Wave and Sound

Properties of waves

A **wave** is a disturbance that carries energy through matter or space. We have worked with electromagnetic waves that do not require a medium through which to travel. Sound waves and seismic waves do require a **medium** through which to travel because these waves have mechanical energy. Waves transfer energy that thus waves have the ability to do work; they set particles in motion. The particles vibrate in response to receiving the energy transferred to them from the wave. Waves contain kinetic energy and the kinetic energy in the motion of the wave can be transferred to any object it may encounter such as a small leaf or a large boat.

Have you ever dropped a pebble into water? You notice that the waves will move equally in all directions from the point of origin. If you shine the light from a flash light onto a wall, the farther you are, the farther the light waves spread out on the wall.

Two fundamental types of waves:
1) mechanical waves - a wave that requires a medium(matter) through which to travel
examples: **1. sound wave** - travels through air, water, solids
2. seismic waves – travels through the Earth

2) electromagnetic waves - electric field energy (including light) that travels through the absence of matter (space or vacuum)
examples: **1. radio waves** - travels through space, carries signals to radio or TV
2. light - travels through space, visible electromagnetic waves

The waves we are working with in this unit are mechanical waves.

medium - matter that the wave travels through
examples of the medium are:
a) water - ocean waves; tsunami
b) air - sound waves - speed is 346 m/s
c) earth - seismic waves
d) vacuum - electromagnetic waves

Three types of **mechanical waves** that move through a medium:

a) Transverse waves - motion of particles are **perpendicular** to the direction of the traveling wave; particles move **up and down**
examples – a rope shaking up and down; water moving up and down, light

b) Longitudinal waves - motion of particles are **parallel** to the direction of the traveling wave; particles move back and forth - **compression and rarefaction**
examples – a slinky in motion, sound waves

c) Surface waves - 1. occur at the boundary between two different mediums such as air and water. **2.** particles move both perpendicular and parallel to the direction that the wave travels.

An ideal **transverse wave** has the shape of a **sine wave** and the components of a sine wave are:

a) amplitude - displacement of particles from their normal resting position

b) wavelength (l) - the distance from the beginning of one cycle to the beginning of the next

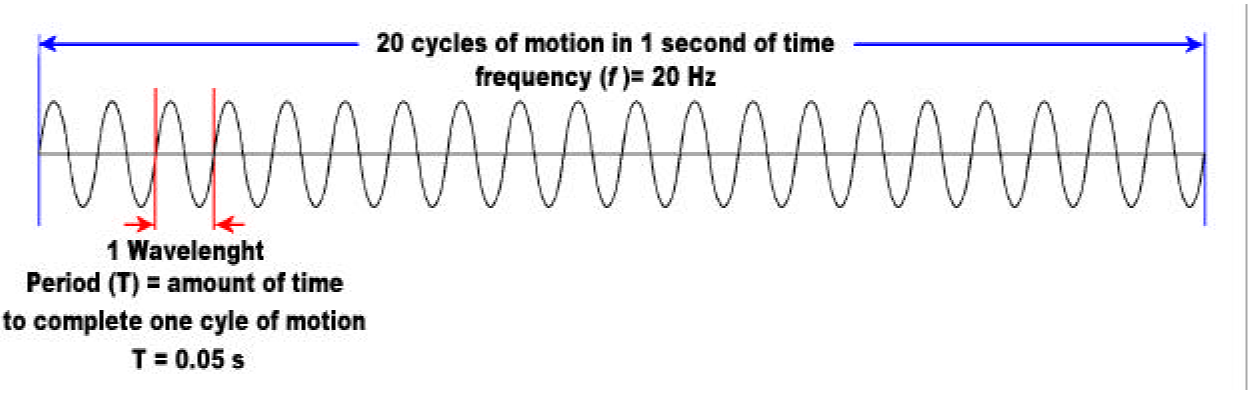
c) period (**T**)- time required one wavelength to pass through a point in the medium

d) frequency (***f***) - time required for a given number of wavelengths or vibrations to pass through a certain distance

