Vibrations and Waves

For a vibration to occur an object must repeat a movement during a time interval. A wave is a disturbance that extends from one place to another through space. Light and sound are vibrations that move through space -- they are waves!

Properties of Vibrations

A pendulum swings in a periodic motion. It repeats its motion with regularity. A mass on a spring when set in motion also repeats its motion. Now lets move this vibration over a distance and trace the movement of the mass through space. The curve that the bob makes through space is called a sine wave (Fig. 10-1). Waves have the following characteristics:

1. **Amplitude** - the height of the bob above or below the equilibrium position. The greater the disturbance the greater the mass moves from its equilibrium point. The crest is the highest point above the equilibrium point. The trough is the lowest point. Waves with a greater energy have a greater amplitude.

2. **Wavelength** - the distance from **one point** in the wave to **the next corresponding** point is the wavelength. Wavelengths have various lengths from very short (millionths of a meter) to a very long wavelengths (hundreds of meters).

3. **Frequency** - how frequent the vibrations occur over time. The unit of frequency is the hertz (Hz) or cycles/second. High frequencies are measured in kiloHertz (kHz). The frequency on the AM radio dial of 940 kHz is 940,000 cycles/second. Higher frequencies are measured in Megahertz (MHz). FM dial station at 101 MHz is 101,000,000 cycles/sec. The range of human hearing is approximately 20 Hz - 20,.000 Hz.

4. **Velocity** - Sound travels through air at approximately **330 m/s,** or 1200 km/hr, or 740 mi/hr at 0ºC. Thus it takes about 5 seconds for sound to travel 1 mile, or 3 seconds for air to travel 1 km. In a storm, watch for lightening and count the number of seconds for the sound to reach you. Divide by 5 and this approximates the number of miles away the lightening struck, or divide by 3 to get the distance in kilometers.

Sound travels about 4 times faster in water because the molecules are closer together, and thus the vibrations can be transferred faster. Sound travels about 15 times faster in steel. In air, sound travels faster in warmer air than in colder air. Even though the colder air is at a greater density, the warmer air has a greater kinetic energy and thus its particles are moving at a greater velocity. Therefore they are able to transfer the energy of the sound through collisions with other molecules much faster. Sound can be reflected off solid objects such as in an echo. The energy of the sound wave does not match the natural resonant frequency of the object so the sound bounces off.

Sound waves can move through solid, liquid or gas phases. As the density of the material increases (more compact) the speed of sound increases. Sound must travel through a medium. Sound waves move through the medium by causing the medium to vibrate back and forth. The closer the particles are together, the easier and faster it is for the particles to vibrate and collide with other particles which carry the disturbance through the medium. It is the disturbance that moves, not the medium through which it is moving.

Increasing the temperature of the medium also causes the speed of the sound to increase. The increasing kinetic energies of the particles causes the particles to move faster (greater velocities). This allows the particles to collide more frequently and increase the propagation of the sound.

Waves

All waves begin with a disturbance. The speed at which a wave moves is a function of the waves frequency and its wavelength.

velocity = meters/second
f (frequency) = cycles/second
λ (lambda = wavelength) = meters/cycle

The wave equation is the relationship between these variables. $v = f\lambda$

If the speed of the wave is constant, then the frequency and the wavelength are **inversely proportional.** As the frequency increases, then the wavelength decreases. If the frequency of a wave is held constant then speed and wavelength are **directly proportional** [$f = v / \lambda$]

Problem: A wave has a wavelength of 10 cm and a velocity of 1 meter/second. What is the wave's frequency?

$v = f\lambda$, so rearrange the equation to find f [$f = v / \lambda$]
$v = 1$ m/s, $\lambda = 0.1$ m/cycle
$f = (1 \text{ m/s}) / (0.1 \text{ m/cycle})$ so, $f = 10$ cycles/sec or 10 Hz.

Types of Waves (Section 10.3)

1. **Transverse** - the motion of the wave is at right angles to the movement of the wave. An example of this is the shaking a rope or a string. Light waves and water waves are transverse waves.

2. **Longitudinal** - the motion of the wave moves in the same direction as the movement of the wave. The wave is composed of areas of compressions and expansions of the medium. These are compressions and rarefactions. Sound waves are longitudinal waves, where air is compressed and expanded by the energy of the wave.

Standing Waves

Standing waves are produced from producing a wave in a rope or spring. When a string is attached to a wall and shaken, the wall is too rigid to move, so the wave bounces off the wall and returns down the rope or spring. Standing waves are the result of interference. The wave interferes with itself.

The wave which is sent out by us is the incident wave. The wave which is reflected from the wall is called the reflected wave. The incident wave and reflective wave are out of phase, causing a distinct destructive interference points called nodes. Changing the frequency of the standing wave changes the wavelength. Doubling the frequency, reduces the wavelength by half. Tripling the frequency, reduces it by one-third. Sounds produced by musical instruments are standing waves. A guitar string which is plucked produces a standing wave with the vibrating string. An flute or tuba produces a standing wave with the vibrating air within the instrument.

Interference (Section 10.9)

Two waves traveling in opposite directions can collide and pass through each other. Since waves are disturbances not particles, they do not bounce off each other. The overlap of waves form interference patterns. The disturbance can be increased, decreased, or neutralized (cancelled) depending on how the waves interact.

