10.3 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, 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 10.17). 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.

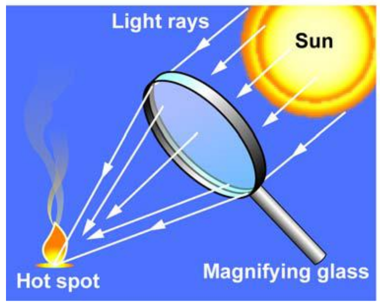


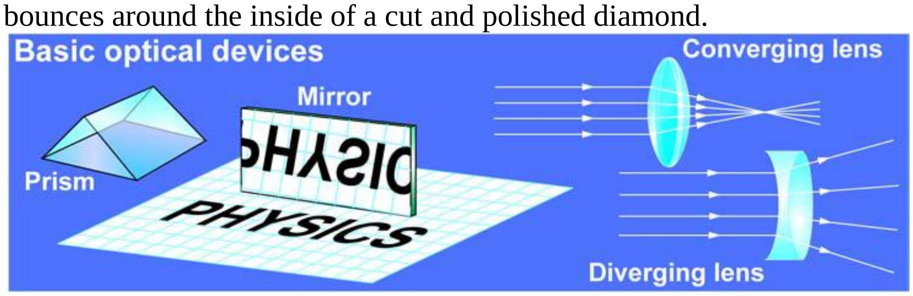
Figure 10.17: *A magnifying glass is a converging lens. This is why a magnifying glass can be used to make a hot spot of concentrated light. You should NOT try this yourself - the science is interesting, but can be unsafe.*

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 look appear thinner, wider, or even upside down!

Prisms

A **prism** is usually made of a solid piece of glass with flat polished surfaces. A common triangular prism is shown in the picture below. Prisms can both bend and/or reflect light. Telescopes, cameras, and supermarket laser scanners use prisms of different shapes to bend and reflect light in precise ways. A diamond is a 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 inside of a cut and polished diamond.



Four ways that light is affected by matter

The four interactions

When light interacts with matter, like glass, wood, or anything else, here are four of the things that can happen.

- The light can go through almost unchanged (transparency).
- The light can go through but be scattered (translucency).
- The light can bounce off (reflection).
- The light can transfer its energy to the material (absorption).

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 though a transparent material if the surfaces are smooth, like a glass window.

Translucency
An object is **translucent** if some light can pass through but the light is scattered in many directions (Figure 10.18). Tissue paper is translucent, and so is frosted glass. 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. That is why a black road surface gets hot on a sunny day. A perfect absorber looks black because it reflects no light at all.

All interactions at once
All four interactions almost always happen together. A glass window is mostly transparent but also absorbs about 10% of light. The glass scatters some light (translucency) and reflects some light. The same material also behaves differently depending on how well the surface is polished. Frosted glass has a rough surface and is translucent. Look at the illustration at the left. Green colored paper absorbs some light, reflects some light, and is partly translucent. Can you tell which colors are absorbed and which are reflected?

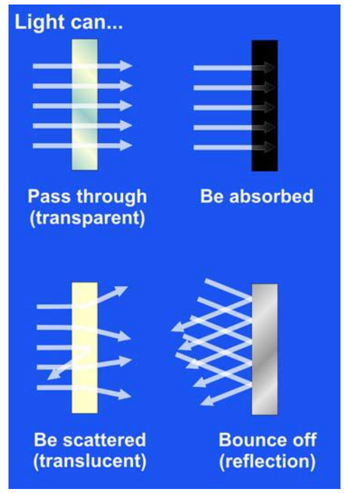
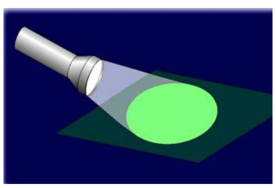


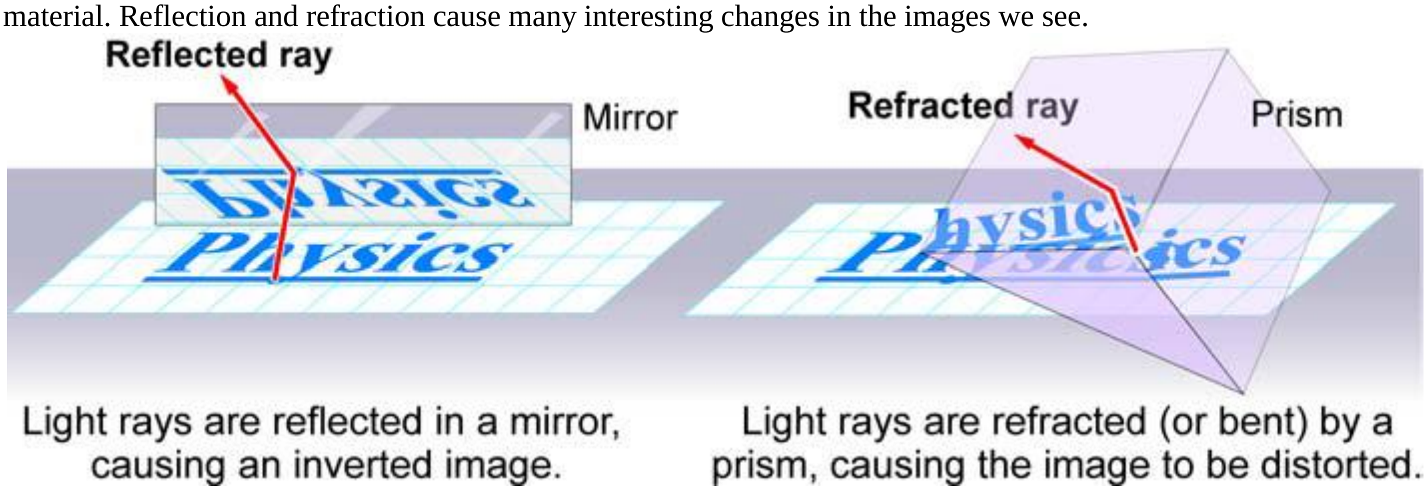
Figure 10.18: *The four interactions of light with matter.*



