Chapter 10:
WAVES AND SOUND
This lecture will help you understand:

- Vibrations and Waves
- Wave Motion
- Transverse and Longitudinal Waves
- Sound Waves
- Reflection and Refraction of Sound
- Forced Vibrations and Resonance
- Interference
- Doppler Effect
- Bow Waves and the Sonic Boom
- Musical Sounds
Vibrations and Waves

Vibration:
  a wiggle in time

Wave:
  a wiggle in space and 
time that transports energy
Vibrations and Waves

When a bob vibrates up and down, a marking pen traces out a sine curve on the paper that moves horizontally at constant speed.
Vibrations and Waves

Vibration and wave characteristics

- crests
  - high points of the wave
- troughs
  - low points of the wave
Vibrations and Waves

Vibration and wave characteristics (continued)

• amplitude
  – distance from the midpoint to crest or trough

• wavelength
  – distance from the top of one crest to the top of the next crest, or distance between successive identical parts of the wave
The distance between adjacent peaks in the direction of travel for a transverse wave is its

A. frequency.
B. period.
C. wavelength.
D. amplitude.
The distance between adjacent peaks in the direction of travel for a transverse wave is its

A. frequency.
B. period.
C. **wavelength**.
D. amplitude.

*Explanation:*
Or between adjacent troughs or any adjacent identical parts of the waveform.
Vibrations and Waves

Description:

- Vibration
described by frequency—how frequently vibratory motion occurs

- Wave
described by frequency, speed, amplitude, and wavelength
Vibrations and Waves

Frequency:
number of to-and-fro vibrations in a given time
unit: 1 vibration per second = 1 Hertz

Period:
defined as the time it takes for a complete vibration
unit: any unit of time, often the second
Vibrations and Waves

Relationship between frequency and period:
Frequency = 1/period
Unit: Hertz (Hz)
Period = 1/frequency
Unit: second (s)
The source of all waves is a vibration.
Higher frequency means increased rate of energy transfer — shorter wavelengths.
If the frequency of a particular wave is 20 Hz, its period is

A. $\frac{1}{20}$ second.
B. 20 seconds.
C. more than 20 seconds.
D. none of the above.
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B. 20 seconds.
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Explanation:
Note when $f = 20$ Hz, $T = \frac{1}{f} = \frac{1}{(20 \text{ Hz})} = \frac{1}{20}$ second.
Wave Motion

Wave speed

- describes how fast a disturbance moves through a medium
- related to the frequency and wavelength of a wave

Example:
- a wave with wavelength 1 meter and frequency of 1 Hz has a speed of 1 m/s
Transverse and Longitudinal Waves

Two common types of waves that differ because of the direction in which the medium vibrates compared with the direction of travel:

- longitudinal wave
- transverse wave
The vibrations along a transverse wave move in a direction

A. along the wave.
B. perpendicular to the wave.
C. Both of the above.
D. Neither of the above.
The vibrations along a transverse wave move in a direction

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*Comment:* The vibrations in a longitudinal wave, in contrast, are along (or parallel to) the direction of wave travel.
The Nature of Sound

Sound

travels in longitudinal waves — vibrating compressions and rarefactions through air

Speed of Sound

Sound travels at 340 m/s in air at 20°C
Consider a person attending a concert being broadcast over the radio, sitting about 45 m from the stage. The person listens to the radio broadcast with a transistor radio over one ear and the nonbroadcast sound signal with the other ear. Further suppose that the radio signal must travel all the way around the world before reaching the ear.
Which signal will be heard first?

A. Radio signal.
B. Nonbroadcast sound signal.
C. Both at the same time.
D. None of the above.
Which signal will be heard first?

A. Radio signal.
B. Nonbroadcast sound signal.
C. **Both at the same time.**
D. None of the above.

**Explanation:**
A radio signal travels at the speed of light—$3 \times 10^8$ m/s.
Time to travel 45 m at 340 m/s $\approx 0.13$ s.
Time to travel $4 \times 10^7$ m (Earth’s circumference) at $3 \times 10^8$ m/s $\approx 0.13$ s. So if you sit farther back at the concert, the radio signal would reach you first!
Sound Waves

How sound is heard from a radio loudspeaker

- radio loudspeaker is a paper cone that vibrates
- air molecules next to the loudspeaker set into vibration
- produces compressions and rarefactions in air
- sound waves reach your ears, setting your eardrums into vibration
- sound is heard
Radio Speaker

- (a) paper cone vibrates in rhythm with an electric signal.
- (b) vibrations are displayed on an oscilloscope — a graph of pressure versus time.
The Nature of Sound

For each increase of 1°C above 0°C, speed of sound increases by 0.6 m/s.

Order of increasing speeds of sound:
• in air (≈ 340 m/s)
• in warm air (>340 m/s)
• in water (≈ four times speed in air)
• in steel (≈ 15 times speed in air)
Reflection

• process in which sound encountering a surface is returned
• often called an echo
• multiple reflections called reverberations

Angle of Incidence = Angle of Reflection
Reflection

Diffuse Reflection

When sound or light is incident on a rough surface, it is reflected in many directions.
Compared with a dry road, seeing is difficult when driving at night on a wet road. Why?

