Section 1: Sound

Preview

• Key Ideas
• Bellringer
• Properties of Sound
• Sound Intensity and Decibel Level
• Musical Instruments
• Hearing and the Ear
• The Ear
• Ultrasound and Sonar
Key Ideas

› 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?
Bellringer

1. Sound must have a medium through which to travel. Through which medium—solid, liquid, or gas—does sound travel the fastest? *(Hint: Use the kinetic theory.)*

2. Explain how a wind instrument, such as a clarinet, makes sound.
3. On a string instrument, such as a guitar or violin, how does one string make different musical notes?

4. Using wave theory, explain how making sound with a wind instrument is essentially the same as making sound with a string instrument.
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.
Properties of Sound, continued

- 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.
Properties of Sound, continued

Speed of Sound in Various Mediums

<table>
<thead>
<tr>
<th>Medium</th>
<th>Speed of sound (m/s)</th>
<th>Medium</th>
<th>Speed of sound (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air (0 °C)</td>
<td>331</td>
<td>Liquids at 25 °C</td>
<td></td>
</tr>
<tr>
<td>Air (25 °C)</td>
<td>346</td>
<td>Water</td>
<td>1,490</td>
</tr>
<tr>
<td>Air (100 °C)</td>
<td>386</td>
<td>Sea water</td>
<td>1,530</td>
</tr>
<tr>
<td>Helium (0 °C)</td>
<td>972</td>
<td>Solids</td>
<td></td>
</tr>
<tr>
<td>Hydrogen (0 °C)</td>
<td>1,290</td>
<td>Copper</td>
<td>3,813</td>
</tr>
<tr>
<td>Oxygen (0 °C)</td>
<td>317</td>
<td>Iron</td>
<td>5,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rubber</td>
<td>54</td>
</tr>
</tbody>
</table>
Properties of Sound, *continued*

- 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.
## Sound Intensity and Decibel Level

### Some Common Decibel Levels

<table>
<thead>
<tr>
<th>Sound</th>
<th>Decibel level</th>
</tr>
</thead>
<tbody>
<tr>
<td>The softest sounds you can hear</td>
<td>0</td>
</tr>
<tr>
<td>Whisper</td>
<td>20</td>
</tr>
<tr>
<td>Purring cat</td>
<td>25</td>
</tr>
<tr>
<td>Normal conversation</td>
<td>60</td>
</tr>
<tr>
<td>Lawn mower, vacuum cleaner, truck traffic</td>
<td>80</td>
</tr>
<tr>
<td>Chain saw, snowmobile</td>
<td>100</td>
</tr>
<tr>
<td>Sandblaster, loud rock concert, automobile horn</td>
<td>115</td>
</tr>
<tr>
<td>Threshold of pain</td>
<td>120</td>
</tr>
<tr>
<td>Jet engine 30 m away</td>
<td>140</td>
</tr>
<tr>
<td>Rocket engine 50 m away</td>
<td>200</td>
</tr>
</tbody>
</table>
Properties of Sound, continued

• 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.
Properties of Sound, continued

- 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**: 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.
Musical Instruments, *continued*

- 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.
Sound and Light

Section 1

Hearing and the Ear, *continued*

- 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.
1. In the outer ear, sound waves cause the eardrum to vibrate.

2. In the middle ear, vibrations cause the stirrup bone to strike the outer membrane of the inner ear.

3. In the inner ear, the basilar membrane vibrates. The movement of this membrane causes a signal to be sent to the brain.
Ultrasound and Sonar

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 and Sonar, continued

- 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.
Ultrasound and Sonar, continued

• 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

Preview

• Key Ideas
• Bellringer
• Waves and Particles
• Energy of a Photon
• The Electromagnetic Spectrum
Key Ideas

› How do scientific models describe light?

› What does the electromagnetic spectrum consist of?
Bellringer

1. Name five common applications of waves in the electromagnetic spectrum, and list the type of wave used in each case.

2. An airplane can be detected by radar. When radio waves strike an airplane, they are reflected back to a detector and the airplane shows up on a radar screen. Explain how stealth airplanes fly through the air without being detected by radar.

3. Radio waves that carry radio station transmissions and gamma rays that destroy cancer cells are both electromagnetic waves. What property makes one wave harmless and the other destructive?
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.
Waves and Particles, continued

• 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
Waves and Particles, continued

• 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
Waves and Particles, *continued*

- 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.
Waves and Particles, *continued*

- 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
<table>
<thead>
<tr>
<th>Type of wave</th>
<th>Wavelength</th>
<th>Wave frequency</th>
<th>Photon energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrared</td>
<td>$1.33 \times 10^{-6}$ m</td>
<td>$2.25 \times 10^{14}$ Hz</td>
<td>$1.5 \times 10^{-19}$ J</td>
</tr>
<tr>
<td>Visible light</td>
<td>$6.67 \times 10^{-7}$ m</td>
<td>$4.5 \times 10^{14}$ Hz</td>
<td>$3.0 \times 10^{-19}$ J</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>$3.33 \times 10^{-7}$ m</td>
<td>$9.0 \times 10^{14}$ Hz</td>
<td>$6.0 \times 10^{-19}$ J</td>
</tr>
</tbody>
</table>
Waves and Particles, continued

• The speed of light depends on the medium.

