bent at the water's surface (Figure 25.18). Look at some objects through a glass of water; move the glass closer and farther away from the objects. What strange illusions do you see?

VOCABULARY

light ray - an imaginary line that represents a beam of light.

reflection - the process of light rays bouncing off a surface. Light reflects from a mirror.

refraction - the process of bending while crossing a surface. Light refracts when passing from air into water.

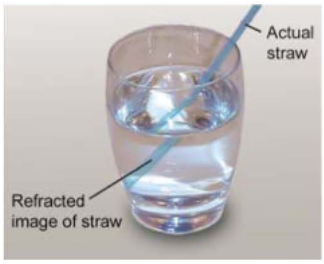


Figure 25.18: *Refraction bends light rays so the straw appears to be in a different place!*

Chapter 25 LIGHT AND OPTICS

Reflection

What is reflection?

When you look into a mirror, your image appears to be the same distance from the other side of the mirror as you are on your side of the mirror. If you step back, so does your image. Reflected light forms images in mirrors.

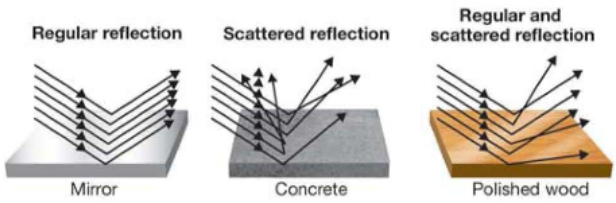
The angle of incidence equals the angle of reflection

Imagine a ray of light striking a mirror. The incident ray is the light ray that strikes the surface of the mirror. The reflected ray is the light ray that bounces off the surface of the mirror (Figure 25.19, top).The lower part of Figure 25.19 shows the reflection of a light ray. The *angle of incidence* is the angle between the incident ray and an imaginary line drawn perpendicular to the surface of the mirror called the *normal line*. *Perpendicular* means "at a 90-degree angle"; it is also called a right angle. The *angle of reflection* is the angle between the reflected light ray and the normal line. The *law of reflection* states that the angle of incidence is equal to the angle of reflection.

The law of reflection:
angle of incidence equals angle of reflection

Regular and scattered reflection

You see your image when you look in a mirror because parallel light rays hitting the mirror at the same angle are all reflected at the same angle. This is called **specular reflection**. You can't see your image when you look at a white piece of paper because even though it seems smooth, its surface has tiny bumps on it. When parallel light rays hit a bumpy surface, the bumps reflect the light rays at different angles. Light rays reflected at different angles cause **scattered reflection**. Many surfaces, such as polished wood, are in between rough and smooth and create both types of reflection.



VOCABULARY

specular reflection - "shiny" surface reflection, where each incident ray produces only one reflected ray.

diffuse reflection - "dull" surface reflection, where each incident ray produces many scattered rays.

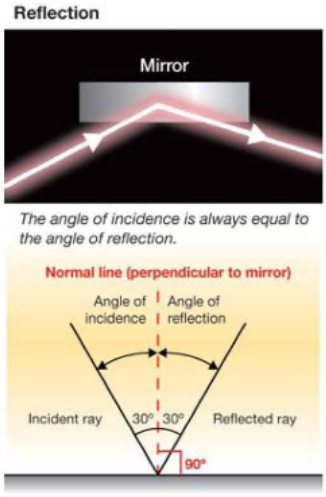


Figure 25.19: *This diagram illustrates the law of reflection.*

Refraction

The index of refraction

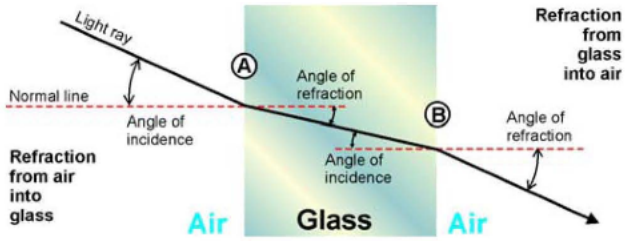
Eyeglasses, telescopes, binoculars, and fiber optics are a few inventions that use refraction to change the direction of light rays. Different materials have different abilities to bend light. Materials with a higher **index of refraction** bend light by a greater angle. The index of refraction for air is approximately 1.00. Water has an index of refraction of 1.33. A diamond has an index of refraction of 2.42. Diamonds sparkle because of their high index of refraction. Table 25.2 lists the index of refraction for some common materials.

Table 25.2: The Index of Refraction for Some Common Materials

Material	Index of Refraction
Air	1.00
Water	1.33
Ice	1.31
Glass	1.45–1.65
Diamond	2.42

The direction a light ray bends

When light goes from air into glass (A), it bends toward the normal line because glass has a higher index of refraction than air. When the light goes from glass into air again (B), it bends away from the normal line. Coming out of the glass, the light ray is going into air with a lower index of refraction than glass.



