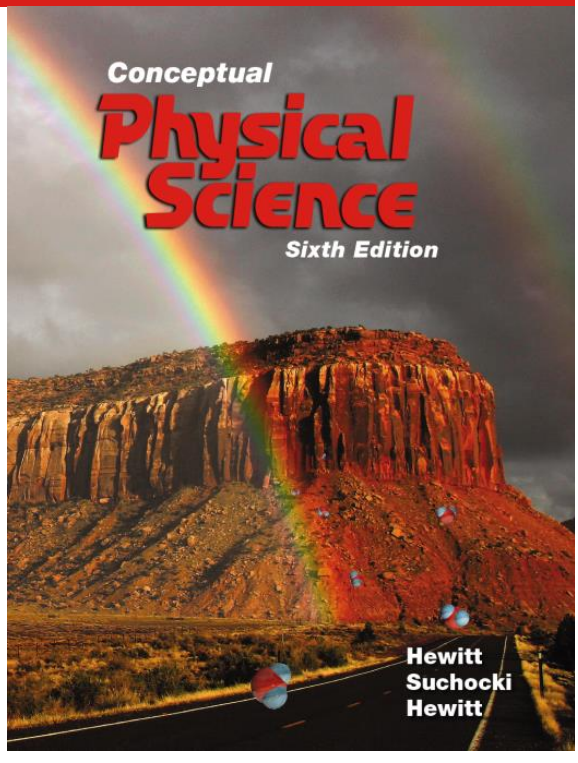
Chapter 10 Lecture

Chapter 10: Waves and Sound



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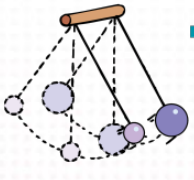


THE BIG IDEA

Waves transmit energy through space and time.

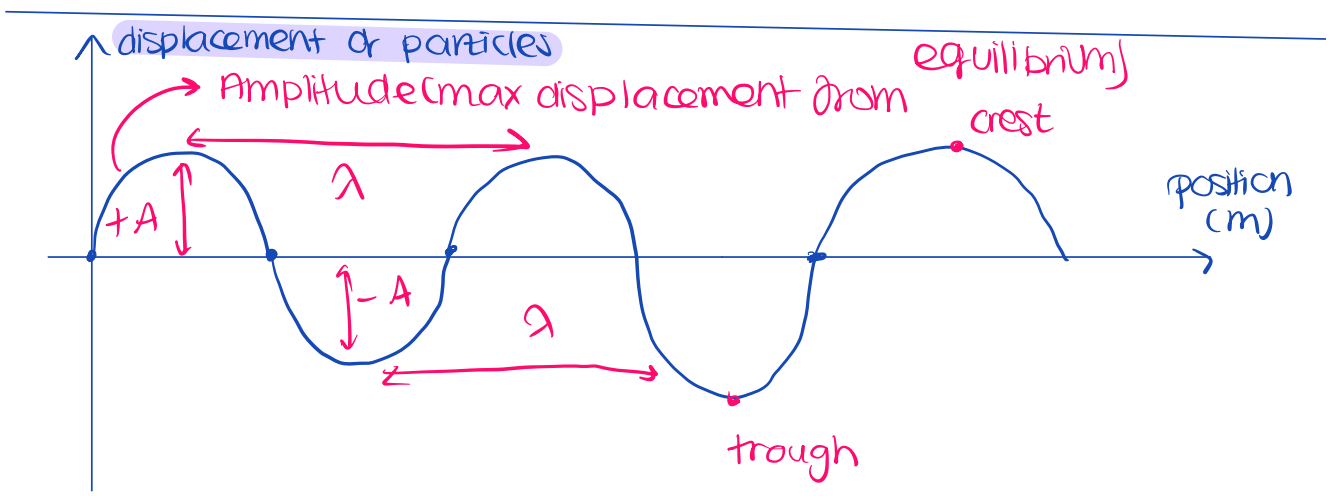
T : period → it is defined as the time needed for 1 repetition / turn

