Conceptual Physics Fundamentals

PAUL G. HEWITT

Chapter 12:

WAVES AND SOUND

This lecture will help you understand:

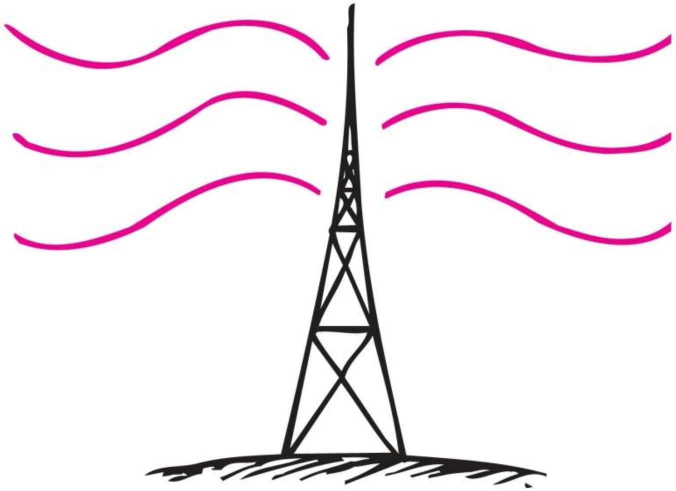
- Vibrations and Waves
- Wave Motion
- Transverse and Longitudinal Waves
- Sound Waves
- Reflection and Refraction of Sound
- Forced Vibrations and Resonance
- Interference
- Doppler Effect
- Wave Barriers and Bow Waves
- Shock Waves and the Sonic Boom
- Musical Sounds

Waves and Sound

"Opera is where a guy gets stabbed in the back, and instead of dying, he sings."

—Robert Benchley

Vibrations and Waves



Vibration

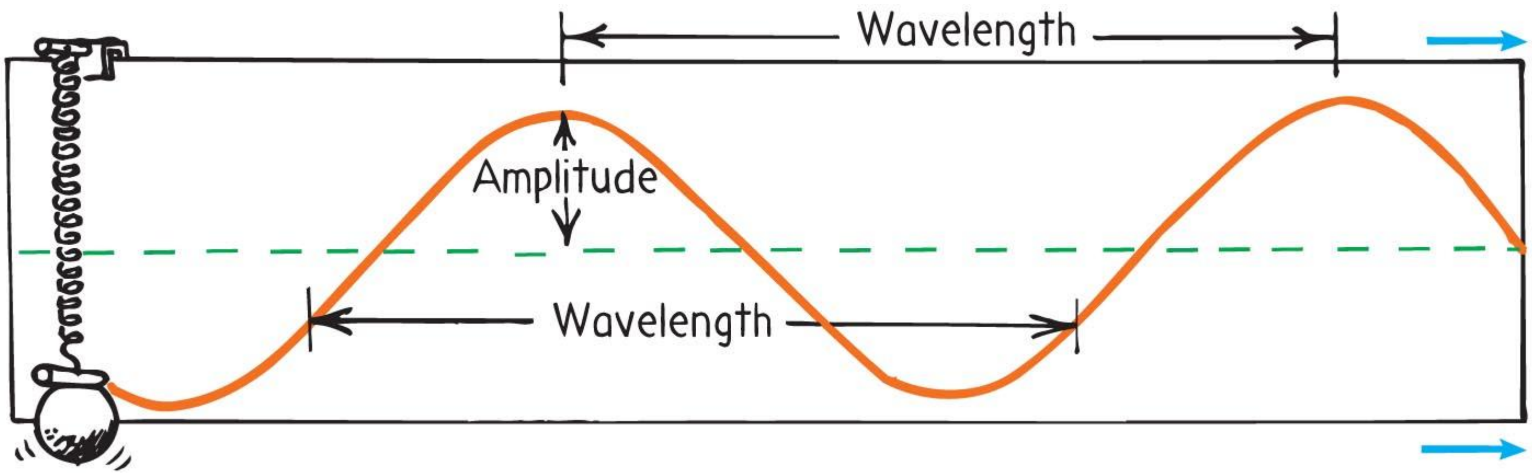
- wiggle in time

Wave

- wiggle in space and time

Vibrations and Waves

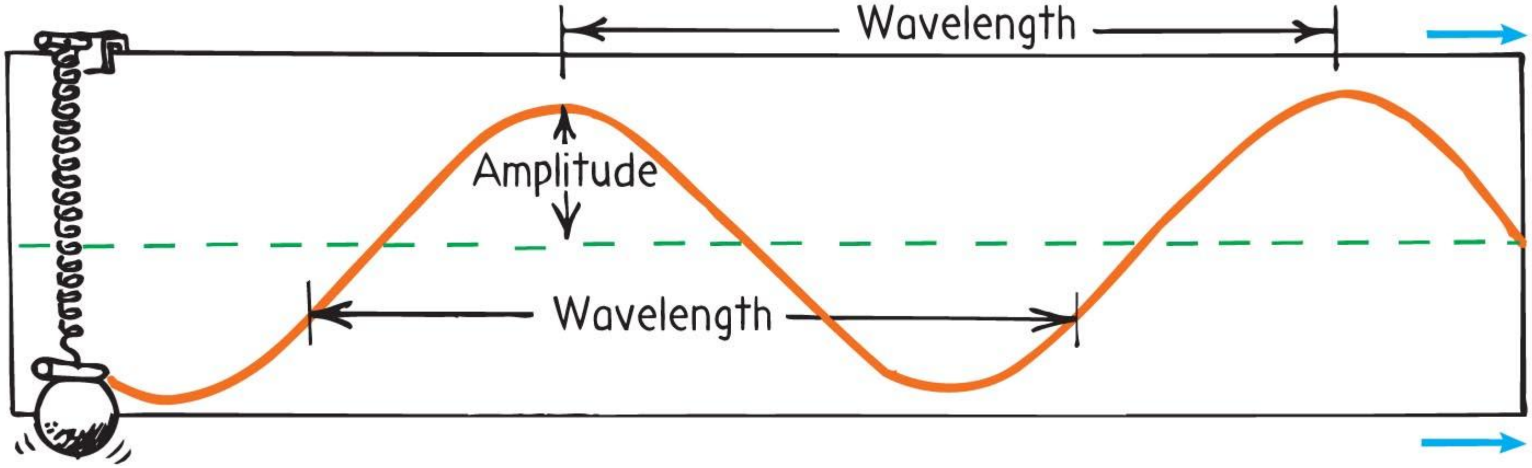
When a bob vibrates up and down, a marking pen traces out a sine curve on the paper that moves horizontally at constant speed.



