CHAPTER OUTLINE

Section 1 Sound

Key Idea questions
> What are the characteristics of sound waves?
> How do musical instruments make sound?
> How do ears help humans hear sound waves?
> How are the reflections of sound waves used?

Properties of Sound

> What are the characteristics of sound waves?

> Sound waves are caused by vibrations and carry energy through a medium.

- sound wave: a longitudinal wave that is caused by vibrations and that travels through a material medium
- In air, sound waves spread out in all directions away from the source.
- The speed of sound depends on the medium.
  - The speed of sound in a particular medium depends on how well the particles can transmit the motions of sound waves.
  - Sound waves travel faster through liquids and solids than through gases.
- Loudness is determined by intensity.
  - *loudness*: depends partly on the energy contained in the sound wave
  - *intensity:* describes the rate at which a sound wave transmits energy through a given area of a medium
  - Intensity depends on
    - the amplitude of the sound wave
    - your distance from the source
  - The greater the intensity of a sound, the louder the sound will seem.

        - Intensity is measured in units called *decibels*, dB.

- Pitch is determined by frequency.
    - pitch: a measure of how high or low a sound is perceived to be depending on the frequency of the sound wave
    - A high-pitched sound corresponds to a high-frequency.
    - A low-pitched sound corresponds to a low frequency.
- Humans hear sound waves in a limited frequency range.
    - Any sound with a frequency below the range of human hearing is known as an infrasound.
        - infrasound: slow vibrations of frequencies lower than 20 Hz
    - Any sound with a frequency above human hearing range is known as an ultrasound.
        - ultrasound: is any sound wave with frequencies higher than 20,000 Hz

Musical Instruments

> How do musical instruments make sound?

> Most instruments produce sound through the vibration of strings, air columns, or membranes.

- Musical instruments rely on standing waves.
    - Standing waves can exist only at certain wavelengths on a string.
    - The primary standing wave on a vibrating string has a wavelength that is twice the length of the string.
        - The frequency of this wave is called the *fundamental frequency.*
- Instruments use resonance to amplify sound.

- resonance: a phenomenon that occurs when two objects naturally vibrate at the same frequency

- *natural frequencies:* the specific frequencies at which an object is most likely to vibrate

  – The natural frequency of an object depends on the object's shape, size, mass, and the material from which the object is made.

Hearing and the Ear

> How do ears help humans hear sound waves?

> The human ear is a sensitive organ that senses vibrations in the air, amplifies them, and then transmits signals to the brain.

- Vibrations pass through three regions in the ear.

  – Your ear is divided into three regions—outer, middle, and inner.

- Resonance occurs in the inner ear.

  – A wave of a particular frequency causes a specific part of the basilar membrane to vibrate.

  – Hair cells near the part of the membrane that vibrates then stimulate nerve fibers that send an impulse to the brain.

The Ear

> How are the reflections of sound waves used?

> Reflected sound waves are used to determine distances and to create images.

- Some ultrasound waves are reflected at boundaries.

- Ultrasound imaging is used in medicine.

  - The echoes of very high frequency ultrasound waves, between 1 million and 15 million Hz, are used to produce computerized images called *sonograms*.

- Some ultrasound waves are reflected at boundaries.
  - Some sound waves are reflected when they pass from one type of material into another.
  - How much sound is reflected depends on the density of the materials at each boundary.
  - The reflected waves can be made into a computer image called a *sonogram.*
- Sonar is used to locate objects underwater.
- Sonar: sound navigation and ranging, a system that uses acoustic signals and echo returns to determine the location of objects or to communicate.
- A sonar system determines distance by measuring the time it takes for sound waves to be reflected back from a surface.

$$d = vt$$

  - d is distance
  - v is the average speed of the sound waves in water
  - t is time

Section 2 The Nature of Light

Key Idea questions
> How do scientific models describe light?
> What does the electromagnetic spectrum consist of?

Waves and Particles

> How do scientific models describe light?

> The two most common models describe light either as a wave or as a stream of particles.

- Light produces interference patterns as water waves do.
- Light can be modeled as a wave.
  - This model describes light as transverse waves that do not require a medium in which to travel.
  - Light waves are also called *electromagnetic waves.*
    - They consist of changing electric and magnetic fields.
  - The wave model of light explains
    - how light waves interfere with one another
    - why light waves may reflect
    - why light waves refract
    - why light waves diffract
- The wave model of light cannot explain some observations.
  - When light strikes a piece of metal, electrons may fly off the metal's surface.
- Light can be modeled as a stream of particles.
  - In the particle model of light, the energy of light is contained in packets called photons.
  - photon: a unit or quantum of light
- A beam of light is considered to be a stream of photons.

  - Photons are particles.
  - Photons do not have mass.
  - The energy in a photon is located in a specific area.
- The model of light used depends on the situation.
  - *dual nature of light:* light can behave both as waves and as particles
- The energy of light is proportional to frequency.
  - The amount of energy in a photon is proportional to the frequency of the corresponding electromagnetic wave
- The speed of light depends on the medium.

The Electromagnetic Spectrum

> What does the electromagnetic spectrum consist of?

> The electromagnetic spectrum consists of light at all possible energies, frequencies, and wavelengths.

- The visible spectrum is only a small part of the electromagnetic spectrum.
- Each part of the electromagnetic spectrum has unique properties.
- Radio waves are used in communications and radar.
  - Radio waves have wavelengths that range from tenths of a meter to thousands of meters.
  - Radar: radio detection and ranging, a system that uses reflected radio waves to determine the velocity and location of objects
- Microwaves are used in cooking and communication.
  - Microwaves have wavelengths in the range of centimeters.
- Infrared light can be felt as warmth.

