

Chapter 29 Reflection and Refraction

Summary

THE BIG IDEA : When waves interact with matter, they can be reflected, transmitted, or a combination of both. Waves that are transmitted can be refracted.

29.1 Reflection

- ✓ When a wave reaches a boundary between two media, usually some or all of the wave bounces back into the first medium.
 - The return of a wave back to its original medium is called **reflection**.
 - If you fasten a spring to a wall and send a pulse along the spring's length, all of the wave energy is reflected back along the spring rather than transmitted into the wall. Waves that travel along the spring are almost *totally reflected* at the wall.
 - If the wall is replaced with a less rigid medium, such as a heavy spring, some energy is transmitted into the new medium. Some of the wave energy is still reflected and the incoming wave is *partially reflected*.
 - Metals reflect almost all the frequencies of visible light.
 - When light shines perpendicularly on the surface of still water or glass, only a very small percentage of its energy is reflected; the rest is transmitted.

29.2 The Law of Reflection

- ✓ The law of reflection states that the angle of incidence and the angle of reflection are equal to each other.
 - Incident rays and reflected rays make equal angles with a line perpendicular to the surface, called the **normal**.
 - The angle between the incident ray and the normal is called the **angle of incidence**. It is equal to the **angle of reflection**, which is the angle between the reflected ray and the normal.
 - The **law of reflection** is the relationship between the angle of incidence and angle of reflection. The law of reflection applies to both partially reflected and totally reflected waves.

29.3 Mirrors

- ✓ Mirrors produce only virtual images.
 - A **virtual image** is an image that appears in a location where light does not really reach.
 - Your eye cannot ordinarily tell the difference between an object and its virtual image because the light that enters your eye is entering in exactly the same manner as it would without the mirror if there really were an object where you see the image.
 - The virtual image formed by a *convex* mirror (a mirror that curves outward) is smaller and closer to the mirror than the object is. When the object is close to a *concave* mirror (a mirror that curves inward like a "cave"), the virtual image is larger and farther away than the object is.

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29.4 Diffuse Reflection

- ✓ When light is incident on a rough surface, it is reflected in many directions.
- **Diffuse reflection** is the reflection of light from a rough surface. Although each ray obeys the law of reflection, the many different angles that incident light rays encounter at the surface cause reflection in many directions.
- Whether a surface is a diffuse reflector or a polished reflector depends on the wavelength of the waves it reflects.
- We see most of the things around us by diffuse reflection.

29.5 Reflection of Sound

- ✓ Sound energy not reflected is absorbed or transmitted.
- An echo is reflected sound. The fraction of sound energy reflected from a surface is greater when the surface is rigid and smooth, and smaller when the surface is soft and irregular.
- The study of the reflective properties of surfaces and sound is called *acoustics*.
- When the walls of a room, auditorium, or concert hall are too reflective, the sound becomes garbled. This is due to multiple reflections of sound waves called **reverberations**. In the design of an auditorium or concert hall, a balance between reverberation and absorption is desired.
- Both sound and light obey the same law of reflection, so if a reflector is oriented so that you can *see* a particular musical instrument, you will *hear* it also. Sound from the instrument will follow the line of sight to the reflector and then to you.

29.6 Refraction

- ✓ When a wave that is traveling at an angle changes its speed upon crossing a boundary between two media, it bends.
- Water waves bend, or refract, when one part of each wave is made to travel slower (or faster) than another part.
- **Refraction** is the bending of a wave as it crosses the boundary between two media at an angle.
- In wave drawings, **wave fronts** are lines that are drawn to represent the positions of different crests.

29.7 Refraction of Sound

- ✓ Sound waves are refracted when parts of a wave front travel at different speeds.
- Sound wave refraction occurs in uneven winds or when sound is traveling through air of uneven temperature.

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- On a cold day or night, when the layer of air near the ground is colder than the air above it, the speed of sound near the ground is reduced. The higher speeds of the wave fronts above cause a bending of the sound toward Earth. When this happens, sound can be heard over considerably longer distances.

29.8 Refraction of Light

- ✓ **Changes in the speed of light as it passes from one medium to another, or variations in the temperatures and densities of the same medium, cause refraction.**
- When light rays enter a medium in which their speed decreases, as when passing from air into water, the rays bend toward the normal.
- When light rays enter a medium in which their speed increases, as when passing from water into air, the rays bend away from the normal.

29.9 Atmospheric Refraction

- ✓ **A mirage is caused by the refraction of light in Earth's atmosphere.**
- The appearance of a distorted image that forms as the result of atmospheric refraction is called a **mirage**.
- On hot days, there may be a layer of very hot air in contact with the ground. Since molecules in hot air are farther apart, light travels faster through this air than through the cooler air above it. The speeding up of the part of the wave nearest the ground produces a gradual bending of the light rays, which can produce a mirage.
- When you watch the sun set, you see the sun for several minutes after it has really sunk below the horizon. This is because light is refracted by Earth's atmosphere.

29.10 Dispersion in a Prism

- ✓ **Since different frequencies of light travel at different speeds in transparent materials, they will refract differently and bend at different angles.**
- The average speed of light is less than c in a transparent medium.
- Light of frequencies closer to the natural frequency of the electron oscillators in a medium travels more slowly in the medium. This is because there are more interactions between the light and the medium.
- Since the natural or resonant frequency of most transparent materials is in the ultraviolet part of the spectrum, visible light of higher frequencies travels more slowly than light of lower frequencies.
- When light is bent twice at nonparallel boundaries, as in a prism, the separation of the different colors of light is quite apparent. This separation of light into colors arranged according to their frequency is called **dispersion**.

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29.11 The Rainbow

- ✓ In order for you to see a rainbow, the sun must be shining in one part of the sky, and the water droplets in a cloud or in falling rain must be in the opposite part of the sky.
- In an individual spherical raindrop, some of the light is reflected and the rest is refracted into the drop. At the first refraction, the light is dispersed into its spectral colors. At the second refraction, light is concentrated in a narrow range of angles.
- Each raindrop disperses a full spectrum of colors. An observer, however, is in a position to see only a single color from any one drop. If violet light from a single drop enters your eye, red light from the same drop falls below your eye.
- The dispersed light of other colors in a rainbow is along similar arcs, each at their own slightly different angle. Altogether, the arcs for each color form the familiar rainbow shape.

29.12 Total Internal Reflection

- ✓ Total internal reflection occurs when the angle of incidence is larger than the critical angle.
- The critical angle is the angle of incidence that results in light being refracted at an angle of 90° with respect to the normal.
- When a flashlight submerged in water is tipped beyond the critical angle (48° from the normal in water), the beam of light cannot enter the air; it is only reflected. The beam is experiencing **total internal reflection**, which is the complete reflection of light back into its original medium.
- Total internal reflection is as the name implies: total—100%. Silvered or aluminized mirrors reflect only 90 to 95% of incident light, and are marred by dust and dirt. Prisms, on the other hand, are more efficient and thus are often used instead of mirrors in many optical instruments.
- The critical angle for a diamond is 24.6° , smaller than in other common substances. This means that light inside a diamond is more likely to be totally internally reflected than to escape. A diamond's small critical angle, plus the pronounced refraction within the material, produces wide dispersion and a wide array of brilliant colors.
- **Optical fibers**, sometimes called *light pipes*, are transparent fibers that pipe light from one place to another.