Vibrations and Waves

Vibration and wave characteristics

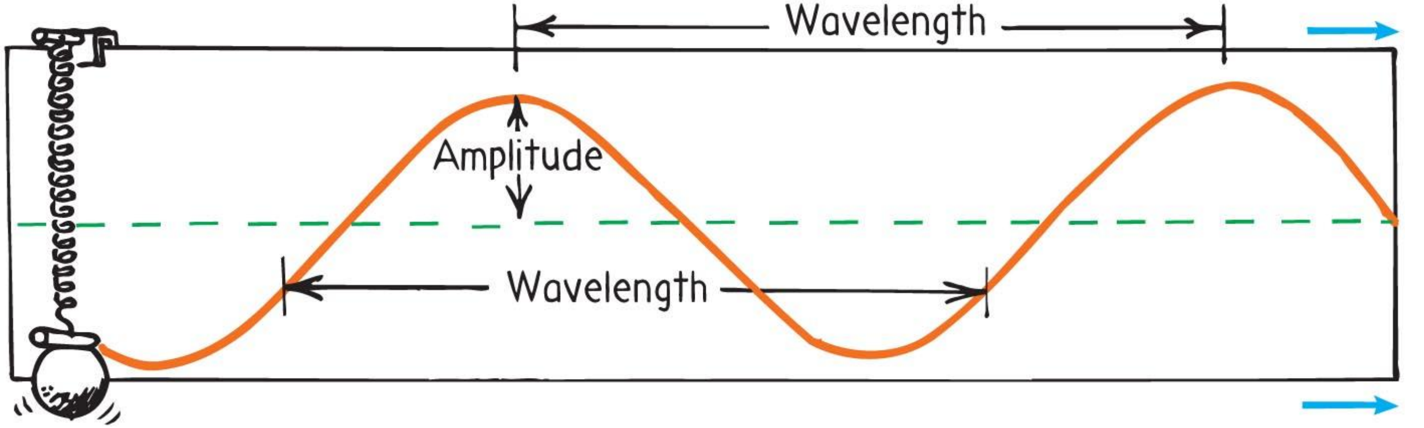
- crests
  - high points of the wave
- troughs
  - low points of the wave



Vibrations and Waves

Vibration and wave characteristics (continued)

- amplitude
  - distance from the midpoint to 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



Vibrations and Waves

Vibration and wave characteristics (continued)

- 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

Vibrations and Waves

Vibration and wave characteristics (continued)

- frequency
  - measured in units of hertz (after Heinrich Hertz)

    example:

    - 1 vibration per second is 1 hertz
    - 2 vibrations per second is 2 hertz
    - AM and FM radio broadcasts radio waves in kHz
    - cell phones operate in GHz

Vibrations and Waves

Period

- time to complete one vibration

$$frequency = \frac{1}{period}$$

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

example: Pendulum makes 2 vibrations in 1 second. Frequency is 2 Hz. Period of vibration is ½ second.

Vibrations and Waves
CHECK YOUR NEIGHBOR

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

Vibrations and Waves
CHECK YOUR ANSWER

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

Explanation:

Note when f = 20 Hz, $T = 1/f = 1/(20 \text{ Hz}) = {}^{1}/_{20}$ 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

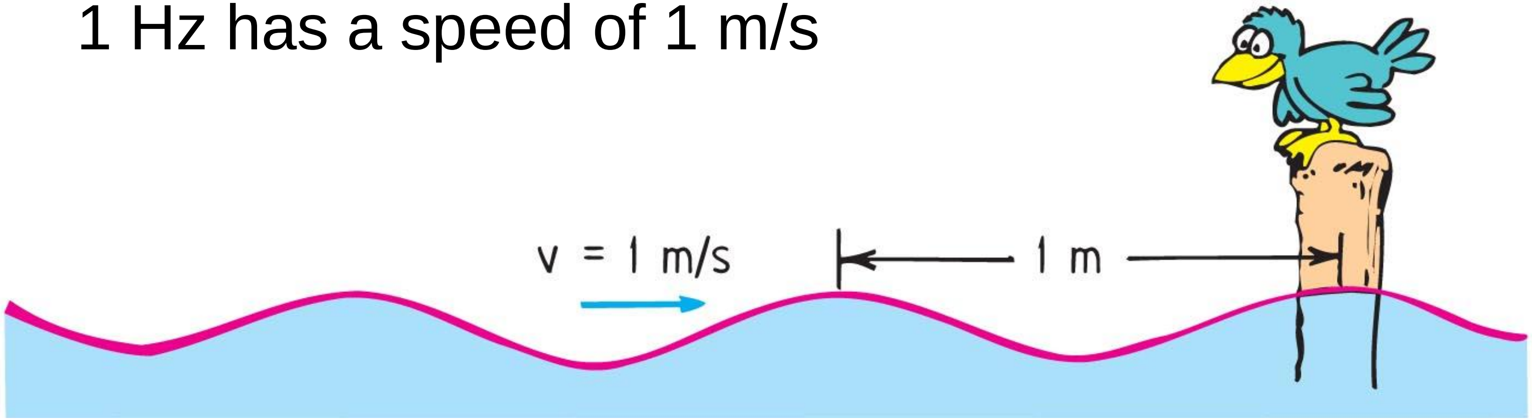
Wave Motion

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



Wave Motion

Wave speed

example:

- a wave with wavelength 10 meters and time between crests of 0.5 second

  speed = wavelength/period = 10 meters/0.5 second = 20 m/s

- the same wave with wavelength 10 m and frequency 2 Hz

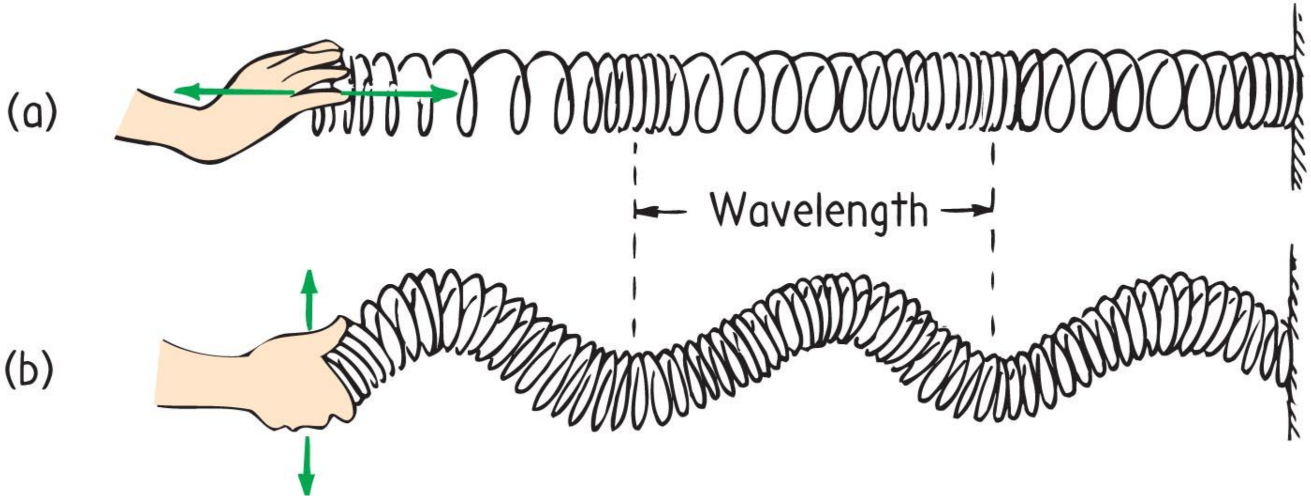
  speed = wavelength $\times$ frequency = 10 m $\times$ 2 Hz =

  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 and Longitudinal Waves

Transverse wave

- medium vibrates perpendicular 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 and Longitudinal 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 and Longitudinal Waves
CHECK YOUR ANSWER