  - Infrared (IR) wavelengths are slightly longer than red visible light.

- Sunlight contains ultraviolet light.

  - The invisible light that lies just beyond violet light falls into the *ultraviolet* (UV) portion of the spectrum.

- X rays and gamma rays are used in medicine.

  - X rays have wavelengths less than 10^{-8} m.

  - *Gamma rays* are the electromagnetic waves with the highest energy.

    - They have wavelengths shorter than 10^{-10} m.

Section 3 Reflection and Color

Key Idea questions
> How do objects interact with incoming light?
> How can you see an image in a mirror?
> Why do we see colors?

Reflection of Light

> How do objects interact with incoming light?

> Every object reflects some light and absorbs some light.

- Light can be modeled as a ray.
  - light ray: a line in space that matches the direction of the flow of radiant energy
  - The direction of the light ray is the same as the direction of wave travel or as the path of photons.
- Light rays are used to describe reflection and refraction.
- *geometrical optics*: the study of light in cases in which light behaves like a ray
- *ray diagrams:* geometrical drawings that use light rays to trace the path of light
- Rough surfaces reflect light rays in many directions.
  - *diffuse reflection*: the reflection of light in random directions
- Smooth surfaces reflect light rays in one direction.
- law of reflection: When light hits a smooth surface, the angle of incidence (θ) equals the angle of reflection (θ').
- *angle of reflection:* the angle of the light rays reflecting off a surface
- *angle of incidence:* the angle of the light rays striking the surface

Mirrors

> How can you see an image in a mirror?

> Mirrors reflect light as described by the law of reflection, and this light reaches your eyes. The type of image you perceive depends on the type of mirror.

- Flat mirrors form virtual images by reflection.
  - virtual image: an image that forms at a location from which light rays appear to come but do not actually come
- Curved mirrors can distort images.
  - Because the surface is not flat, the line perpendicular to the normal points in different directions for different parts of the mirror.
  - *convex mirrors:* mirrors that bulge out
  - *concave mirrors:* indented mirrors
- Concave mirrors can create real images.
  - Concave mirrors are used to focus reflected light.
  - A virtual image may form behind a concave mirror.
  - A real image may form in front of a concave mirror.
  - real image: an image of an object formed by light rays that actually come together at a specific location
  - Light rays exist at the point where the real image appears.

Seeing Colors

> Why do we see colors?

> The colors that you perceive depend on the wavelengths of visible light that reach your eyes.

- Objects have the color of the wavelengths they reflect.

  - White light from the sun actually contains light from the visible wavelengths of the electromagnetic spectrum.

- Mixtures of colors produce other colors.

- Colors may add or subtract to produce other colors.

  - *additive primary colors:* red, green, and blue

    - Mixing light of the three additive primary colors makes white light.

  - *subtractive primary colors:* yellow, cyan, and magenta

    - If filters or pigments of all three colors are combined in equal proportions, all visible light is absorbed.

    - Black is the absence of color.

Section 4 Refractions, Lenses, and Prisms

Key Idea questions

> What happens to light when it passes from one medium to another medium?
> What happens when light passes through a lens?
> How can a prism separate white light into colors?

Refraction of Light

> What happens to light when it passes from one medium to another medium?

> Light waves bend, or refract, when they pass from transparent one medium to another.

- Light bends when it changes mediums because the speed of light differs in each medium.
- When light moves from a material in which its speed is higher to a material in which its speed is lower, the ray is bent toward the normal.
- If light moves from a material in which its speed is lower to one in which its speed is higher, the ray is bent away from the normal.
- Refraction makes objects appear to be in different positions.
- Refraction in the atmosphere creates mirages.
  - *mirage*: a virtual image caused by light in the atmosphere

Lenses

> What happens when light passes through a lens?

> When light passes through a medium that has a curved surface, a lens, the light rays change direction.

- lens: a transparent object that refracts light waves such that they converge or diverge to create an image

- A *converging lens* bends light inward.
  - A converging lens can create either a virtual image or a real image.
- A bends light outward.
  - A *diverging lens* diverging lens can only create a virtual image.
- Lenses can magnify images.
  - A magnifying glass is an example of a converging lens.
  - Magnification: is change in the size of an image compared with the size of an object
  - By adjusting the height of the lens, you can focus the light rays together into a small area, called the *focal point.*
- Microscopes and refracting telescopes use multiple lenses.
- The eye depends on refraction and lenses.
  - Light first enters the eye through a transparent tissue called the cornea.
  - After the cornea, light passes through the pupil.
  - Then, light travels through the lens.
  - Muscles can adjust the curvature of the lens until an image is focused on the back layer of the eye, the retina.
  - The retina is composed of tiny structures, called rods and cones, that are sensitive to light.

Dispersion and Prisms

> How can a prism separate white light into colors?

> A prism can separate the colors of light because the speeds of light waves traveling through the medium depend on the wavelengths of light.

- prism: in optics, a system that consists of two or more plane surfaces of a transparent solid at an angle with each other
- Different colors of light are refracted by different amounts.
- The speed of a light wave in a medium depends on the light wave's wavelength.
  - Violet light has the shortest wavelength and travels the slowest.
  - Red light has the longest wavelength and travels the fastest.
  - Violet light bends more than red light.
- dispersion: the process of separating a wave (such as white light) of different frequencies into its individual component waves (the different colors)
- Rainbows are caused by dispersion and reflection.