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 the light is moving.

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



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 10.19). 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?

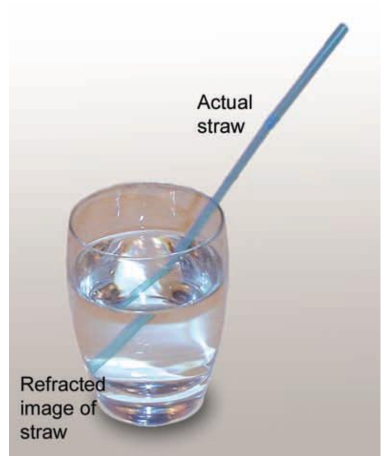


Figure 10.19: *Refraction bends light rays so the straw appears to be in a different place!*

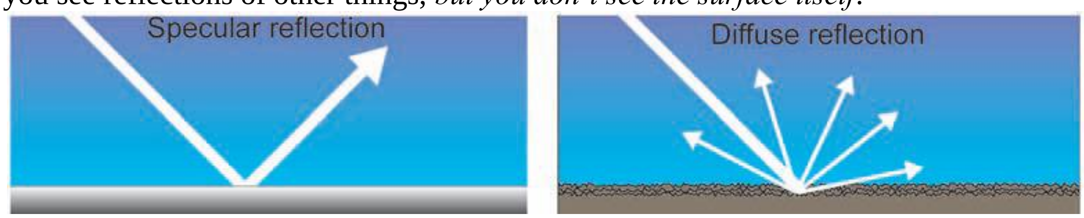
Reflection

The image in a mirror

When you look at yourself in a mirror, you see your own image as if your exact twin were standing in front of you. The image appears to be the same distance from the other side of the mirror as you are on your side of the mirror (Figure 10.20). If you step back, so does your image. Images form in mirrors because of how light is reflected.

Specular reflection

Light is reflected from all surfaces, not just mirrors. But not all surfaces form images. The reason for this is that there are two types of reflections. A ray of light that strikes a shiny surface (like a mirror) creates a single reflected ray. This type of reflection is called **specular reflection**. Specular reflection is why you see an image in a polished surface, like a mirror. In fact, a surface which has perfect specular reflection is *invisible*. If you look at that surface, you see reflections of other things, *but you don't see the surface itself*.



Diffuse reflection

A surface that is dull, (not shiny) creates **diffuse reflection**. In diffuse reflection, each reflected ray of light scatters in many directions creating multiple reflected rays. Diffuse reflection is caused by the roughness of a surface. Even if a surface feels smooth to the touch, on a microscopic level it may be rough. For example, the surface of a wooden board creates a diffuse reflection. When you look at a diffuse reflecting surface *you see the surface itself*.

One surface can create both types of reflection

Many surfaces are in between rough and smooth. These kinds of surfaces create both kinds of reflection. For example, a polished wood tabletop can reflect some light in specular reflection, and the rest of the light in diffuse reflection. The specular reflection creates a faint reflected image on the table surface. You also see the table surface itself by light from diffuse reflection.

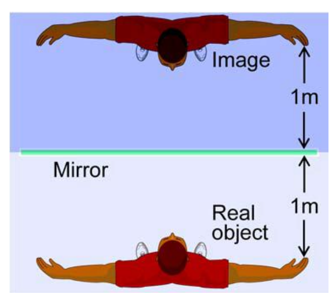


Figure 10.20: *The image you see in a flat mirror appears to be the same distance behind the mirror as you are in front of it.*

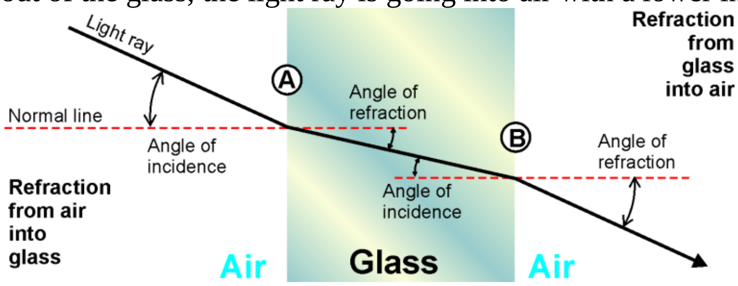
Refraction

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 10.1 lists the index of refraction for some common materials.

