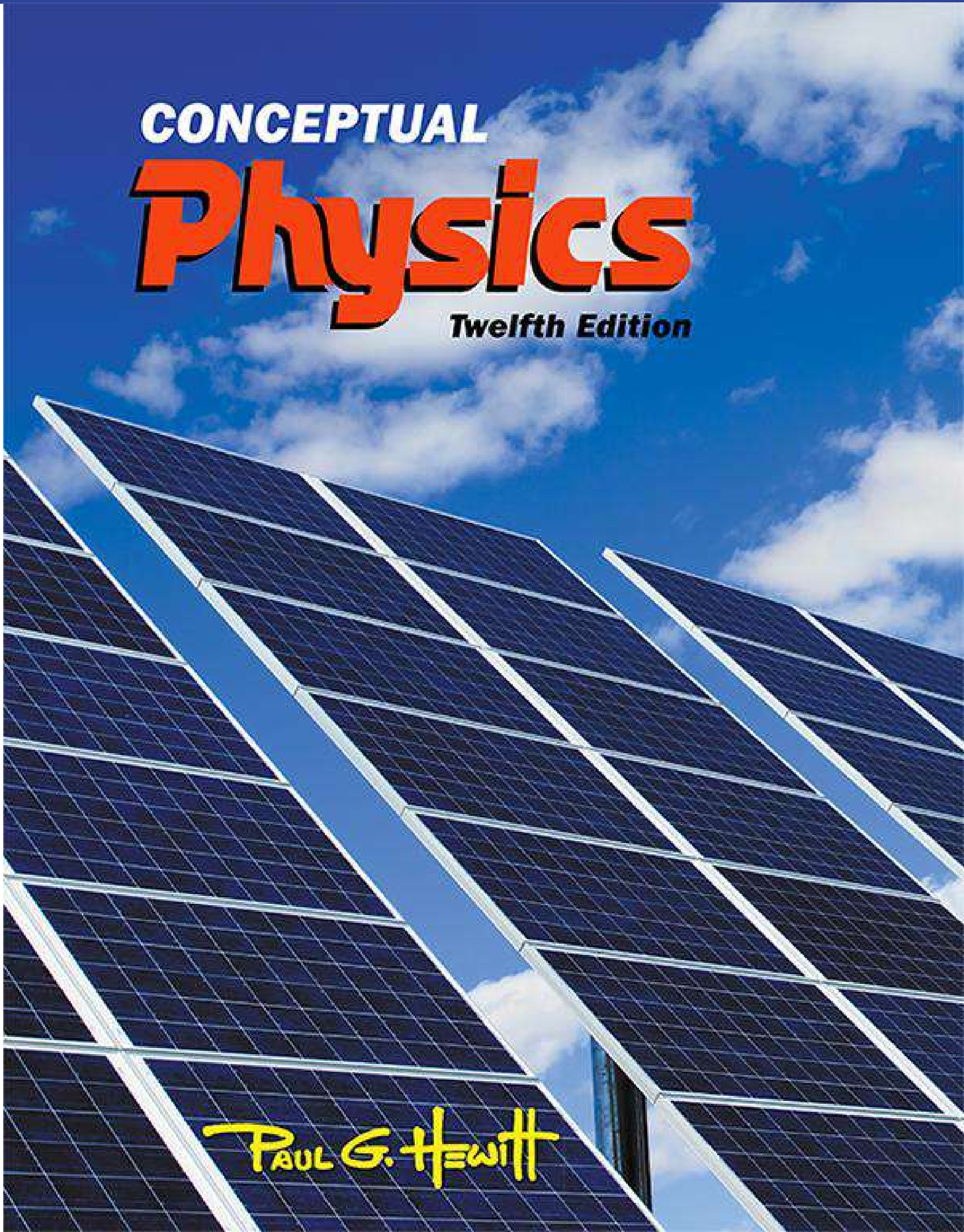
Lecture Outline



Chapter 25: Vibrations And Waves

This lecture will help you understand:

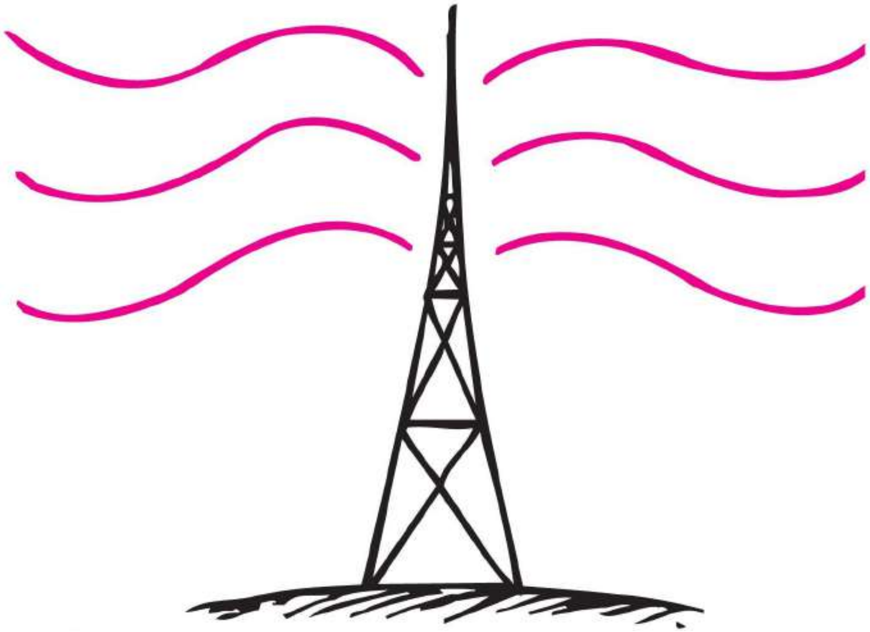
- Vibrations of a Pendulum
- Wave Description
- Wave Speed
- Transverse Waves
- Longitudinal Waves
- Wave Interference
- Standing Waves
- Doppler Effect
- Bow Waves
- Shock Waves

Good Vibrations

- A *vibration* is a periodic wiggle in time.
- A periodic wiggle in both space and time is a *wave.* A wave extends from one place to another. Examples are:
  - light, which is an electromagnetic wave that needs no medium.
  - sound, which is a mechanical wave that needs a medium.