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:

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

Transverse and Longitudinal Waves
CHECK YOUR NEIGHBOR

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 and Longitudinal Waves
CHECK YOUR ANSWER

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

Comment:

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

Transverse and 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)

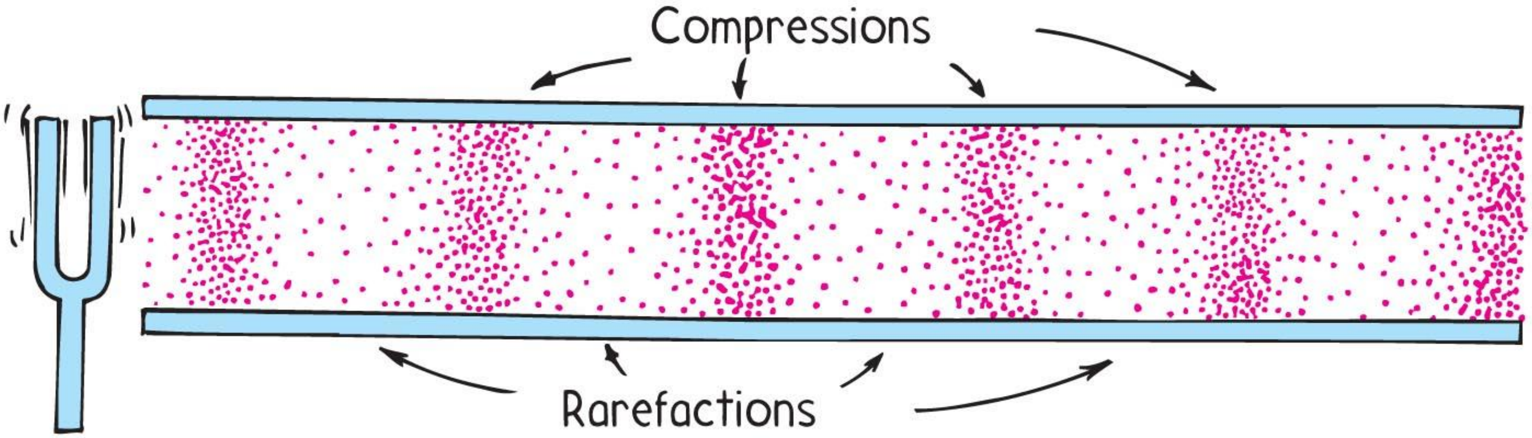
  example: sound waves in solid, liquid, gas

Transverse and Longitudinal Waves

Longitudinal wave

example:

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



Transverse and 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

Transverse and Longitudinal Waves
CHECK YOUR ANSWER

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

Sound Waves

Sound waves

- are vibrations made of compressions and rarefactions
- are longitudinal waves
- require a medium
- travel through solids, liquids, and gases

Wavelength of sound

- distance between successive compressions or rarefactions

Sound Waves

Pitch

- describes perception of sound depending on its frequency

example:

  - tiny bell—high pitch sound
  - large bell—low pitch sound

- range of frequencies
  - infrasonic waves (frequencies below 20 Hz)
    - not heard by humans
  - ultrasonic waves (frequencies above 20,000 Hz)
    - not heard by humans (but dogs and other animals)

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 traveling in air
- sound waves reach your ears, setting your eardrums into vibration
- sound is heard

Sound Waves

Speed of sound

- depends on wind conditions, temperature, humidity
  - speed in dry air at 0°C is about 330 m/s
  - in water vapor slightly faster
  - in warm air faster than cold air
- each degree rise in temperature above 0°C, speed of sound in air increases by 0.6 m/s
- speed in water about 4 times speed in air
- speed in steel about 15 times its speed in air

Sound Waves
CHECK YOUR NEIGHBOR

You watch a person chopping wood and note that after the last chop you hear it 1 second later. How far away is the chopper?

A. 330 m
B. more than 330 m
C. less than 330 m
D. there's no way to tell

Sound Waves
CHECK YOUR ANSWER

You watch a person chopping wood and note that after the last chop you hear it 1 second later. How far away is the chopper?

A. 330 m

B. more than 330 m

C. less than 330 m

D. there's no way to tell

Sound Waves
CHECK YOUR NEIGHBOR

You hear thunder 2 seconds after you see lightning flash. How far away is the lightning?

A. 330 m
B. 660 m
C. more than 660 m
D. there’s no way to tell

Sound Waves
CHECK YOUR ANSWER

You hear thunder 2 seconds after you see lightning flash. How far away is the lightning?

A. 330 m

B. 660 m

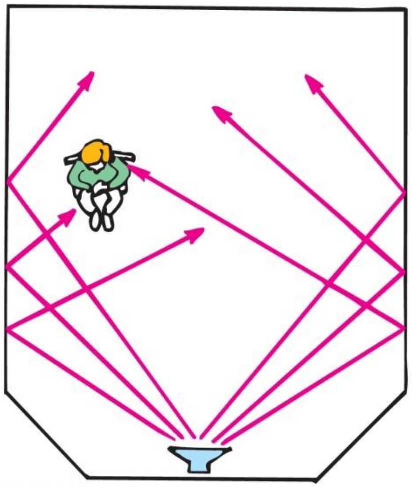
C. more than 660 m

D. there's no way to tell

Reflection and Refraction of Sound

Reflection

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



Reflection and Refraction of Sound
CHECK YOUR NEIGHBOR

Reverberations are best heard when you sing in a room with

A. carpeted walls.
B. hard-surfaced walls.
C. open windows.
D. none of the above

Reflection and Refraction of Sound
CHECK YOUR ANSWER

Reverberations are best heard when you sing in a room with

A. carpeted walls.

B. hard-surfaced walls.

C. open windows.

D. none of the above

Explanation:

Rigid walls better reflect sound energy. Fabric is absorbent, and open windows let sound energy escape from the room.

Reflection and Refraction of Sound

A situation to ponder…

Consider a person attending a concert that is being broadcast over the radio. The person sits about 45 m from the stage and listens to the radio broadcast with a transistor radio over one ear and a 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.

A situation to ponder…

CHECK YOUR NEIGHBOR

Which signal will be heard first?

A. radio signal
B. nonbroadcast sound signal
C. both at the same time
D. none of the above

A situation to ponder…
CHECK YOUR ANSWER

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—3×10^8 m/s.

Time to travel 45 m at 340 m/s ≈ 0.13 s.

Time to travel 4×10^7 m (Earth's circumference) at 3×10^8 m/s ≈ 0.13 s. Therefore, if you sit farther back at the concert, the radio signal would reach you first!