↳ (s)

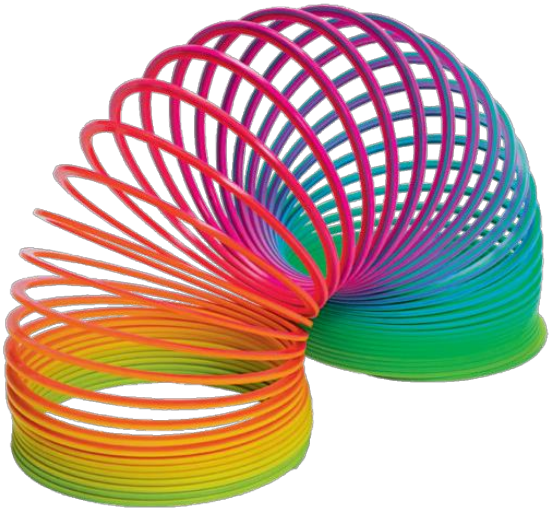
inversely proportional

f : frequency → $\frac{\text{number of turns / repetitions / revolution}}{s}$

↳ Hertz (Hz)



A repeating back-and-forth motion about an equilibrium position is a vibration. A disturbance that is transmitted progressively from one place to the next with no actual transport of matter is a wave. Light and sound are both forms of energy that move through space as waves.



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Frequency

The number of vibrations an object makes in a unit of time is an object's **frequency.**

The frequency specifies the number of back-and-forth vibrations in a given time (usually one second).

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The unit of frequency is called the **hertz** (Hz).

A frequency of one cycle per second is 1 hertz, two cycles per second is 2 hertz, and so on. Higher frequencies are measured in

- kilohertz (kHz—thousands of hertz)
- megahertz (MHz—millions of hertz)
- gigahertz (GHz—billions of hertz)

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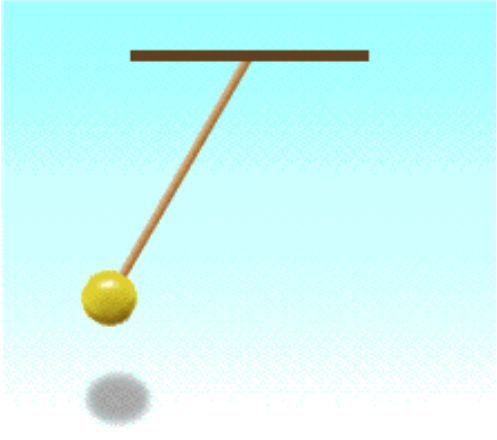
Period

Time required for a full oscillation (one round trip) is called the *period* of oscillation.

Pendulum that is about one meter long has a period of two seconds per oscillation.



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If the frequency of a vibrating object is known, its period can be calculated, and vice versa. Suppose, for example, that a pendulum makes two vibrations in one second. Its frequency is 2 Hz. The time needed to complete one vibration—that is, the period of vibration—is 1/2 second. As you can see below, frequency and period are inverses of each other:

$$\text{frequency} = \frac{1}{\text{period}} \quad \text{or period} = \frac{1}{\text{frequency}}$$

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Question:

If you double the frequency of a vibrating object, what happens to the period?

a) the period doubles

b) the period stays the same

c) the period is cut in half

d) not enough information is given to answer this question.

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Wave Description

The **wavelength** of a wave is the distance from the top of one crest to the top of the next one.

Equivalently, the wavelength is the distance between successive identical parts of the wave.

The wavelengths of waves at the beach are measured in meters, the ripples in a pond in centimeters, of light in billionths of a meter.