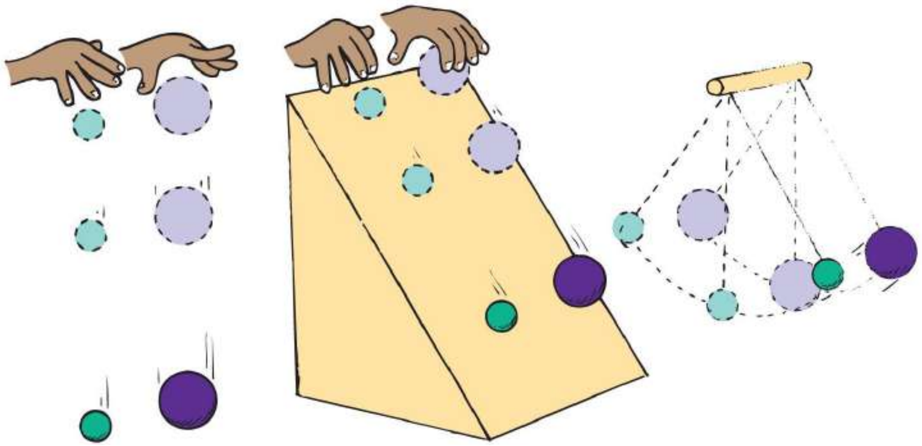
Vibrations and Waves

- Vibration
  - Wiggle in time
- Wave
  - Wiggle in space and time



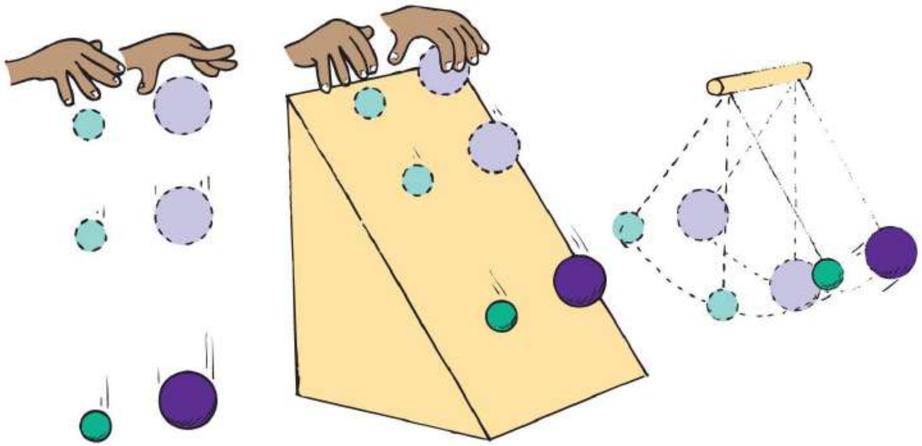
Vibrations of a Pendulum

- If we suspend a stone at the end of a piece of string, we have a simple pendulum.
- The pendulum swings to and fro at a rate that
  - depends only on the *length* of the pendulum.
  - does not depend upon the mass (just as mass does not affect the rate at which a ball falls to the ground).



Vibrations of a Pendulum, Continued

- The time of one to-and-fro swing is called the **period**.
- The longer the length of a pendulum, the longer the period (just as the higher you drop a ball from, the longer it takes to reach the ground).



Vibrations of a Pendulum
CHECK YOUR NEIGHBOR

A 1-meter-long pendulum has a bob with a mass of 1 kg. Suppose that the bob is now replaced with a different bob of mass 2 kg, how will the period of the pendulum change?

A. It will double.
B. It will halve.
C. It will remain the same.
D. There is not enough information.

Vibrations of a Pendulum
CHECK YOUR ANSWER

A 1-meter-long pendulum has a bob with a mass of 1 kg. Suppose that the bob is now replaced with a different bob of mass 2 kg, how will the period of the pendulum change?

C. **It will remain the same.**

Explanation:
The period of a pendulum depends only on the length of the pendulum, not on the mass. So changing the mass will not change the period of the pendulum.

Vibrations of a Pendulum
CHECK YOUR NEIGHBOR, Continued

A 1-meter-long pendulum has a bob with a mass of 1 kg. Suppose that the bob is now tied to a different string so that the length of the pendulum is now 2 m. How will the period of the pendulum change?

A. It will increase.
B. It will decrease.
C. It will remain the same.
D. There is not enough information.

Vibrations of a Pendulum
CHECK YOUR ANSWER, Continued

A 1-meter-long pendulum has a bob with a mass of 1 kg. Suppose that the bob is now tied to a different string so that the length of the pendulum is now 2 m. How will the period of the pendulum change?

A. **It will increase.**

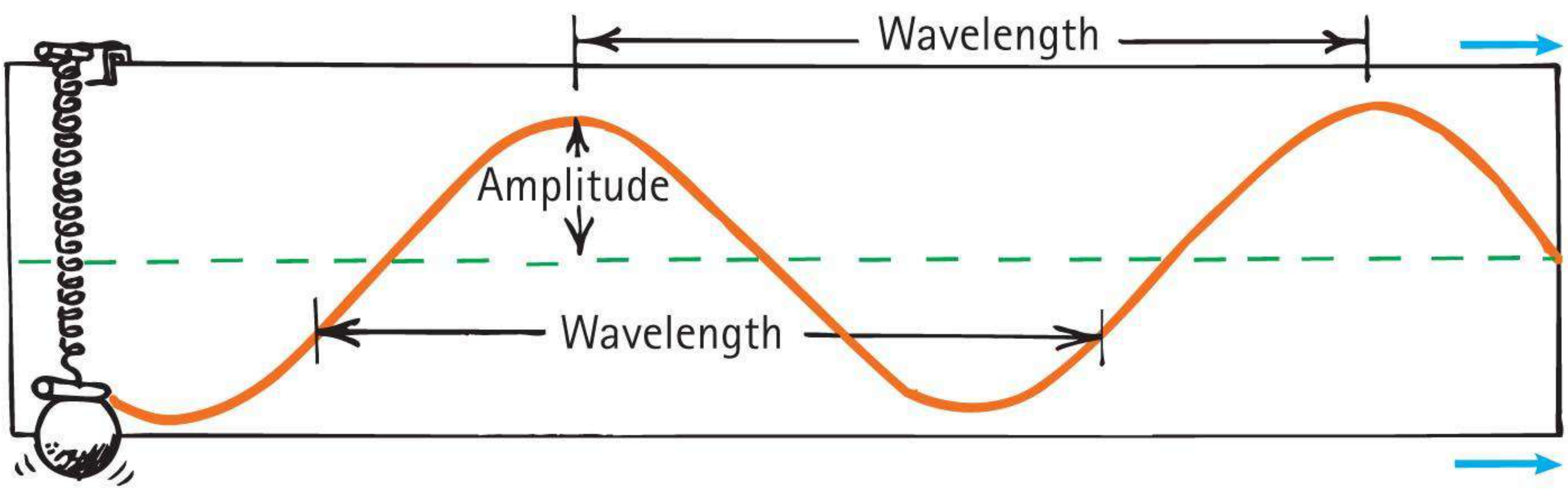
Explanation:
The period of a pendulum increases with the length of the pendulum.