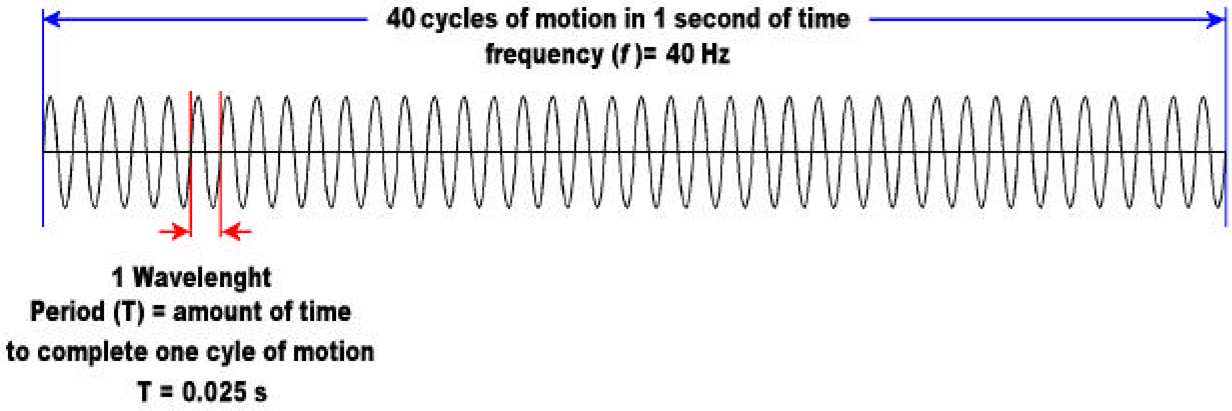
Frequency and period of a wave:

1. To calculate the frequency of a wave when given the period: $f = \frac{1}{T}$
2. To calculate the period of a wave when given the frequency: $T = \frac{1}{f}$

In the diagram below there are 20 cycles of motion. If the 20 cycles of motion are completed in one second of time, then the frequency is 20 Hz. The period is the amount of time for one cycle of motion to be completed for a given frequency. As shown above one cycle of motion or one wavelength requires 0.05 second to complete.

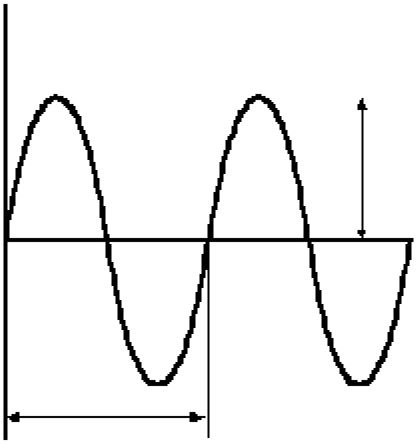


In the diagram below the frequency has been doubled to 40 Hz (second harmonic energy). Note what happens to the wavelength and to the period. The wavelength has halved and the period has also halved requiring 0.025 seconds to complete.

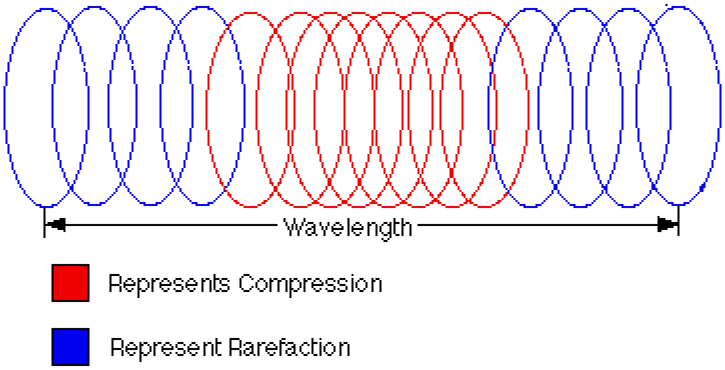


Two complete sine waves are shown in the diagram to the right.

Label the **amplitude**, **wavelength**, **crest**, and **trough** of the wave. Also label the point of **zero deviation**.



A **longitudinal wave** has elements of compression and rarefaction as the particles move back and forth, parallel, to the direction of wave travel. Amplitude is also parallel to the direction of travel, the maximum parallel displacement of the particles in the direction of travel.