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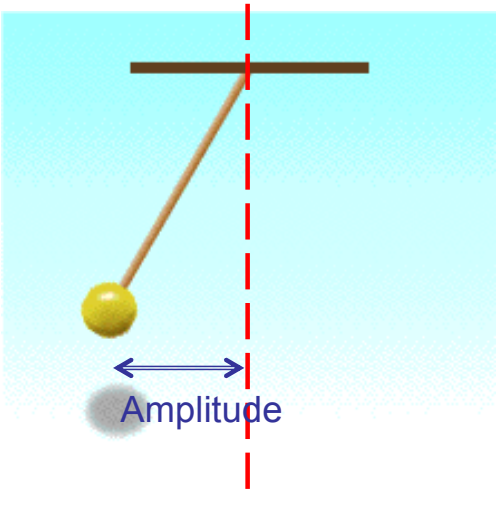
Amplitude

The distance from the rest position is the *amplitude* of oscillation.



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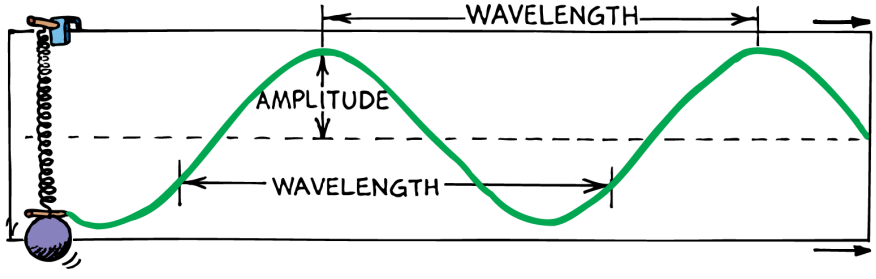
Wave Description

The Parts of a Wave

A weight attached to a spring undergoes a periodic motion.

A marking pen attached to the bob traces a sine curve on a sheet of paper that is moving horizontally at constant speed.

A sine curve is a pictorial representation of a wave.



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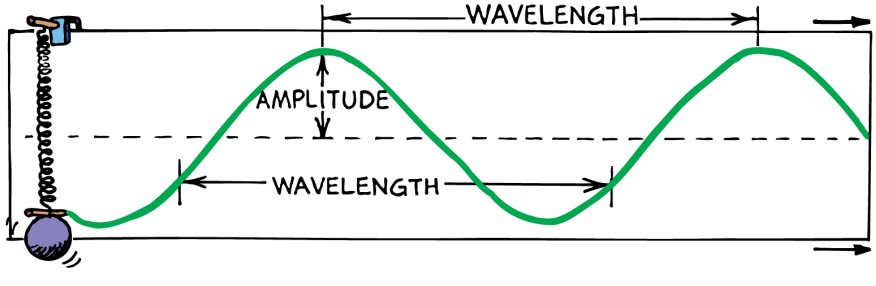
Wave Description

- The high points on a wave are called **crests.**
- The low points on a wave are called **troughs.**
- The term **amplitude** refers to the distance from the midpoint to the crest (or trough) of the wave.
- The amplitude is the maximum displacement from equilibrium.



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Wave Motion

Most information gets to us in some form of wave.

- Sound is energy that travels to our ears in the form of a wave.
- Light is energy that comes to our eyes in the form of a different kind of wave (an electromagnetic wave).
- The signals that reach our radio and television sets also travel in the form of electromagnetic waves.

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Wave Motion

When energy is transferred by a wave from a vibrating source to a distant receiver, no matter is transferred between the two points.

Think about the very simple wave produced when one end of a horizontally stretched string is shaken up and down.

Each part of the string moves up and down and the disturbance moves horizontally along the length of the string.

The disturbance moves, not parts of the string itself.

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Wave Motion

Drop a stone in a quiet pond and you'll produce a wave that moves out from the center in an expanding circle.

It is the disturbance that moves, not the water.

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Wave Motion

When someone speaks to you from across the room, the sound wave is a disturbance in the air that travels across the room.

The air molecules themselves do not move along.

The air, like the rope and the water in the previous examples, is the medium through which wave energy travels.