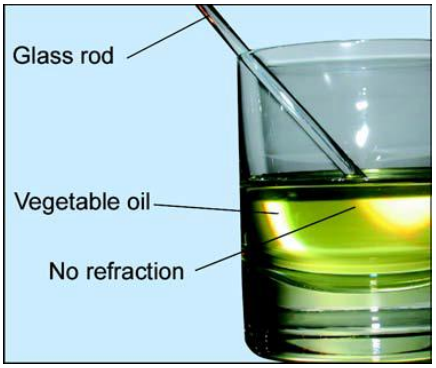
The direction a light ray bends

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.



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

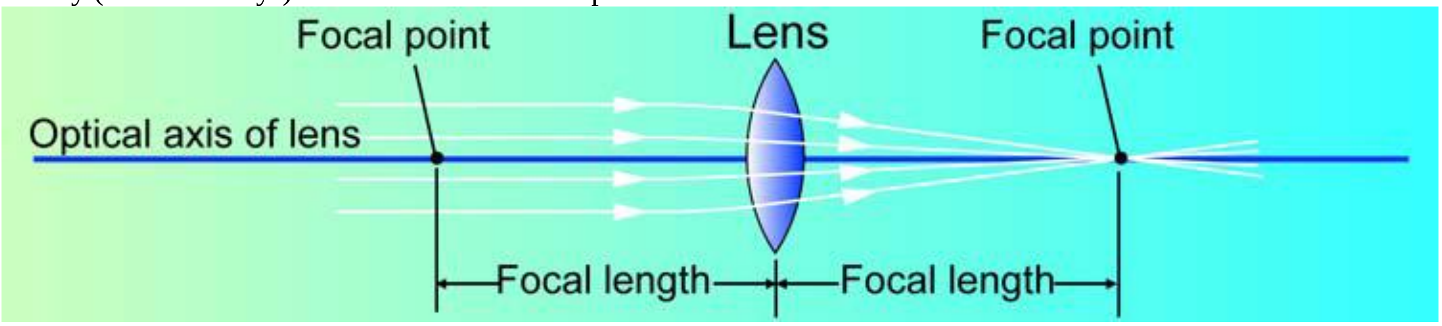
An ordinary lens is a polished, transparent disc, usually made of glass. The surfaces are curved to refract light in a specific way. The exact shape of a lens's surface depends on how strongly and in what way the lens needs to bend light.

How light travels through a converging lens

The most 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 10.21). For a converging lens, 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 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.



Converging and diverging lenses

Figure 10.22 shows how light rays enter and exit two types of lenses. The entering rays are parallel to the optical axis. A *converging lens* bends exiting rays toward the focal point. A *diverging lens* bends the rays outward, away from the focal point.

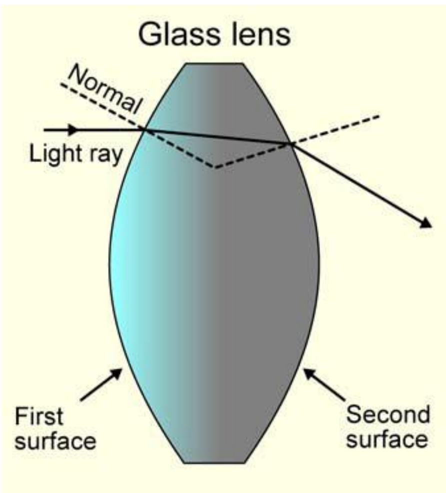


Figure 10.21: *Most lenses have spherically shaped surfaces*

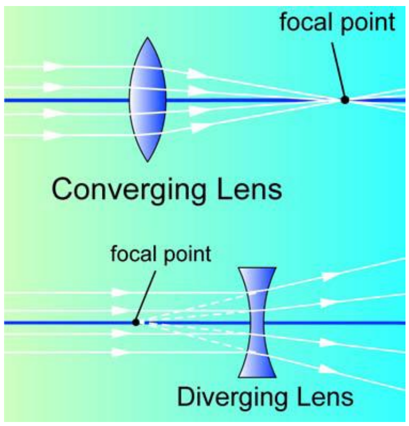


Figure 10.22: *Converging and diverging lenses*

10.3 Section Review

1. A lens uses what process to deflect light rays passing through it?
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. Make a list of all the optical devices you use on 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 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. Why is the true surface of a perfect mirror invisible?

8. The index of refraction determines (pick the best fit)
a. the color of glass
b. the ratio of thickness to focal length for a lens
c. the amount a material bends light rays
d. whether a material is transparent or translucent

9. A clear plastic rod seems to disappear when it is placed in water. Based on this observation and Table 10.1, predict the index of refraction for the plastic.

10. Fill in the blank. When light travels from water into the air, the refracted light ray bends ___________ (away from or toward) the normal line.

11. What is the difference between a converging lens and a diverging lens?