The diagram above shows rarefaction, compression, and then no displacement of particle movement. Think of the motion of a slinky.

Wave speed is the speed at which a wave passes trough a medium.

Three formulas for finding **wave speed** are:

1. $v = \frac{d}{t}$ where ***v*** is velocity; ***d*** is distance, and ***t*** is the time
2. $v = \frac{\lambda}{T}$ where v is velocity; λ is the Greek symbol for wavelength and **T** is period
3. $v = f \times \lambda$ where **v** is velocity; **f** is frequency and λ is the Greek symbol for wavelength

Determining **wave speed** of ocean waves or tsunamis**:**

1. Count the number of crests passing by in a certain amount of time.
2. Measure the distance between the crests.
3. Select the appropriate formula from above to determine the wave speed.

wave speed depends upon the medium – the denser the medium, then faster the wave

We can then summarize that materials with greater kinetic energy transfer mechanical waves **slower** and materials with less kinetic energy transfer mechanical waves **faster**.

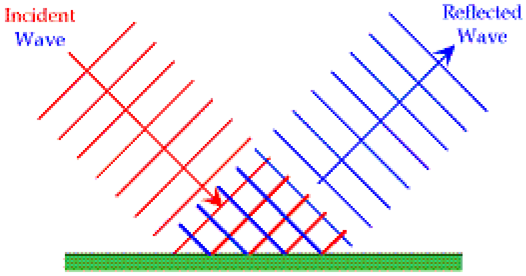
Wave Interactions

As waves move without interference through a non-changing medium, the waves move in a **straight line.** If a wave encounters an obstacle or a change in medium, there can be numerous effects on the wave.

Reflection - the bouncing back of a wave as it meets a surface or boundary

The incident wave is the incoming wave and the reflected wave is the outgoing wave.

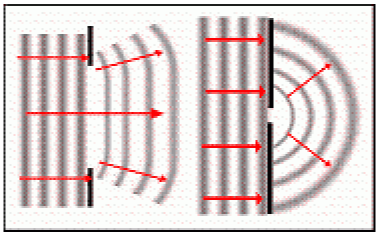
Example – When you focus a light from a flashlight onto a mirror, the outgoing reflected light wave will have the same angle as the incident (incoming) wave.



http://www.gcsescience.com/pwav34.htm

Diffraction - the bending of a wave as it passes an edge or an opening

Example – Back to that puddle of water … if the wave encounters a stick or other obstruction in the water, then the wave bends around the side of the obstruction.



Refraction – the bending of a wave due to a change in speed as the wave passes from one medium to the next medium of different density.

If the next medium has a higher density, the wave slows down, and if the next medium is less dense, the wave speeds up. The **index of refraction** compares the speed of light in vacuum with speed of light in medium. This is useful physical property of matter to identify various types of substances. This is a number without units, thus a ratio, and the value will always be greater than 1.