Energy is not transferred by matter moving from one place to another within the medium.

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Wave Motion

think!

The Sears Tower in Chicago sways back and forth at a frequency of about 0.1 Hz. What is its period of vibration?

Answer: The period is

$$T = \frac{1 \text{ vib}}{0.1 \text{ Hz}} = \frac{1 \text{ vib}}{0.1 \text{ vib/s}} = 10 \text{ s}$$

$$T = \frac{1}{f} = \frac{1}{0.1}$$

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Wave Speed

The speed of a wave depends on the medium through which the wave moves.

Whatever the medium, the speed, wavelength, and frequency of the wave are related.

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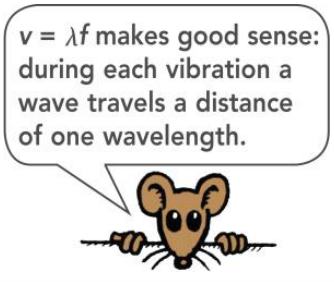
Wave Speed

If the wavelength is 3 meters and if two crests pass a stationary point each second, then 3 meters × 2 waves pass by in 1 second.

The waves therefore move at 6 meters per second.

$$v = \lambda f$$

where v is wave speed, λ is wavelength, and f is wave frequency.



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Wave Speed

think!

$\frac{1}{f} = \frac{1}{2}$ → freq = 2, period = $\frac{1}{2}$

If a water wave vibrates up and down two times each second and the distance between wave crests is 1.5 m, what is the frequency of the wave? What is its wavelength? What is its speed?

$\lambda = 1.5$

$v = \frac{\lambda}{T}$ or $\lambda f = 1.5 \times 2$ or $\frac{1.5}{0.5} = 3 m/s$

Answer:

The frequency of the wave is 2 Hz; its wavelength is 1.5 m; and its wave speed is

$$v = \lambda \times f = (1.5 \text{ m}) \times (2 \text{ Hz}) = 3 \text{ m/s}$$

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Wave Speed

think!

What is the wavelength of a 170-Hz sound wave when the speed of sound in air is 340 m/s?

Answer:

The wavelength must be 2 m.

Then wave speed = (2 m) × (170 Hz) = 340 m/s.

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Exercise

- Microwaves travel at the speed of light, 3.00×10^8 m/s. When the frequency of microwaves is 9.00×10^9 Hz, what is their wavelength?

$v = 3 \times 10^8$ m/s

$f = 9 \times 10^9$ Hz

$\lambda = ?$

$v = \lambda f$

$\frac{v}{f} = \frac{\lambda f}{f}$

$\lambda = v/f$

- A: 0.03 m

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Exercise

- The piano string tuned to middle C vibrates with a frequency of 264 Hz. Assuming the speed of sound in air is 343 m/s, find the wavelength of the sound waves produced by the string.

$f = 264\ Hz$

$v = 343\ m/s$

$\lambda = ??$

$\frac{v}{f} = \frac{\lambda f}{f} \rightarrow \lambda = \frac{v}{f}$

$\lambda = \frac{343}{264}$

- A: 1.30 m

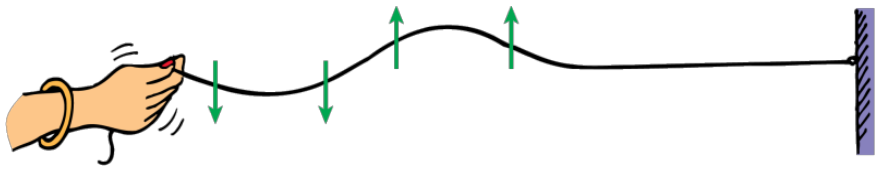
Transverse Waves

Suppose you create a wave along a rope by shaking the free end up and down.