Reflection and Refraction of Sound

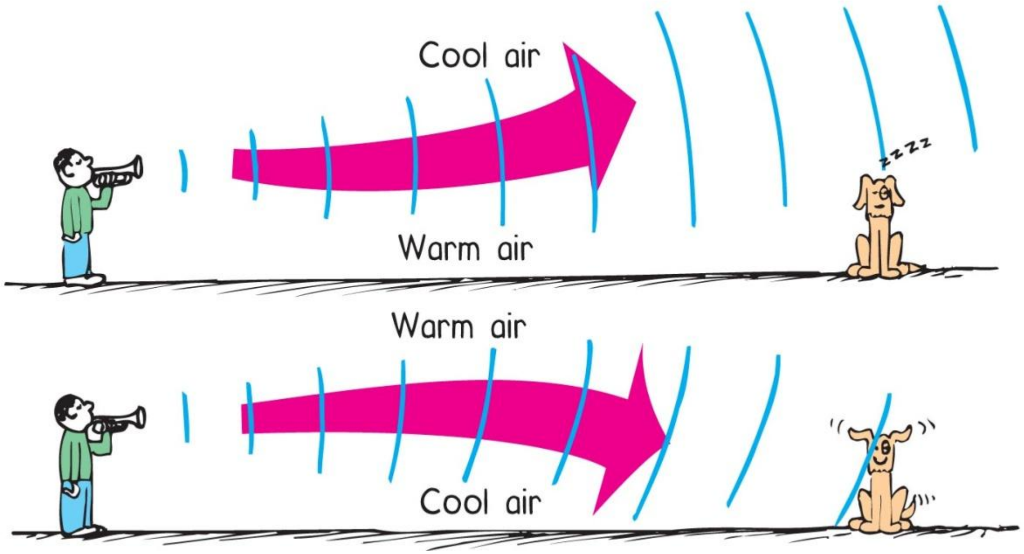
Acoustics

- study of sound

example: A concert hall aims for a balance between reverberation and absorption. Some have reflectors to direct sound (which also reflect light—so what you see is what you hear).

Reflection and Refraction of Sound

Refraction



- bending of waves—caused by changes in speed affected by
  - wind variations
  - temperature variations

Reflection and Refraction of Sound
CHECK YOUR NEIGHBOR

When air near the ground on a warm day is warmed more than the air above, sound tends to bend

A. upward.
B. downward.
C. at right angles to the ground.
D. none of the above

Reflection and Refraction of Sound
CHECK YOUR ANSWER

When air near the ground on a warm day is warmed more than the air above, sound tends to bend

A. upward.
B. downward.
C. at right angles to the ground.
D. none of the above

.

Reflection and Refraction of Sound
CHECK YOUR NEIGHBOR

In the evening, when air directly above a pond is cooler than air above, sound across a pond tends to bend

A. upward.
B. downward.
C. at right angles to the ground.
D. none of the above

Reflection and Refraction of Sound
CHECK YOUR ANSWER

In the evening, when air directly above a pond is cooler than air above, sound across a pond tends to bend

A. upward.

B. downward.

C. at right angles to the ground.

D. none of the above

Explanation:

This is why sound from across a lake at night is easily heard.

Reflection and Refraction of Sound

Multiple reflection and refractions of ultrasonic waves

- device sends high-frequency sounds into the body and reflects the waves more strongly from the exterior of the organs, producing an image of the organs
- used instead of X-rays by physicians to see the interior of the body

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

Forced Vibrations and Resonance

Resonance

- a phenomenon in which the frequency of forced vibrations on an object matches the object's natural frequency

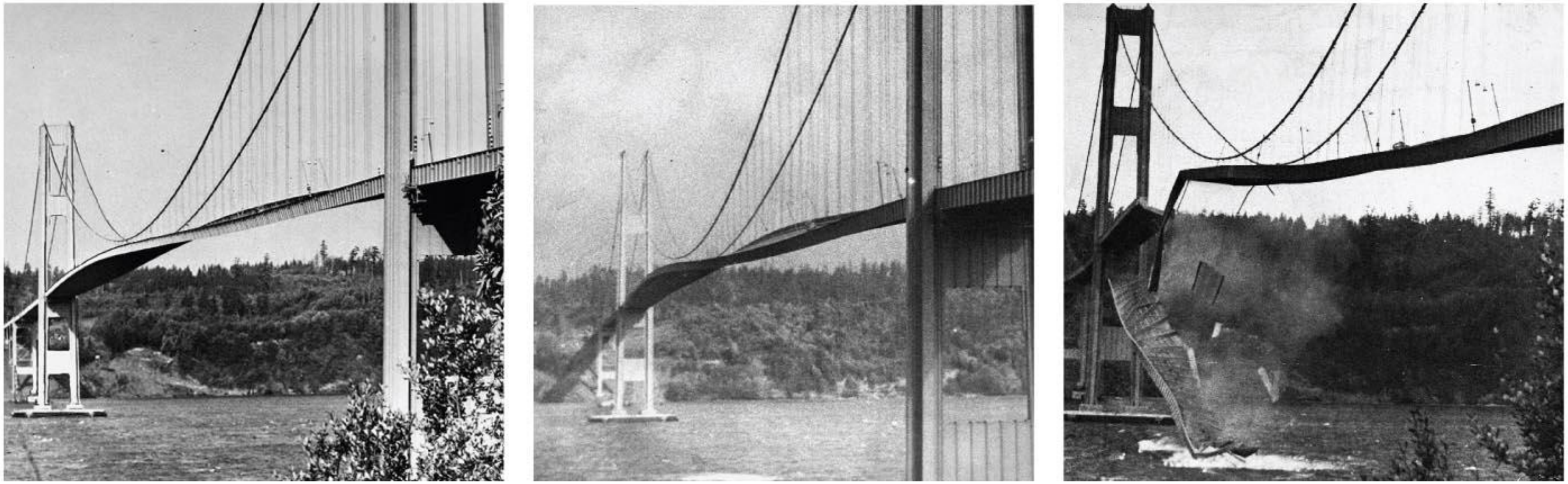
  example:

  - swinging in rhythm with the natural frequency of a swing
  - tuning a radio station to the "carrier frequency" of the radio station
  - troops marching in rhythm with the natural frequency of a bridge (a no-no!)

Forced Vibrations and Resonance

Resonance (continued)

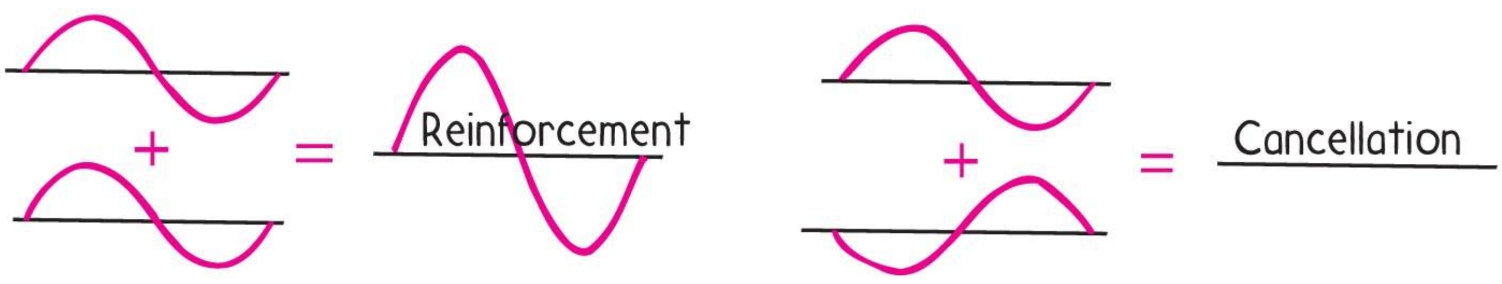
- dramatic example of wind-generated resonance