Wave Description

- A wave is pictorially represented by a *sine curve*.
- A sine curve is obtained when you trace out the path of a vibrating pendulum over time.
  - Put some sand in the pendulum and let it swing.
  - The sand drops through a hole in the pendulum onto a sheet of paper.
  - As the pendulum swings back and forth, pull the sheet of paper on which the sand falls.
  - The sand makes a sine curve on the paper.

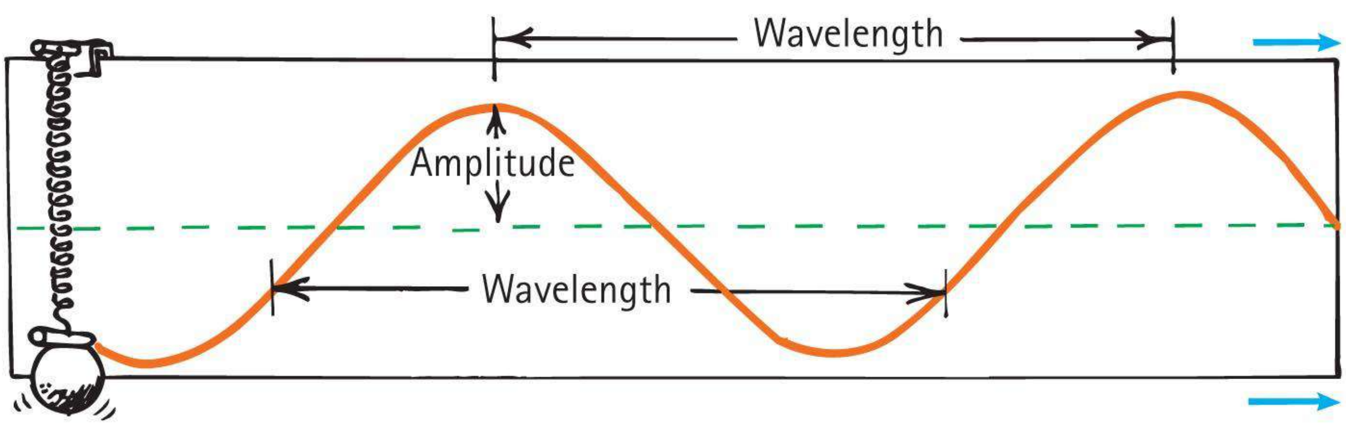
Wave Description, Continued

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



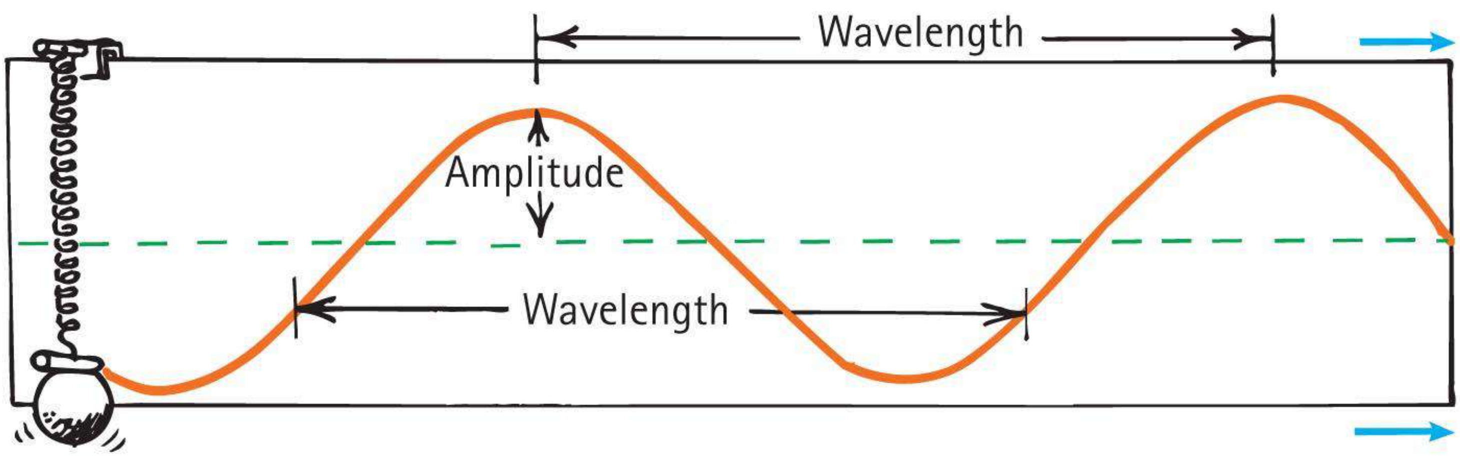
Wave Description, Continued-1

- Vibration and wave characteristics
  - Crests
    - high points of the wave
  - Troughs
    - low points of the wave



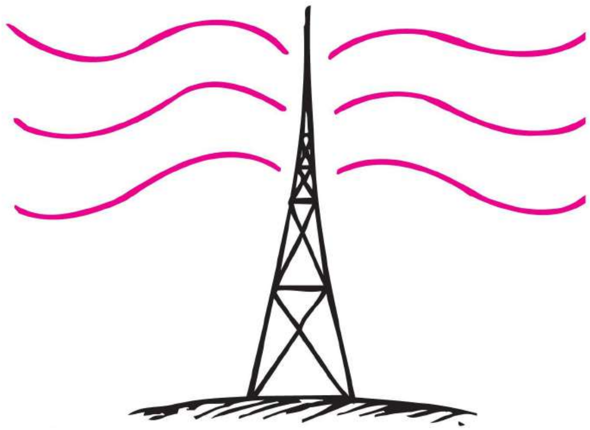
Wave Description, Continued-2

- Vibration and wave characteristics (continued)
  - Amplitude
    - distance from the midpoint to the crest or to the 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



Wave Description, Continued-3

- How frequently a vibration occurs is called the **frequency.**
  - The unit for frequency is Hertz (Hz), after Heinrich Hertz
  - A frequency of 1 Hz is a vibration that occurs once each second.
  - Mechanical objects (e.g., pendulums) have frequencies of a few Hz.
  - Sound has a frequency of a few 100 or 1000 Hz.
  - Radio waves have frequencies of a few million Hz (MHz).
  - Cell phones operate at few billon Hz (GHz).