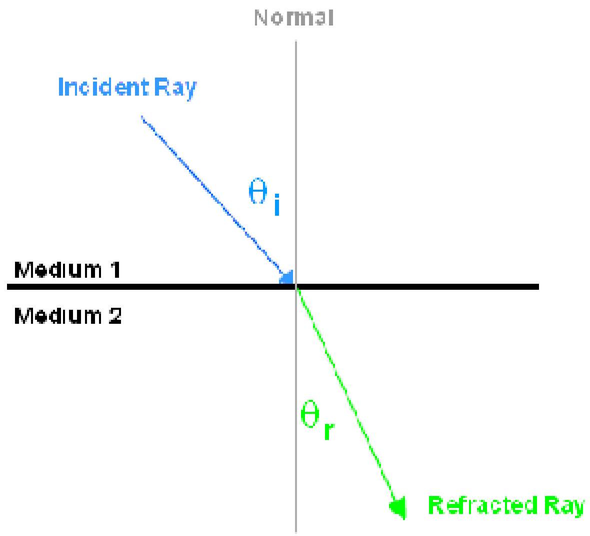


Fig 1. Low density to high density

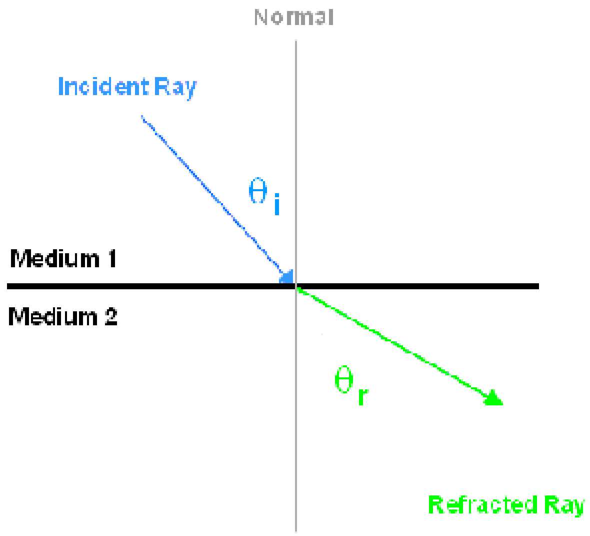


Fig 2. High density to low density

Example – Place a pencil into a glass of water and observe. Which of the above figures would match that scenario?

Wave Interference

The combination of two or more waves that exist in the same place at the same time is called **interference**. The two types of interferences are constructive and destructive.

1. **constructive interference** - waves combine in such a manner that the amplitudes add resulting in a more powerful wave crest – these waves are in phase with one another

2. **destructive interference** - waves combine in such a manner that the amplitudes are reduced resulting in a less powerful wave crest these waves are 180 degrees out of phase with each other

An effect of interference between waves is **standing waves**. If the incident wave and the reflected wave occupy the same space and have the same amplitude, a standing wave is produced, a wave that does not move. Standing wave patterns are always characterized by an alternating pattern of nodes and antinodes.

nodes - a point on the wave that has no vibration - minimum amplitude due to destructive interference, the meeting of the crest and a trough.

antinodes - a point that has maximum vibration – maximum amplitude due to constructive interference, the meeting of a crest and crest and a trough meeting a trough.

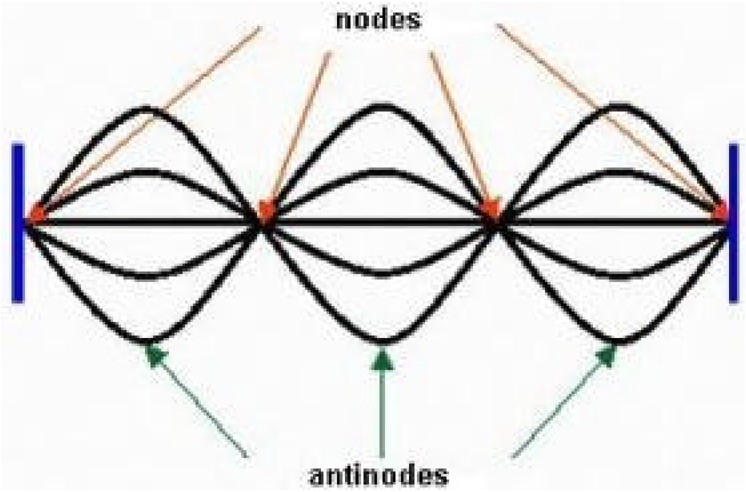


Image is from http://media.nasaexplores.com/lessons/02-027/images/waves.jpg

The age-old question:

"If a tree falls in the forest and nobody is around to hear it, was there sound?"
or
"If a tree falls on the moon, will there be sound?'
or
"Why do you hear the roar of an engine in space in a sci-fi movie?"