Interference

Interference

- property of all waves and wave motion
- superposition of waves that may either reinforce or cancel each other



Interference
CHECK YOUR NEIGHBOR

Interference is a property of

A. sound.
B. light.
C. both A and B
D. neither A nor B

Interference
CHECK YOUR ANSWER

Interference is a property of

A. sound.
B. light.
C. both A and B
D. neither A nor B

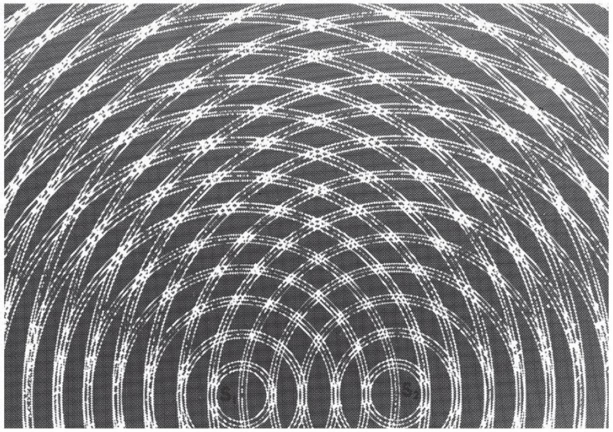
Explanation:

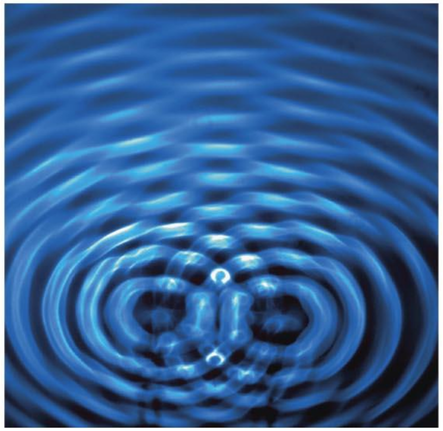
See Figure 12.21 to see illustrations of both light and sound interference. Interestingly, the presence of interference tells a physicist whether something is wavelike. All types of waves can interfere.

Interference

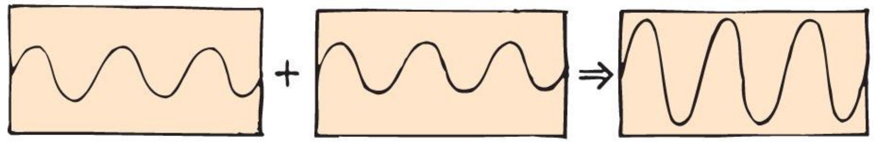
Two patterns of interference

- constructive interference
  - increased amplitude when the crest of one wave overlaps the crest of another wave
- destructive interference
  - reduced amplitude when the crest of one wave overlaps the trough of another wave

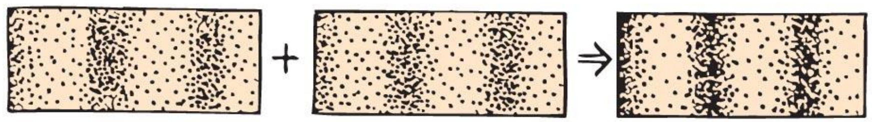




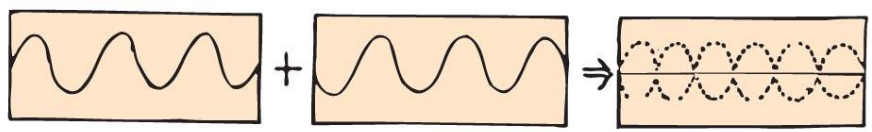
Interference



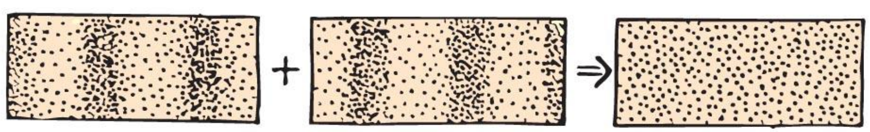
The superposition of two identical transverse waves in phase produces a wave of increased amplitude.



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.

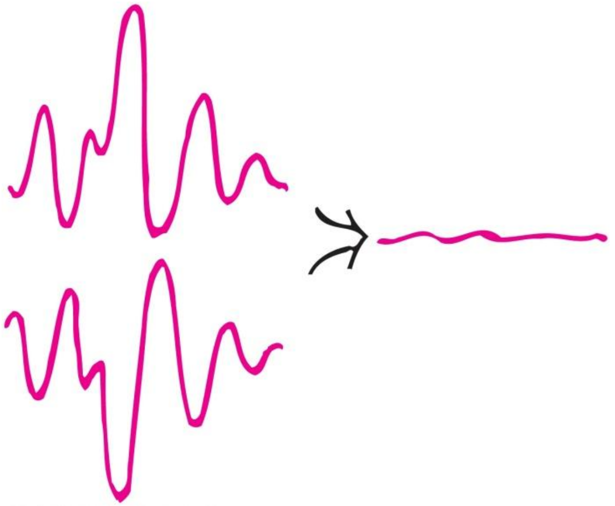


Two identical longitudinal waves that are out of phase destroy each other when they are superimposed.

Interference

Application of sound interference

- destructive sound interference in noisy devices such as jackhammers that are equipped with microphones to produce mirror-image wave patterns fed to operator's earphone, cancelling the jackhammer's sound



Interference

Application of sound interference (continued)

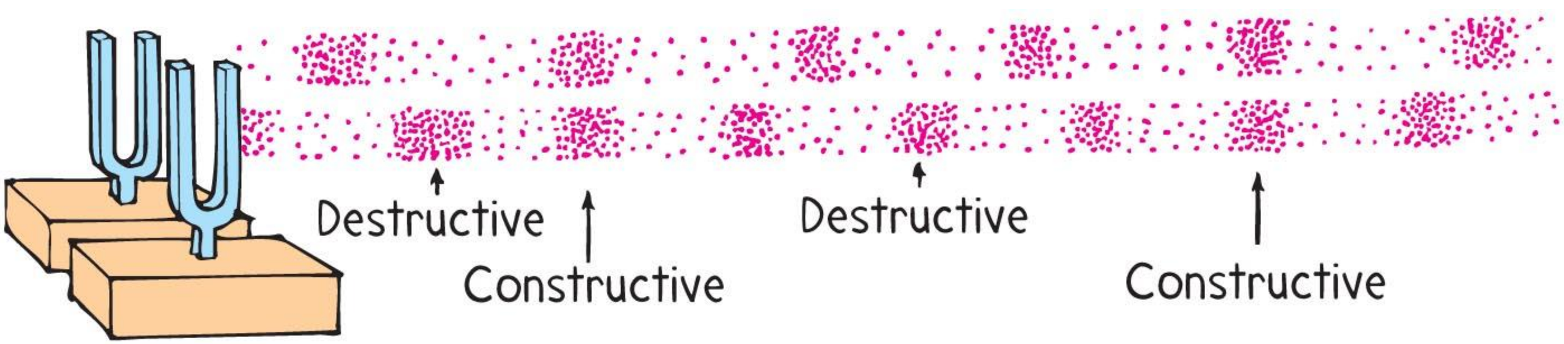
- sound interference in stereo speakers out of phase sending a monoaural signal (one speaker sending compressions of sound and other sending rarefactions)