Wave Description, Continued-4

- Frequency
  - Specifies the number of to and fro vibrations in a given time
  - Number of waves passing any point per second
  - Example: 2 vibrations occurring in 1 second is a frequency of 2 vibrations per second.

Wave Description, Continued-5

- Period
  - Time to complete one vibration

$$\text{Period} = \frac{1}{\text{frequency}}$$

or, vice versa, $$\text{Frequency} = \frac{1}{\text{period}}$$

- Example: Pendulum makes 2 vibrations in 1 second. Frequency is 2 Hz. Period of vibration is 1/2 second.

Wave Description
CHECK YOUR NEIGHBOR

A sound wave has a frequency of 500 Hz. What is the period of vibration of the air molecules due to the sound wave?

A. 1 s
B. 0.01 s
C. 0.002 s
D. 0.005 s

Wave Description
CHECK YOUR ANSWER

A sound wave has a frequency of 500 Hz. What is the period of vibration of the air molecules due to the sound wave?

C. **0.002 s**

Explanation:

$$\text{Period} = \frac{1}{\text{frequency}}$$

So:

$$\text{Period} = \frac{1}{500\ Hz} = 0.002\ s$$

Wave Description
CHECK YOUR NEIGHBOR, Continued

If the frequency of a particular wave is 20 Hz, its period is

A. 1/20 second.
B. 20 seconds.
C. more than 20 seconds.
D. None of the above.

Wave Description
CHECK YOUR ANSWER, Continued

If the frequency of a particular wave is 20 Hz, its period is

A. **1/20 second.**

Explanation:

Note when f = 20 Hz, $T = 1/f$ = 1/(20 Hz) = 1/20 second.

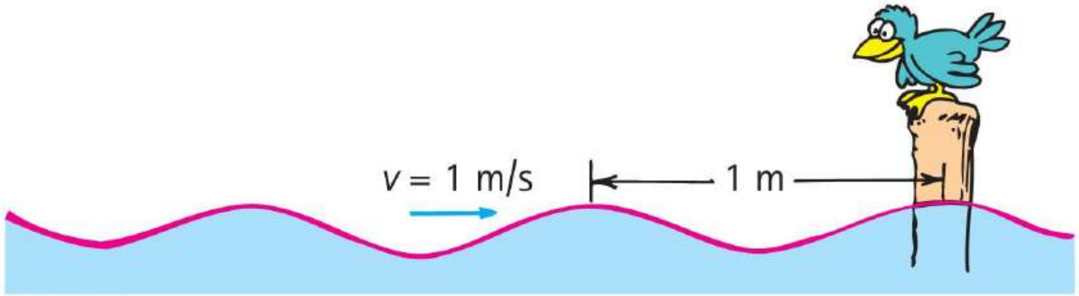
Wave Motion

- Wave motion
  - Waves transport energy and not matter.
  - Example:
    - Drop a stone in a quiet pond and the resulting ripples carry no water across the pond.
    - Waves travel across grass on a windy day.
    - Molecules in air propagate a disturbance through air.

Wave Motion, Continued

- Wave speed
  - Describes how fast a disturbance moves through a medium
  - Related to frequency and wavelength of a wave

    Wave speed = frequency x wavelength
- Example:
  - A wave with wavelength 1 meter and frequency of 1 Hz has a speed of 1 m/s.



Wave Speed
CHECK YOUR NEIGHBOR

A wave with wavelength 10 meters and time between crests of 0.5 second is traveling in water. What is the wave speed?

A. 0.1 m/s
B. 2 m/s
C. 5 m/s
D. 20 m/s

Wave Speed
CHECK YOUR ANSWER

A wave with wavelength 10 meters and time between crests of 0.5 second is traveling in water. What is the wave speed?

D. **20 m/s**

Explanation: $\text{Frequency} = \frac{1}{\text{period}}$

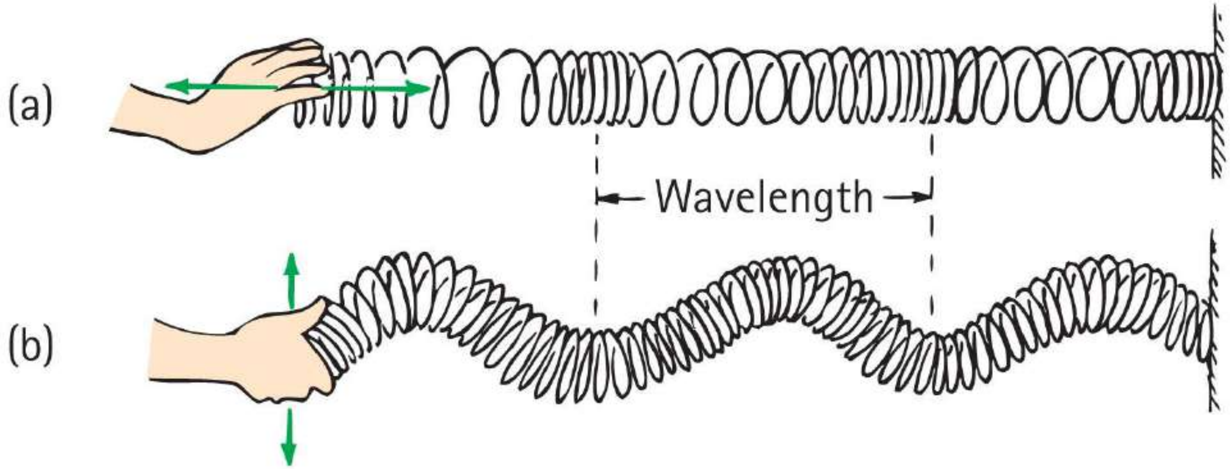
So: $\text{Frequency} = \frac{1}{0.5\ \text{s}} = 2\ \text{Hz}$

Also: Wave speed = frequency x wavelength

So: Wave speed = 2 Hz x 10 m = 20 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



Transverse Waves

- Transverse wave
  - Medium vibrates perpendicularly to direction of energy transfer
  - Side-to-side movement
  - Example:
    - Vibrations in stretched strings of musical instruments
    - Radio waves
    - Light waves
    - S-waves that travel in the ground (providing geologic information)

Transverse Waves
CHECK YOUR NEIGHBOR

The distance between adjacent peaks in the direction of travel for a transverse wave is its

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

Transverse Waves
CHECK YOUR ANSWER

The distance between adjacent peaks in the direction of travel for a transverse wave is its

C. **wavelength.**

Explanation:

The wavelength of a transverse wave is also the distance between adjacent troughs, or between any adjacent identical parts of the waveform.