A. Wet surface is smooth with less diffuse reflection, part of which would otherwise reach the driver’s eyes.
B. Wet road usually means a wet windshield.
C. Wet road usually means more vapor in the air.
D. There is no reason—that’s just the way it is.
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Refraction:

the bending of a wave due to a change in the medium and/or speed of the wave
Refraction

Sound waves refract when parts of the wave fronts
• travel at different speeds.
• are affected by uneven winds
• when air near the ground is warmer than air above.
Reflection and Refraction of Sound

Dolphins emit ultrasonic waves to enable them to locate objects in their environment.
Forced Vibrations and Resonance

Forced vibration
• setting up of vibrations in an object by a vibrating force
Example: factory floor vibration caused by running of heavy machinery

Natural frequency
• own unique frequency (or set of frequencies)
• dependent on
  – elasticity
  – shape of object
Stages of Force Vibration
Resonance

Resonance occurs whenever successive impulses are applied to a vibrating object in rhythm with its natural frequency.
Interference

Interference
combined effect of two or more overlapping waves
Interference

Two types of interference:

- Constructive interference
  crest of one wave overlaps crest of another wave $\Rightarrow$ adding to a wave of increased amplitude
- Destructive interference
  crest of one wave overlaps the trough of another $\Rightarrow$ amplitude effects are reduced

$\text{Reinforcement}$  

$\text{Cancellation}$
The superposition of two identical transverse waves in phase produces a wave of increased amplitude.

The superposition of two identical longitudinal waves in phase produces a wave of increased intensity.

Two identical transverse waves that are out of phase destroy each other when they are superimposed.

Two identical longitudinal waves that are out of phase destroy each other when they are superimposed.
Interference is a property of

A. sound.
B. light.
C. Both of these.
D. Neither of these.
Interference is a property of

A. sound.
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D. Neither of these.

Explanation:
Interestingly, the presence of interference tells a scientist whether something is wavelike or not. All types of waves can interfere.
Interference

Application of sound interference

- noisy devices such as jackhammers are equipped with microphones to produce mirror-image wave patterns fed to operator’s earphone, cancelling the device’s sound
Interference

Application of sound interference (continued)

- Sound interference in stereo speakers out of phase sending a monoaural signal (one speaker sending compressions of sound and other sending rarefactions)

- As speakers are brought closer to each other, sound is diminished
Interference

Beats

- periodic variations in the loudness of sound due to interference
- occur with any kind of wave
- provide a comparison of frequencies
Interference

Standing waves

Node (null point)

Incident wave
In phase
Reflected wave

Node

Incident wave
Out of phase
Reflected wave

Node

Incident wave
Reflected wave
In phase
Interference

Nodes of standing wave
Doppler Effect

Doppler Effect:

the change in frequency as measured by an observer due to the motion of the

• source or
• listener

Named after Austrian physicist and mathematician, Christian Johann Doppler
Water Bug Doppler Effect

- Top view of water waves made by a stationary bug jiggling (up and down) in still water.
- Water waves made by a bug swimming in still water toward point B.
- A & B receive different wave frequencies.
Doppler Effect

Example of Doppler Effect:

Frequency of waves received by an observer increases as a sound source approaches. Wave frequency decreases as the source recedes.
When a fire engine approaches you, the

A. speed of its sound increases.
B. frequency of sound increases.
C. wavelength of its sound increases.
D. All increase.
When a fire engine approaches you, the

A. speed of its sound increases.
B. frequency of sound increases.
C. wavelength of its sound increases.
D. All increase.

Comment:
Be sure you distinguish between sound, speed, and sound frequency.
The Doppler effect occurs for

A. sound.
B. light.
C. Both A and B.
D. Neither A nor B.
The Doppler effect occurs for

A. sound.
B. light.
C. Both A and B.
D. Neither A nor B.

*Explanation:*
Astronomers measure the spin rates of stars using the Doppler effect for light.
Bow Wave

• The wave pattern made by a bug swimming at wave speed.
• Idealized wave pattern made by a bug swimming faster than wave speed.
Stages of Wave Speeds

- Bug swims at successively greater speeds. Overlapping at the edges occurs only when the bug swims faster than wave speed.

\[ v \text{ less than } v_w \quad v \text{ equals } v_w \quad v \text{ exceeds } v_w \quad v \text{ greatly exceeds } v_w \]
Shock Waves and the Sonic Boom

Shock wave
• pattern of overlapping spheres that form a cone from objects traveling faster than the speed of sound
Shockwave

- The shockwave actually consists of two cones.
  - A high pressure cone with its apex at the bow
  - A low pressure cone with its apex at the tail.
  - A graph of the air pressure at ground level between the cone takes the shape of the letter N.
Shockwave

- The shock wave has not yet reached listener A, but it is now reaching listener B, and it has already reached listener C.
Musical Sound

- Graphical representations of noise and music.
  (a) Noise has no clear repeatable pattern.
  (b) Music has a frequency (repeatable wave), wavelength, and speed.
Music and Standing Waves

- Each harmonic of a guitar string is a standing wave.
- Image shows the first four harmonics on the string.
Variations in Tone

- Images of a piano and clarinet playing note C
- Each has the same frequency, but with different extra vibrations.
- These differences produce tone.