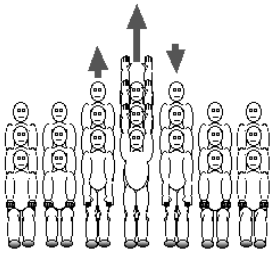
The motion of the rope is at right angles to the direction in which the wave is moving.

Whenever the motion of the medium is at right angles to the direction in which a wave travels, the wave is a **transverse wave.**

ex: water in a pond, electromagnetic waves (light)



Doing “The Wave”



Synchronized standing and sitting by a stadium’s crowd is an example of a transverse wave.

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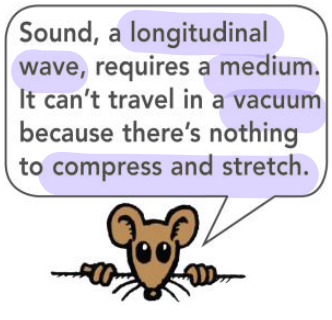
Longitudinal Waves

parallel

Sometimes the particles of the medium move back and forth in the same direction in which the wave travels.

When the particles oscillate parallel to or *along* the direction of the wave, the wave is a **longitudinal wave.**



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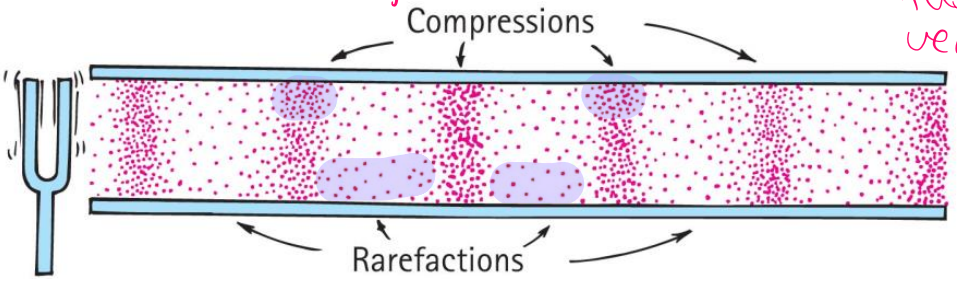
The Nature of Sound

- Sound
  - travels in longitudinal waves—vibrating compressions and rarefactions through air
- Speed of Sound
  - Sound travels at 340 m/s in air at 20ºC

when the temperature increases the molecules move faster, and vice versa when the temperature decreases



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The Nature of Sound
A situation to ponder…

- 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.

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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.

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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. So if you sit farther back at the concert, the radio signal would reach you first!

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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

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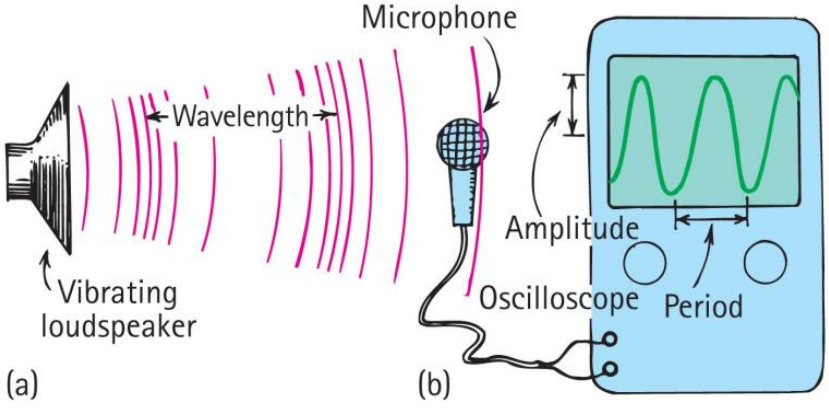
Radio Speaker

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



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The Nature of Sound

- For each increase of 1ºC above 0ºC, 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)

1 °C ×10 = 0.6m ×10

10°C × 0.6 = 6m/s

+10°C { T = 20 °C v = 340m/s

T = 30°C v = ??