Transverse Waves
CHECK YOUR NEIGHBOR, Continued

The vibrations along a transverse wave move in a direction

A. along the wave.
B. perpendicular to the wave.
C. Both A and B.
D. Neither A nor B.

Transverse Waves
CHECK YOUR ANSWER, Continued

The vibrations along a transverse wave move in a direction

B. perpendicular to the wave.

Comment:

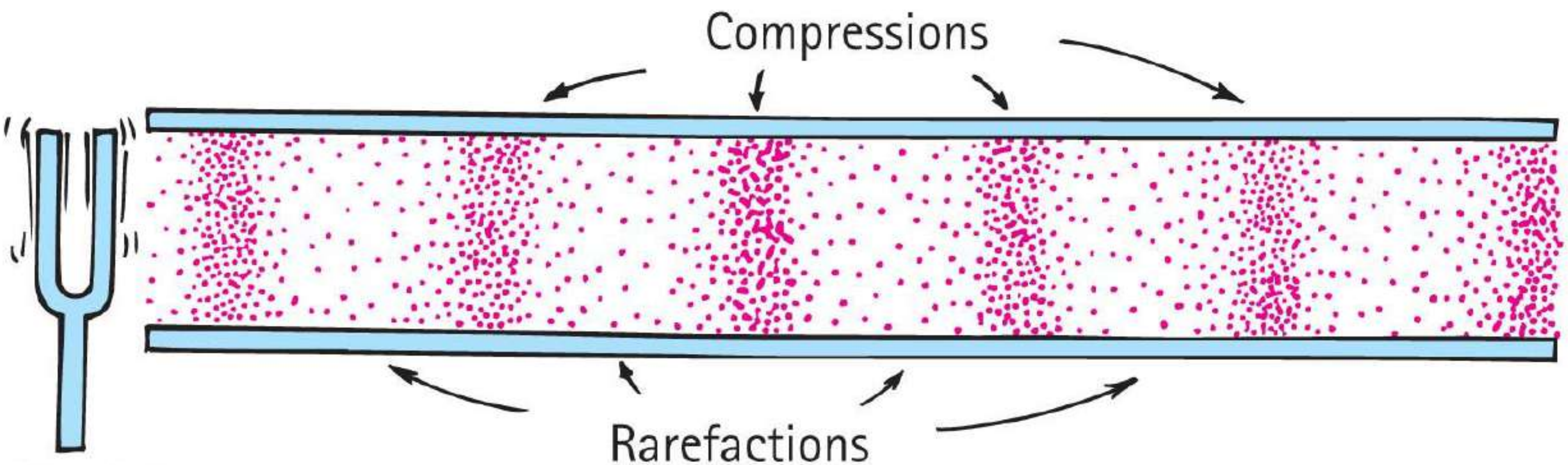
The vibrations in a longitudinal wave, in contrast, are along (or parallel to) the direction of wave travel.

Longitudinal Waves

- Longitudinal wave
  - Medium vibrates parallel to direction of energy transfer
  - Backward and forward movement consists of
    - compressions (wave compressed)
    - rarefactions (stretched region between compressions)
    - Example: sound waves in solid, liquid, gas

Longitudinal Waves, Continued

- Longitudinal wave
  - Example:
    - sound waves in solid, liquid, gas
    - P-waves that travel in the ground (providing geologic information)



Longitudinal Waves
CHECK YOUR NEIGHBOR

The wavelength of a longitudinal wave is the distance between

A. successive compressions.
B. successive rarefactions.
C. Both A and B.
D. None of the above.

Longitudinal Waves
CHECK YOUR ANSWER

The wavelength of a longitudinal wave is the distance between

C. **Both A and B.**

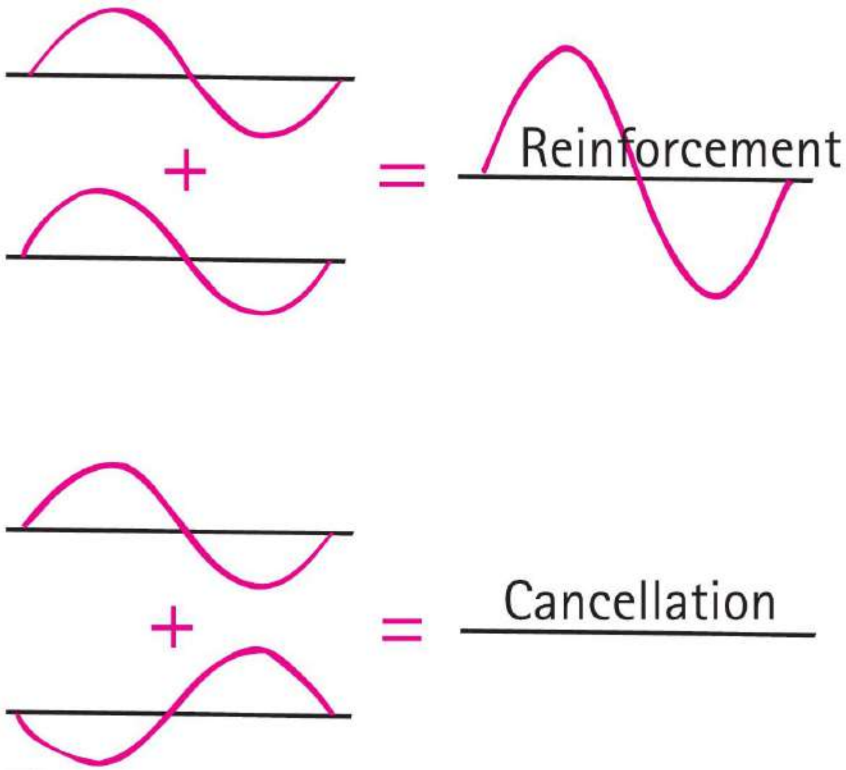
Wave Interference

- **Wave interference** occurs when two or more waves interact with each other because they occur in the same place at the same time.
- **Superposition principle:** The displacement due the interference of waves is determined by adding the disturbances produced by each wave.