- 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

Beats (continued)

- applications
  - piano tuning by listening to the disappearance of beats from a tuning fork and a piano key
  - tuning instruments in an orchestra by listening for beats between instruments and piano tone

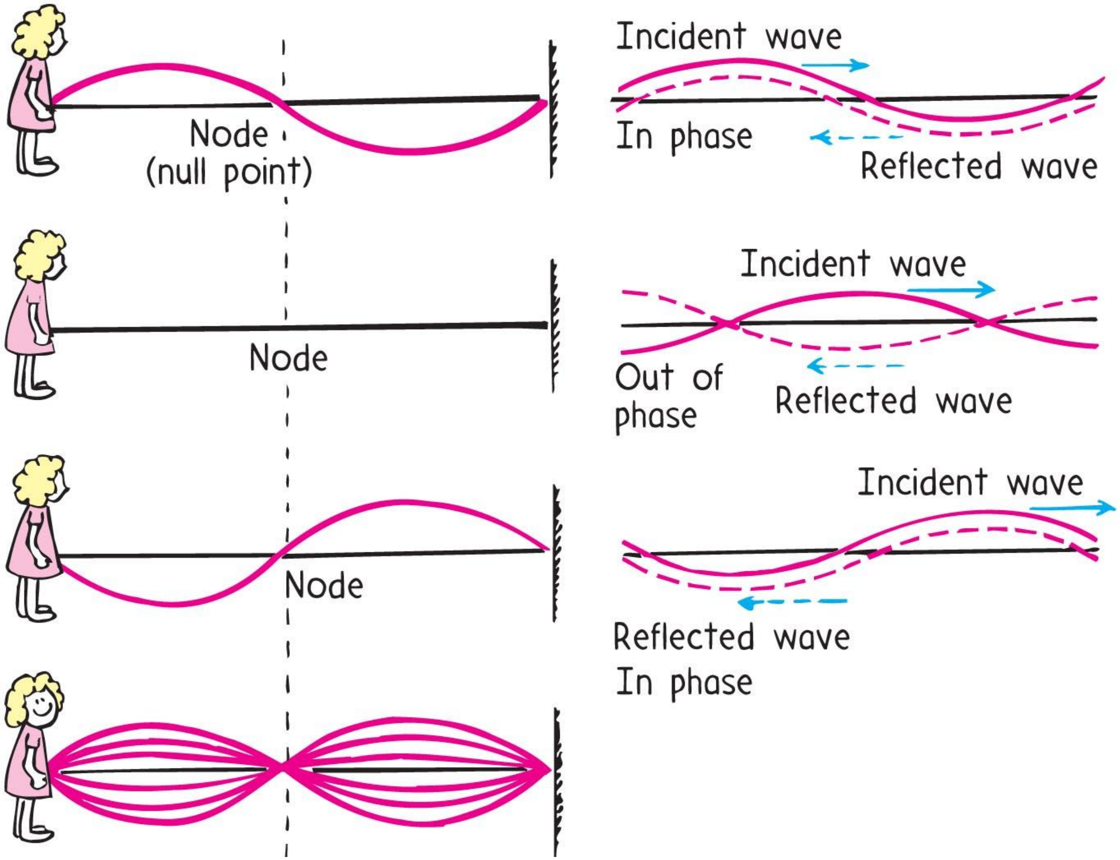
Interference

Standing waves

- produced by interference of incoming and reflected waves
- stationary wave pattern formed in a medium in which two waves of equal amplitude and wavelength pass through each other in opposite directions
- does not move along the medium, but remains in place

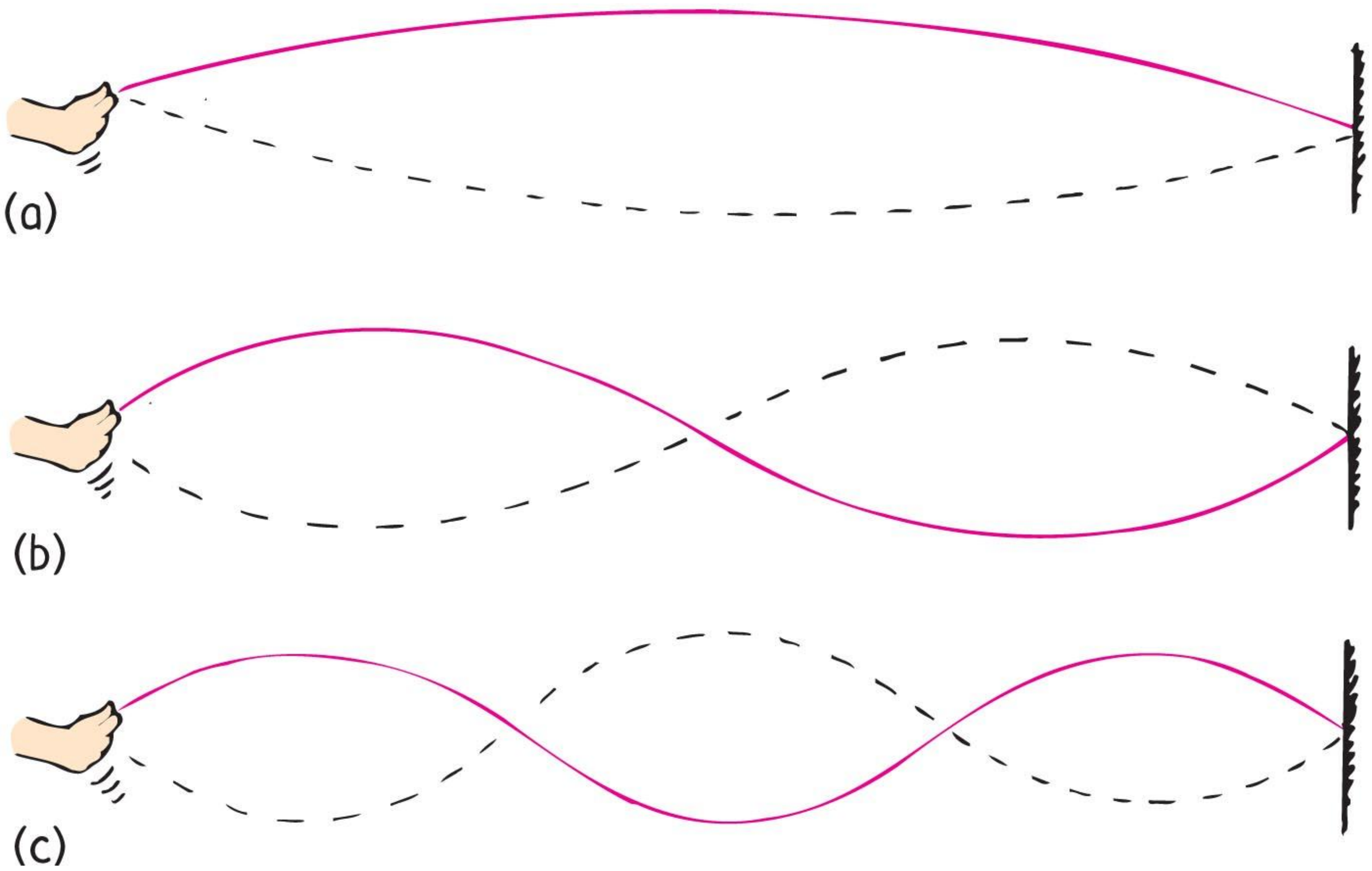
Interference

Standing waves



Interference

Nodes of standing wave



Interference

Nodes of standing wave

- stationary points where the incoming and reflected waves always interfere destructively
- antinodes of standing wave
- positions with the largest displacements
- occur halfway between nodes
- incoming and reflected waves move up and down constantly by alternating periods of destructive and constructive interference