<table>
<thead>
<tr>
<th>Medium</th>
<th>Speed of light ($\times 10^8$ m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>2.997925</td>
</tr>
<tr>
<td>Air</td>
<td>2.997047</td>
</tr>
<tr>
<td>Ice</td>
<td>2.29</td>
</tr>
<tr>
<td>Water</td>
<td>2.25</td>
</tr>
<tr>
<td>Quartz</td>
<td>2.05</td>
</tr>
<tr>
<td>Glass</td>
<td>1.97</td>
</tr>
<tr>
<td>Diamond</td>
<td>1.24</td>
</tr>
</tbody>
</table>
Waves and Particles, continued

• The brightness of light depends on intensity.

• The quantity that measures the amount of light illuminating a surface is called intensity.

• **Intensity**: the rate at which energy flows through a given area of space
  – Intensity depends on the number of photons per second, or power, that pass through a certain area of space.
The intensity of light decreases as distance from the light source increases because the light spreads out in spherical wave fronts.
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.
The Electromagnetic Spectrum, continued

- 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.
The Electromagnetic Spectrum, continued

- 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

Preview
• Key Ideas
• Bellringer
• Reflection of Light
• The Law of Reflection
• Mirrors
• Seeing Colors
Key Ideas

› How do objects interact with incoming light?

› How can you see an image in a mirror?

› Why do we see colors?
Bellringer

1. A car mirror on the passenger-side door often has a sign that reads “Objects in mirror are closer than they appear.” Why do objects in the mirror seem farther away than they actually are?

2. Light is reflected off of paper. Why can’t you see your reflection in a piece of paper?

3. a. Name the 3 additive primary colors.
   
b. Name the 3 subtractive primary colors.
   
c. What do you see when there is an absence of color?
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.
Reflection of Light, *continued*

- 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
Reflection of Light, continued

- 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.
Reflection of Light, *continued*

- **law of reflection**: the angle of incidence equals the angle of reflection

- **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
The Law of Reflection

When light hits a smooth surface, the angle of incidence ($\theta$) equals the angle of reflection ($\theta'$).
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.
Mirrors, continued

- Flat mirrors form virtual images by reflection.

- **virtual image**: an image from which light rays appear to diverge, even though they are not actually focused there; a virtual image cannot be projected on a screen.
Mirrors, continued

- 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
Mirrors, *continued*

• 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 that is formed by the intersection of light rays; a real image can be projected on screen.
  – Light rays exist at the point where the real image appears.
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.
Seeing Colors, continued

- 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

Preview

- Key Ideas
- Bellringer
- Refraction of Light
- Lenses
- Dispersion and Prisms
Key Ideas

› 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?
Bellringer

1. Erin is driving through the desert on a hot, dry day and sees what appears to be water on the road. What is Erin probably seeing? Explain your answer.

2. Lenses are used to make objects appear larger or smaller. List at least five different uses for a lens.

3. Explain why a rainbow of colors appears after white light passes through a prism.
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 one transparent medium to another.

- Light bends when it changes mediums because the speed of light differs in each medium.
Refraction
Refraction of Light, continued

• 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
**Refraction**

**A** To the cat on the pier, the fish appears to be closer than it actually is.

**B** To the fish, the cat seems to be farther from the surface than it actually is.
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
Lenses, continued

• A *converging lens* bends light inward.
  – A converging lens can create either a virtual image or a real image.

• A *diverging lens* bends light outward.
  – A diverging lens can only create a virtual image.
Lenses, continued

- Lenses can magnify images.
  - A magnifying glass is an example of a converging lens.
  - **Magnification:** the increase of an object’s apparent size by using lenses or mirrors
  - 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.
A compound microscope uses several lenses to produce a highly magnified image.
Lenses, continued

• 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.
The Eye

1. The cornea is a transparent membrane that covers the eye and refracts light.
2. Light passes through a hole in the colorful iris known as the pupil.
3. Light is refracted again by the lens, which is made up of transparent fibers.
4. The refracted light is focused onto the back surface of the eye, the retina.
5. The light is detected by rods and cones in the retina.
6. The optic nerve carries signals to the brain.
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.
Dispersion and Prisms, continued

• 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.