Wave Interference, Continued

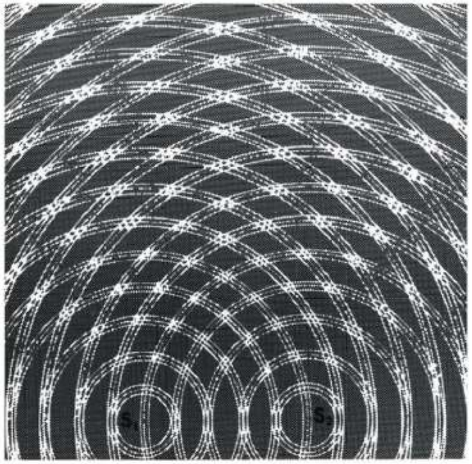
Constructive interference : When the crest of one wave overlaps the crest of another, their individual effects add together to produce a wave of increased amplitude.

Destructive interference: When the crest of one wave overlaps the trough of another, the high part of one wave simply fills in the low part of another. So, their individual effects are reduced (or even canceled out).



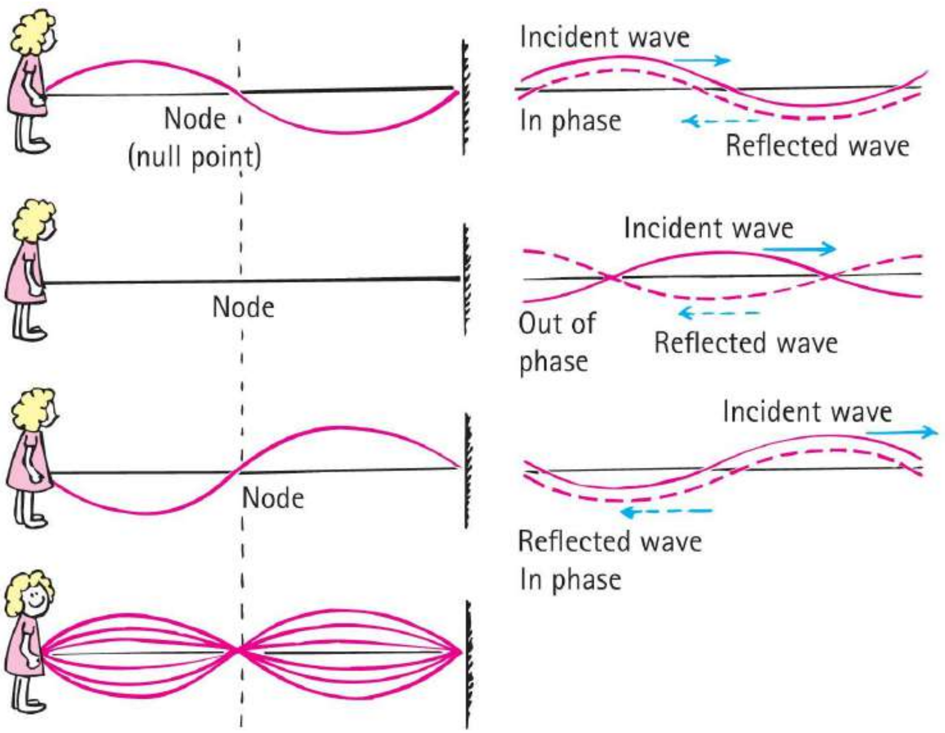
Wave Interference, Continued-1

- Example:
  - We see the interference pattern made when two vibrating objects touch the surface of water.
  - The regions where a crest of one wave overlaps the trough of another to produce regions of zero amplitude.
  - At points along these regions, the waves arrive out of step, i.e., *out of phase* with each other.



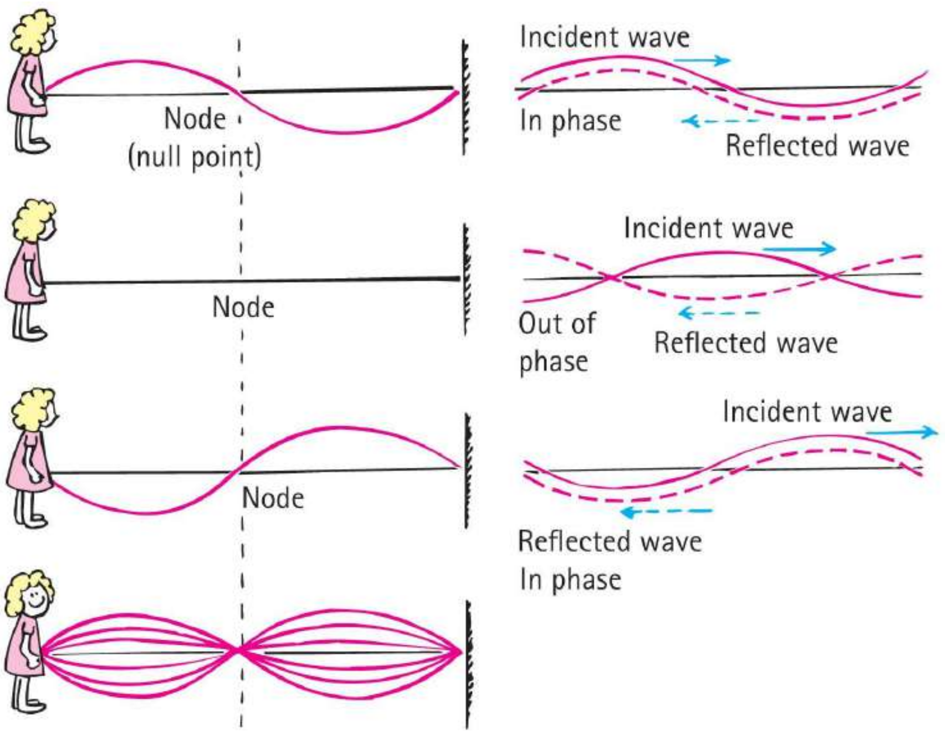
Standing Waves

- If we tie a rope to a wall and shake the free end up and down, we produce a train of waves in the rope.
- The wall is too rigid to shake, so the waves are reflected back along the rope.
- By shaking the rope just right, we can cause the incident and reflected waves to form a **standing wave.**