Doppler Effect

Doppler effect

- change of frequency due to the motion of the wave source
- named after Austrian physicist and mathematician Christian Johann Doppler
- applies to waves of water, light, and sound

Doppler Effect

Doppler effect (continued)

- most evident in change of pitch
  - frequency of waves increases as the siren approaches (hear higher pitch)
  - frequency of waves decreases as siren moves away (hear lower pitch)

The Doppler Effect
CHECK YOUR NEIGHBOR

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 of the above increase

The Doppler Effect
CHECK YOUR ANSWER

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 of the above increase

Comment:

Be sure you distinguish between sound, speed, and sound frequency.

Doppler Effect

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

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

A. sound.
B. light.
C. both A and B
D. neither A nor B

Explanation:

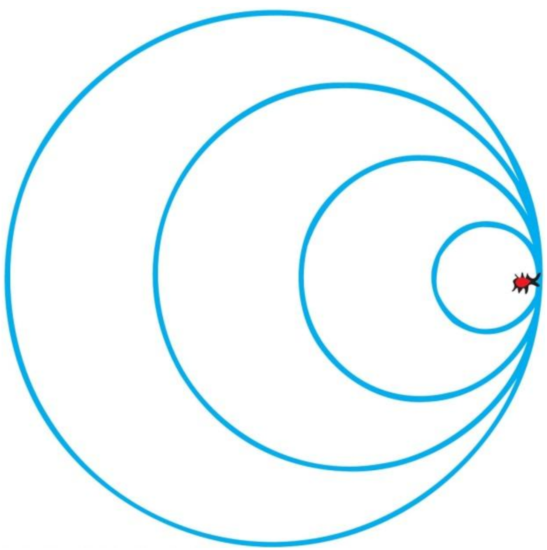
The Doppler effect occurs for both sound and light. Astronomers measure the spin rates of stars by the Doppler effect.

Wave Barriers and 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



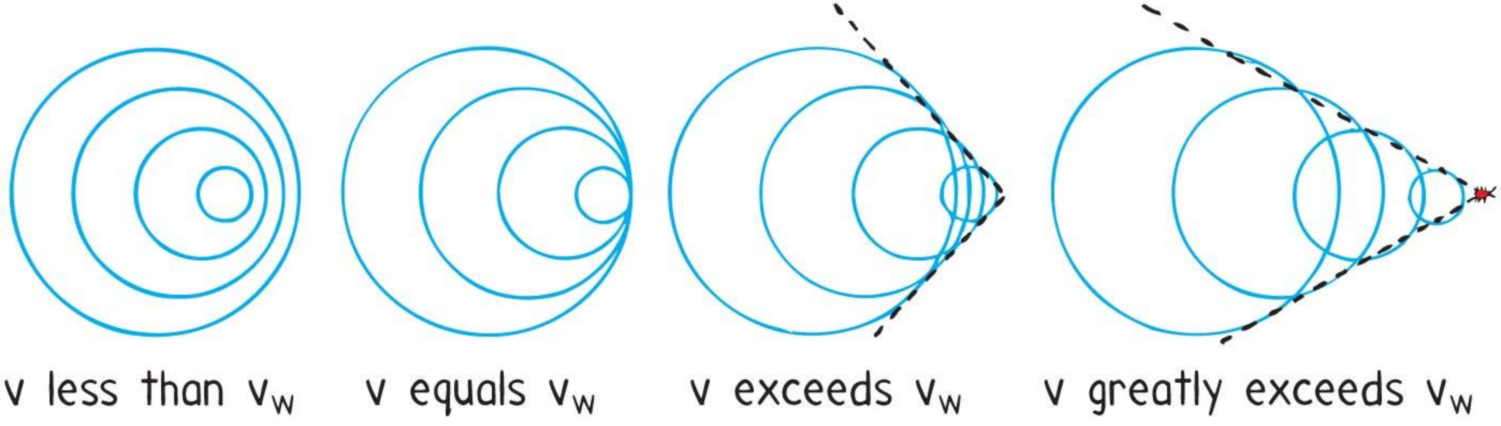
Wave Barriers and Bow Waves

Supersonic

- aircraft flying faster than the speed of sound

Bow wave

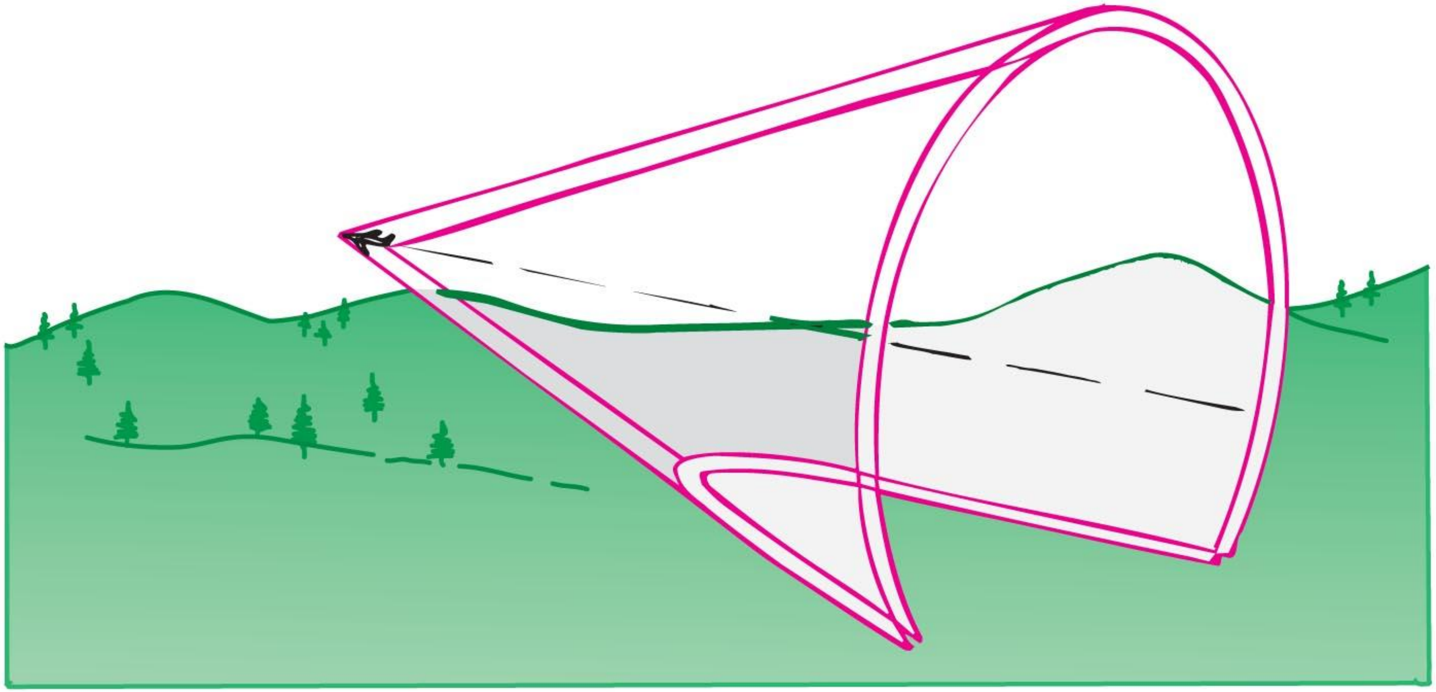
- V-shape form of overlapping waves when object travels faster than wave speed
- an increase in speed will produce a narrower V-shape of overlapping waves.