340 + 6 = 346m/s

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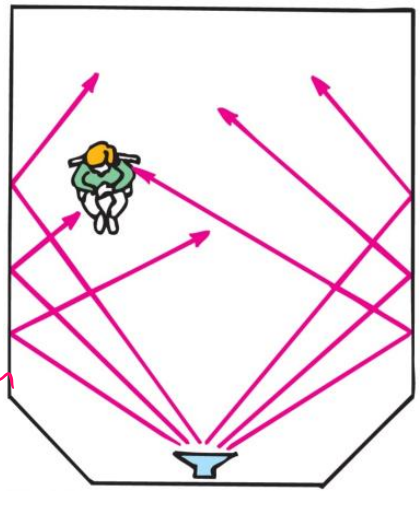
340 + 6 = 346m/s

Reflection

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

1) specular (smooth) reflection

2) Diffuse reflection



- Angle of Incidence = Angle of Reflection

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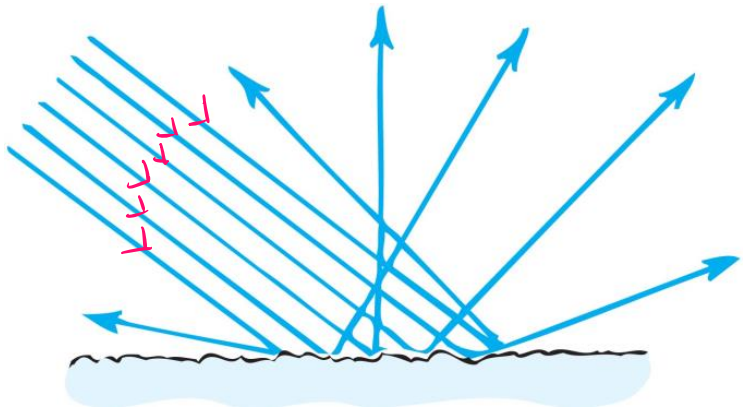
smooth reflection

Reflection

- Diffuse Reflection
  - When sound or light is incident on a rough surface, it is reflected in many directions.



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Reflection
CHECK YOUR NEIGHBOR

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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Reflection
CHECK YOUR ANSWER

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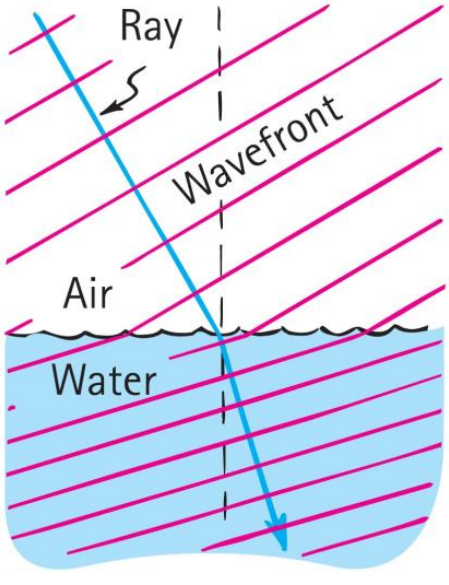
Refraction

(bending of light → it won't continue in the same direction)

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



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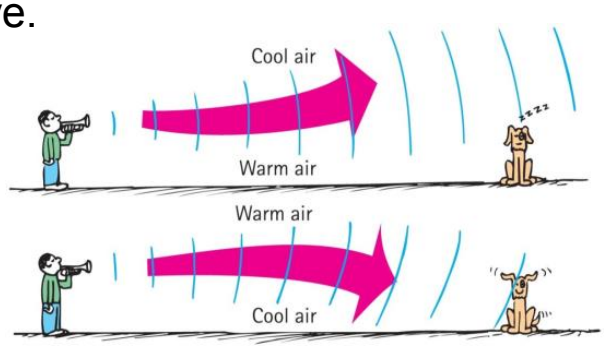
Refraction

- 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.