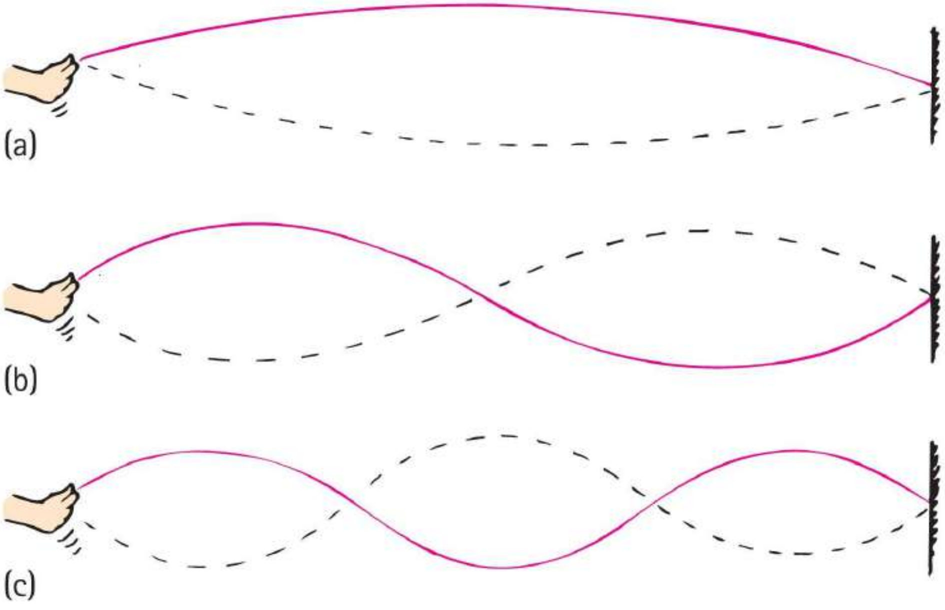
Standing Waves, Continued

- **Nodes** are the regions of minimal or zero displacement, with minimal or zero energy.
- **Antinodes** are the regions of maximum displacement and maximum energy.
- Antinodes and nodes occur equally apart from each other.



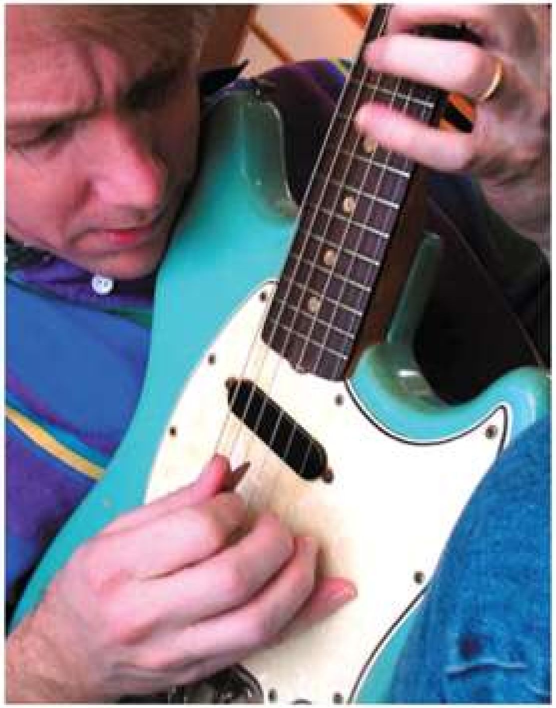
Standing Waves, Continued-1

- Tie a tube to a firm support. Shake the tube from side to side with your hand.
- If you shake the tube with the right frequency, you will set up a standing wave.
- If you shake the tube with **twice** the frequency, a standing wave of **half** the wavelength, having **two** loops results.
- If you shake the tube with **three times** the frequency, a standing wave of **one-third** the wavelength, having **three** loops results.



Standing Waves, Continued-2

- Examples:
  - Waves in a guitar string
  - Sound waves in a trumpet



Doppler Effect

- The Doppler effect also applies to light.
  - Increase in light frequency when light source approaches you
  - Decrease in light frequency when light source moves away from you
  - Star's spin speed can be determined by shift measurement

Doppler Effect, Continued

- Doppler effect of light
  - Blue shift
    - increase in light frequency toward the blue end of the spectrum
  - Red shift
    - decrease in light frequency toward the red end of the spectrum
  - Example: Rapidly spinning star shows a red shift on the side facing away from us and a blue shift on the side facing us.

The Doppler Effect
CHECK YOUR NEIGHBOR

The Doppler effect occurs for

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

The Doppler Effect
CHECK YOUR ANSWER

The Doppler effect occurs for

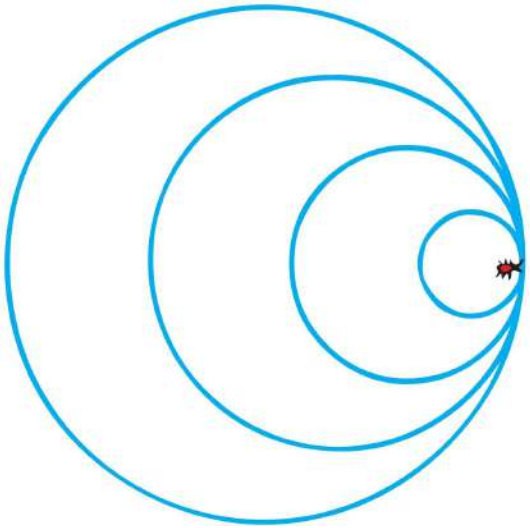
C. **Both A and B.**

Explanation:

The Doppler effect occurs for both sound and light. Astronomers measure the spin rates of stars by the Doppler effect.