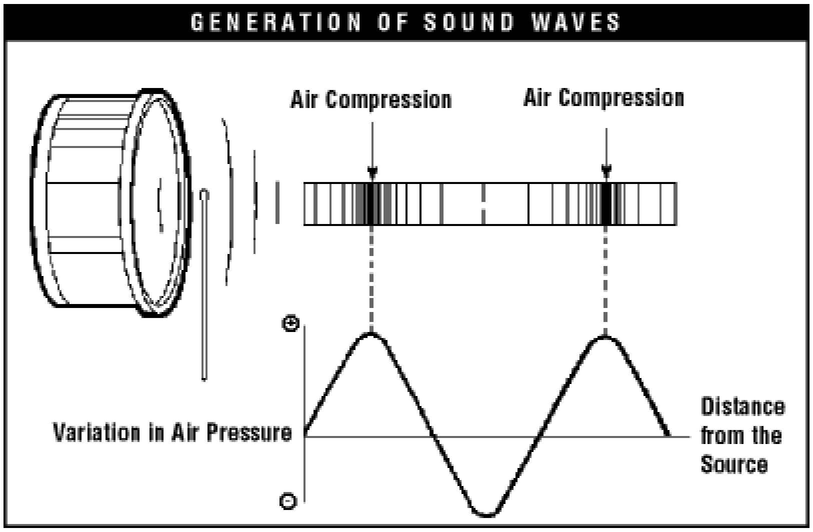
What do ya'll think and why?

Sound wave Production

As an object vibrates, it will produce a series of **compressions** and **rarefactions** in the air around it. The compressions and rarefactions expand and spread out in all directions like the ripples waves on a pond.

Compression – the region of molecules in which the density and pressure are greater than normal (high pitch) – air molecules are forced closer together
Rarefaction – the region of molecules in which the density and pressure are less than normal (low pitch) – air molecules are spread apart

Look at the diagram below. As the drumstick makes contact with the drum's membrane, the membrane is first pushed in and then flexes outward. As the membrane flexes out, the air molecules are forced together (compressed). When the membrane flexes back into the drum, the molecules are spread apart (rarefacted).



Characteristics of Sound Waves

The magnetic wave (electromagnetic energy) does not require a medium to travel through. Sound waves require a medium to travel because sound waves are mechanical energy. Sound waves are longitudinal waves and the vibration of the air molecules are parallel to the direction of the wave motion. Below is listed the three types of audible sound waves with reference to the human hearing.

We humans …

Audible sound – sound the average human can hear; **20 Hz to 20,000 Hz**
Infrasonic sound – sound wave **below 20 Hz**; humans can't hear but may sense
Ultrasonic sound – sound waves **above 20,000 Hz**; human can't hear nor sense

Elephants can communicate several km with infrasonic sounds, dogs can hear ultrasonic sounds very well, and bats use ultrasonic sounds to detect insects.

The pitch of sound is determined by the ***frequency*** of the sound and maybe perceived and "high" or "low." This chart shows the relationship between frequency, pitch and wavelength.

High pitch sound	Low pitch sound
Short wavelength	Long wave length
High frequency	Low frequency

Speed of sound – The speed of sound depends upon the density of the medium it is moving through. Other factors that affect the speed of sound are temperature. The speed of sound in air at **0° C** is **331 m/s.** At **20° C** (about room temperature) the speed of sound is **343 m/s**. Why?

To compensate for temperature variations for the velocity of sound in air use the formula:
V = 331 + 0.6T where **V** is the new velocity, **T** is air temperature in Celsius.

Propagation of sound – sound moves spherically in all directions from a source (referred to as three dimensional)

Wave front – the center of compression of the sound wave as it radiates from a source. The distance from one wave front to the next wave front is **1** l. Lambda (l) is the Greek letter used to indicate wavelength.

Ray – A line perpendicular to the wave front that radiates from the source.

The Doppler Effect

Doppler Effect – a frequency shift that is the result of relative motion between the source of waves and an observer.

The **Doppler effect** is easily illustrated with a fast moving car. A person standing on the side of the road will hear a high pitched sound (**wave compression**) as the car is moving toward him and the person will hear a low pitched **(wave rarefaction**) sound as the car is moving away from him. The following formulas can be used to solve for frequency of the pitch for moving objects.

Source and receiver moving apart: $f' = f \blacklozenge \frac{v - v_o}{v + v_s}$

Source and receiver moving together: $f' = f \blacklozenge \frac{v + v_o}{v - v_s}$

Doppler radar is used to detect rapidly rotating cells with in thunderstorms that may indicate the formation of tornados. In San Antonio, the weathermen on occasions enjoy showing bat emergence and their flight from Bracken Bat Cave on their Doppler radar.