Shock Waves and the Sonic Boom

Shock wave

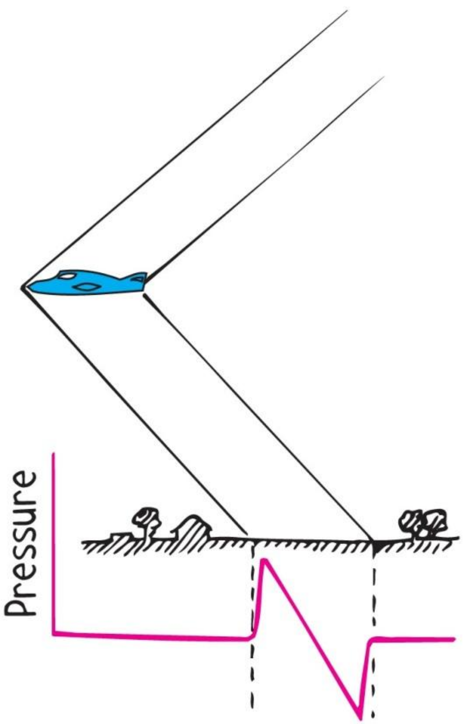
- pattern of overlapping spheres that form a cone from objects traveling faster than the speed of sound



Shock Waves and the Sonic Boom

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



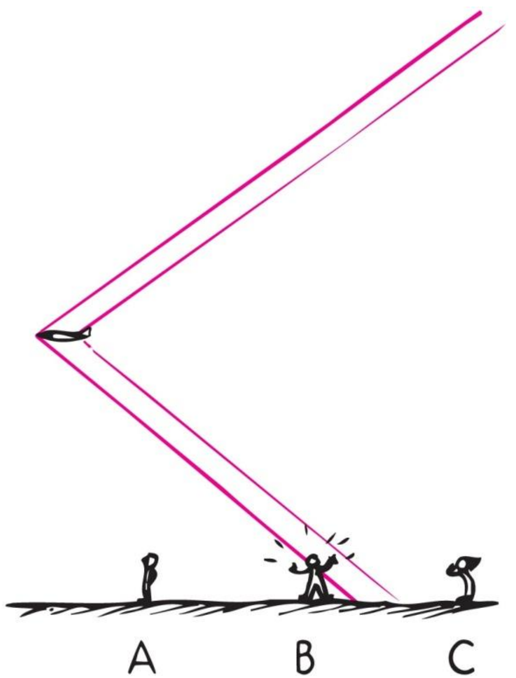
Shock Waves and the Sonic Boom

Sonic boom

- sharp cracking sound generated by a supersonic aircraft
- intensity due to overpressure and underpressure of atmospheric pressure between the two cones of the shock waves
- produced before it broke the sound barrier

  example:

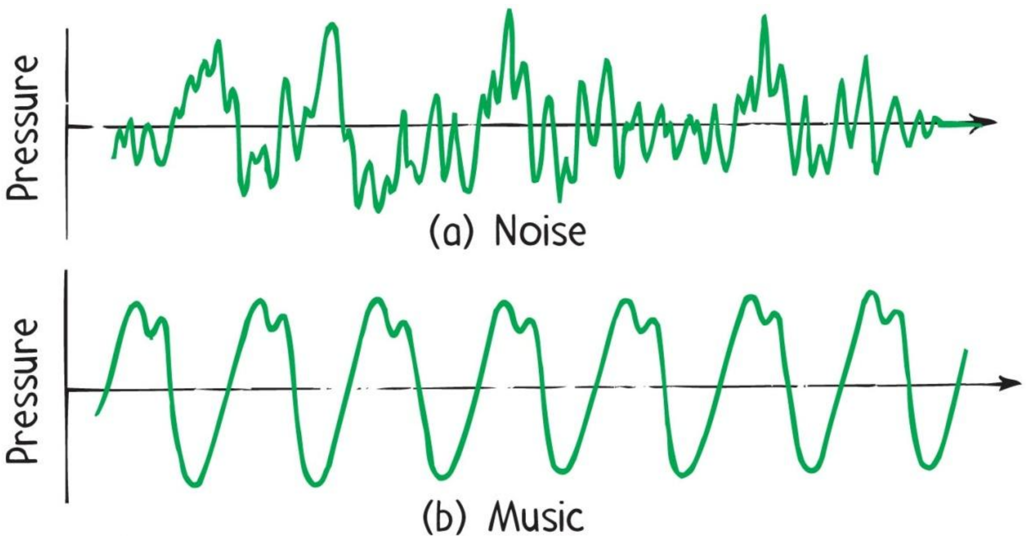
  - supersonic bullet
  - crack of circus whip



Musical Sounds

Musical sounds

- most composed of a superposition of many frequencies called partial tones
  – harmonics
    - whole multiples of the fundamental frequency



Musical Sounds

Musical tone

- three characteristics:
  - pitch
    - determined by frequency of sound waves as received by the ear
    - determined by fundamental frequency, lowest frequency
  - intensity
    - determines the perceived loudness of sound

Musical Sounds

Musical tone

- three characteristics (continued):
  - quality
    - determined by prominence of the harmonics
    - determined by presence and relative intensity of the various partials

Musical Sounds

Sound production from musical instruments

- grouped into:
  - vibrating strings
    - vibration of stringed instruments is transferred to a sounding board and then to the air
  - vibrating air columns
    - brass instruments
    - woodwinds—stream of air produced by musician sets a reed vibrating
    - fifes, flutes, piccolos—musician blows air against the edge of a hole to produce a fluttering stream

Musical Sounds

Sound production from musical instruments (continued)

- percussion
  - striking a 2-dimensional membrane
  - tone produced depends on geometry, elasticity, and tension in the vibrating surface
  - pitch produced by changes in tension

Musical Sounds

Electronic musical instrument

- differs from conventional musical instruments
- uses electrons to generate the signals that make up musical sounds
- modifies sound from an acoustic instrument
- demands the composer and player demonstrate an expertise beyond the knowledge of musicology

Musical Sounds

Electronic musical instrument

- Waveforms
- Native instruments - West Africa
- Native Intstruments - Razor