VOCABULARY

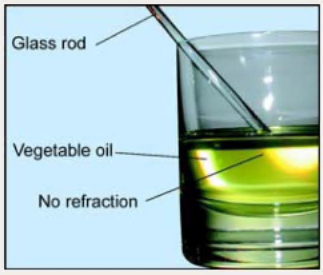
index of refraction - a number that measures how much a material is able to bend light.

SCIENCE FACT

A Trick of Refraction

If two materials have the same index of refraction, light doesn't bend at all. Here's a neat trick you can do with a glass rod. You see the edges of a glass rod because of refraction. The edge appears dark because light is refracted away from your eyes.

Vegetable oil and glass have almost the same index of refraction. If you put a glass rod into a glass cup containing vegetable oil, the rod disappears because light is NOT refracted around its edges!



Lenses

A lens and its optical axis

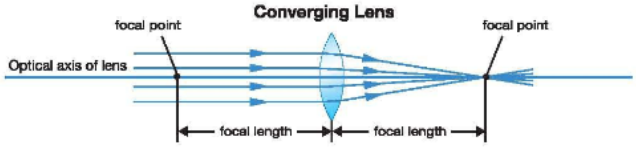
An ordinary lens is a polished, transparent disc, usually made of glass. The surfaces are curved to refract light in a specific way. The exact shape of a lens's surface depends on how strongly and in what way the lens needs to bend light.

How light travels through a converging lens

Common lenses have surfaces shaped like part of a sphere. Any radius of a sphere is also a normal line to the surface. When light rays fall on a spherical surface from air, they bend *toward* the normal line (Figure 25.20). For a **converging lens**, which has convex surfaces, the first surface (air to glass) bends light rays toward the normal line. At the second surface (glass to air), the rays bend *away* from the normal line. Because the second surface "tilts" the other way, it also bends rays toward the focal point.

Focal point and focal length

Light rays that enter a converging lens parallel to its axis bend to meet at a point called the *focal point* (see the illustration below). Light can go through a lens in either direction, so there are always two focal points, one on either side of the lens. The distance from the center of the lens to the focal point is the *focal length*. The focal length is usually (but not always) the same for both focal points of a lens.



Diverging lenses

Figure 25.21 shows how parallel light rays enter and then exit a **diverging lens**, which has concave surfaces. As with the converging lens, light bends toward the normal line when it enters and away from the normal line when it exits the lens. However, because of the shape of the lens surfaces, the light ends up bending away from the optical axis and away from the focal point. For a diverging lens, you can show the focal point in a diagram by extending the path of the exiting light rays back through the lens. These extended lines are drawn as dotted lines in Figure 25.21.

VOCABULARY

converging lens - a lens that bends exiting light rays toward the focal point.

diverging lens - a lens that bends exiting light rays outward, away from the focal point.

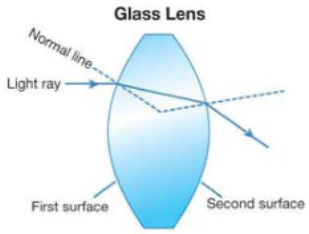


Figure 25.20: *Most lenses have spherically shaped surfaces.*

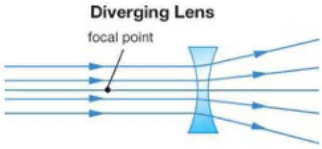


Figure 25.21: *Diverging lens.*

25.3 Section Review

1. What process takes place when light rays enter a lens?
   a. reflection
   b. refraction
   c. absorption
   d. transparency
2. Can light be reflected and refracted at the same time? If so, give an example.
3. What optical devices do you use during an average day?
4. Name an object that is mostly transparent, one that is translucent, one that is mostly absorbent, and one that is mostly reflective.
5. Windows that look into bathrooms or other private spaces are often translucent instead of transparent. Why?
6. Why can you see your own reflected image in a mirror but not on a dry, painted wall?
7. Describe how your brain interprets the light rays reflected off a mirror.
8. How are light rays shown in diagrams?
9. Make a diagram that shows a light ray striking a mirror. Label the angle of incidence, the angle of reflection, and the normal line.
10. The index of refraction describes:
    a. the color of a material.
    b. the focal length for a lens.
    c. how much a material bends light rays.
    d. whether a material is transparent or translucent.
11. A clear plastic rod seems to disappear when it is placed in water. Based on this observation and Table 25.1, predict the index of refraction for the plastic.
12. Fill in the blank. When light travels from water into air, the refracted light ray bends _____ (*away from* or *toward*) the normal line.
13. What is the difference between a converging lens and a diverging lens?

SCIENCE FACT

Twinkling of Stars

Another example of the refraction of light is the twinkling of a star in the night sky. To reach your eyes, starlight must travel from space through Earth's atmosphere, which varies in temperature and density. Cold pockets of air are more dense than warm pockets. Starlight is refracted as it travels through the various air pockets. Since the atmosphere is constantly changing, the amount of refraction also changes. The image of a star appears to "twinkle," or move, because the light coming to your eye follows a zig-zag path due to refraction.