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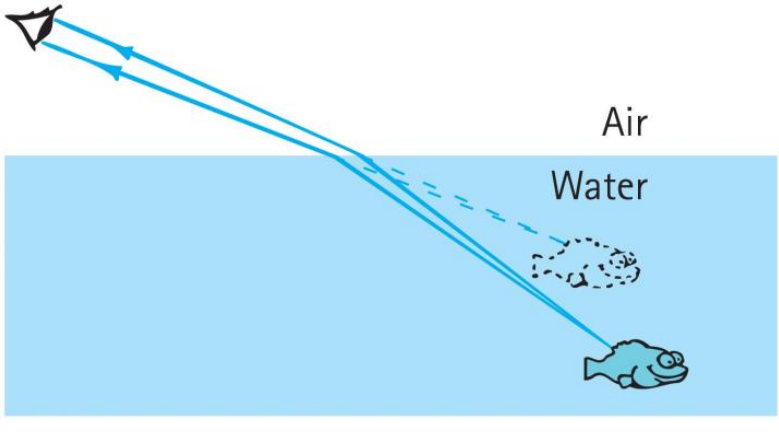
Refraction

- Illusions caused by refraction



  - Objects submerged in water appear closer to the surface.

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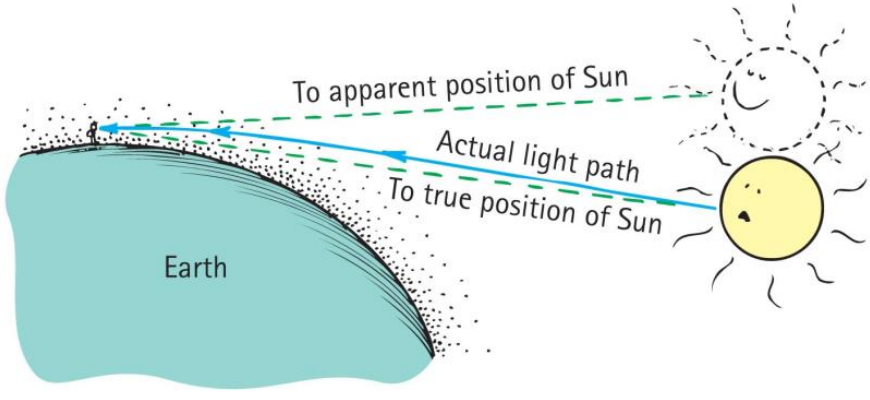
Refraction

- Illusions caused by refraction (continued)



- Objects such as the Sun seen through air are displaced because of atmospheric refraction.

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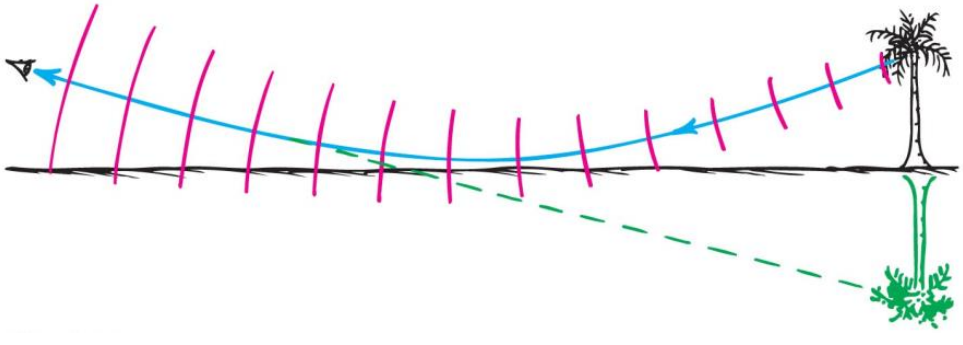
Refraction

- Illusions caused by refraction (continued)



- Atmospheric refraction is the cause of mirages.

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Reflection and Refraction of Sound

- Dolphins emit ultrasonic waves to enable them to locate objects in their environment

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