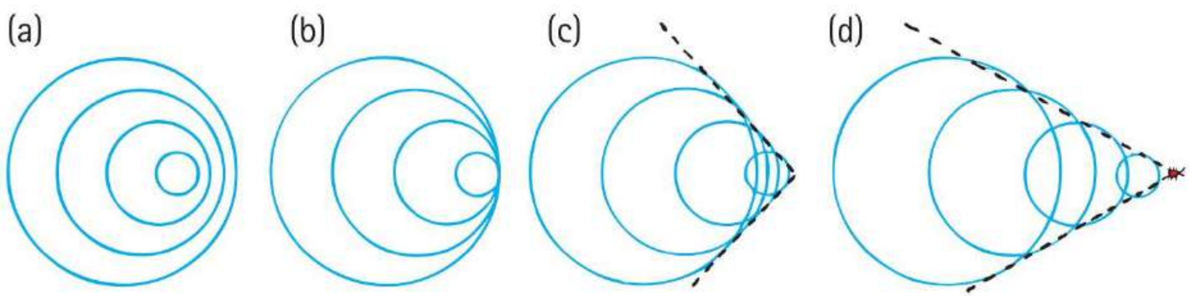
Bow Waves

- Wave barrier
  - Waves superimpose directly on top of one another producing a "wall".
  - Example: bug swimming as fast as the wave it makes



Bow Waves, Continued

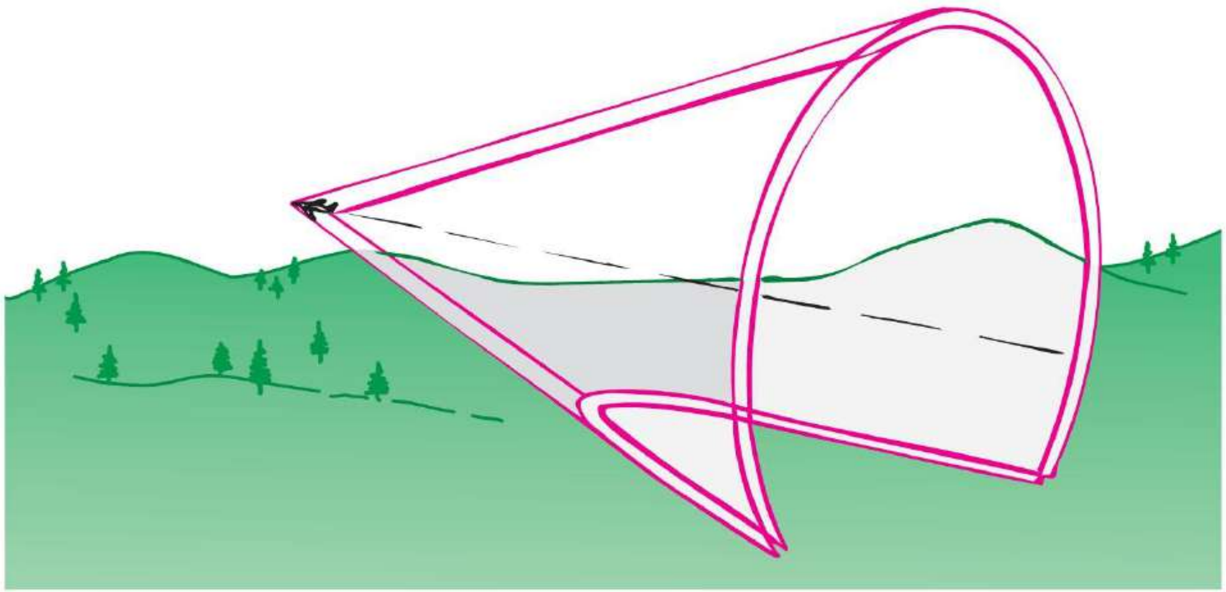
- Supersonic
  - Aircraft flying faster than the speed of sound.
- Bow wave
  - V-shape form of overlapping waves when object travels faster than wave speed.
  - An increase in speed will produce a narrower V-shape of overlapping waves.



v less than v_w | v equals v_w | v exceeds v_w | v greatly exceeds v_w

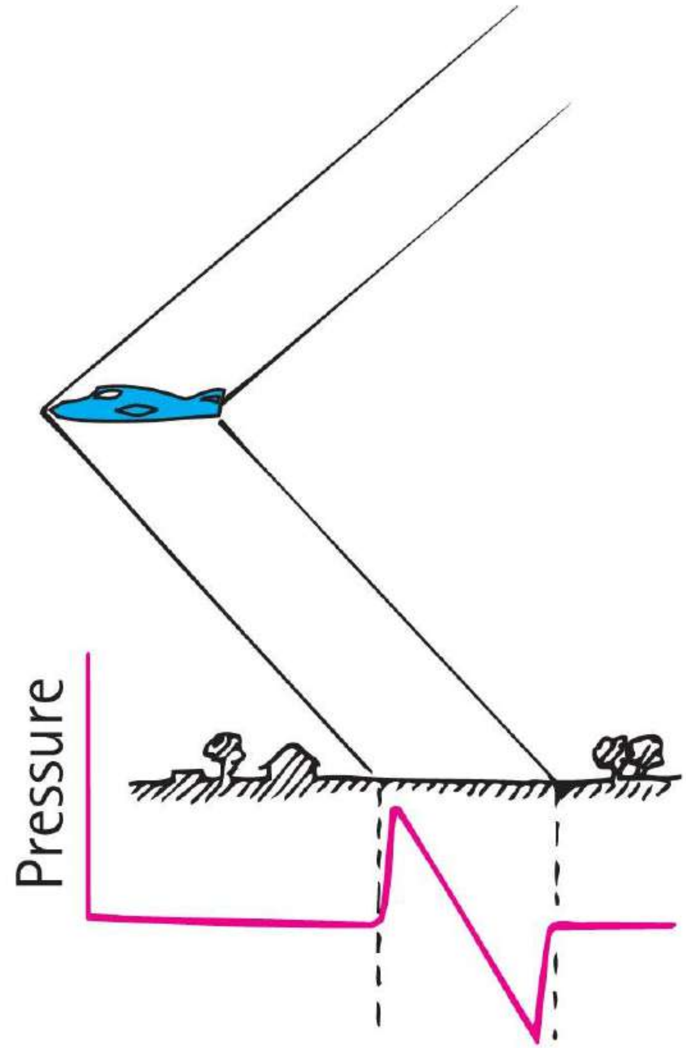
Shock Waves

- Shock wave
  - Pattern of overlapping spheres that form a cone from objects traveling faster than the speed of sound.



Shock Waves, Continued

- Shock wave (continued)
  - Consists of two cones.
    - a high-pressure cone generated at the bow of the supersonic aircraft
    - a low-pressure cone that follows toward (or at) the tail of the aircraft
  - It is not required that a moving source be noisy.



Shock Waves, Continued-1

- Sonic boom
  – Sharp cracking sound generated by a supersonic aircraft
  – Intensity due to overpressure and under pressure of atmospheric pressure between the two cones of the shock waves
  – Produced before it broke the sound barrier
  – Example:
    - supersonic bullet
    - crack of circus whip