When one crest of a wave overlaps with the trough of another, their effects are reduced. Essentially the high part of the wave fills in the low part of the wave of the other wave. This is **destructive interference**. These waves must have the same frequency and the same wavelengths. When two crests or two troughs come together, the amplitude of the wave is increased (it is amplified). This is **constructive interference**. Constructive and destructive interference does not change the velocity, wavelength or frequency of the waves. It only changes the amplitude of the waves.

Sound and Music

Sound can be absorbed by other objects. These objects are set in motion by the sound waves and absorb the waves energy. Sound waves can also be bent. In air, sounds travel faster in warm air than in cold. When a storm front in moving, usually the air closer to the earth is warmer than the air higher up. Therefore, sound waves from thunder which is distant may not reach you because the sound waves are bent upward.

Physicians use "ultrasound" or sound of very high frequencies to see internal organs and fetuses. The sound waves are bent to different degrees depending on the particular structure of the organ. Dense, solid organs, reflect sound waves better than less dense, loose organs.

Resonance - all objects have a natural frequency. For a pendulum its frequency depends on only the length of the string. The longer the string, the slower the swing (the longer its period). When the frequency of a forced vibration (something causing it to vibrate) on the object matches the object's natural frequency, the amplitude of the disturbance increases.

Examples: A pair of matched tuning forks, a child on a swing, the Tacoma Narrows Bridge.

You have seen this many times by pushing someone on the swings. You must synchronize your pushes with the swing of the person. Each time you push, the person swings a little higher. The effects of small pushes which are synchronized to the natural frequency of objects is responsible for the Tacoma Narrows Bridge to collapse. Small continuous pushes of wind which matched the natural swinging frequency of the bridge caused it to collapse.

Beats

Two different frequencies are combined and a fluctuation of the loudness of the sound occurs. The sound is first loud (a large amplitude), then faint (a small amplitude), then loud. This fluctuation is due to alternating constructive and destructive interference. There is no change in the waves frequency or wavelength, only the amplitude of the wave increases.

Pitch

Pitch refers to the sound in terms of its position on the musical scale. A low note refers to a note with a low frequency. A high not refers to a note with a high frequency. The human ear can sense a wide range of sounds, from 20 Hz (low frequency) to 20,000 Hz (high frequency).

The musical scale is divided into octaves of 12 notes. 7 major notes and 5 sharps and flats.

Ab A Bb B C C# D Eb E F F# G (1 octave)

Increasing one octave is the doubling of the frequency of the particular note. A middle C is 256 Hz, so that one octave above this note, high C, is 512 Hz. Two octaves above middle C is 1024 Hz, or double high C.

The ear conveys sound waves which are comprised of compressions and rarefactions into a mechanical movement of small bones within the middle ear (Fig. 10.8). The inner ear converts these vibrations into nerve impulses which are sent to the brain. The ability to hear and recognize various sounds is dependent upon the perception and experience of the individual.

In a stringed instrument, a change of pitch is accomplished by:

- tightening the string (the wave travels faster through a tighter string, increasing the frequency of the wave)
- changing the length of the string
- increasing the mass of the string

In a wind instrument, a change in pitch is accomplished by:

- lengthening the column of air
- changing the location of openings

Loudness

Loudness of a sound in measured in decibels (names after Alexander Graham Bell), and abbreviated dB. The decibel scale is logarithmic, so a sound of 20 dB is 10 times as loud as 10 dB. A sound of 30 dB is 10 times as loud as 20 dB.

Changing the loudness of the sound changes the amplitude of the wave. An amplifier in my stereo amplifies the signal produced from the tape deck (it amplifies the amplitude of the wave). The speakers then convert electrical impulses into mechanical vibrations which compresses and rarefacts the air to produce sound. In an electrical guitar produces sound through resonance of the electrical signal generated from the musical instrument. An electric "pickup" converts the vibration of the string to a vibration of a magnet within an electrical coil within the pickup located under the vibrating strings. This generates an electrical frequency similar to the frequency of the vibration of the string which is sent to the amplifier to be amplified.

String instruments are rather poor producers of sound intensities. They require either large sound boards that resonate when the string vibrates (as in a piano), or have "boxes" of air that vibrate (as in a guitar or cello). Piano's, guitars, violins all are made of wood that vibrate (resonate) when played. This amplifies the sound produced by the vibrating strings.

Increasing the loudness of a sound changes the amplitude of the wave. A louder sound has a higher amplitude than a softer sound. The energy of a loud sound is also greater. The frequency, wavelength, and speed of the waves are not affected by the loudness.

Problems:

1. Calculate the wavelength for the fundamental frequency of middle 'C' at 0^{o} C.

2. If the sound of thunder takes 4.5 seconds to reach me during a storm, how many miles did the lightening occur? How many kilometers away did it occur?

3. What is the velocity of a wave that has a frequency of 750 Hz and a wavelength of 45.7 cm?

4. A warning buoy in the Narragansett Bay is observed to rise every 5.0 seconds as the crests of waves pass by it. (a) What is the period of these waves? (b) What is the frequency?

5. Draw a wave representing a) high frequency and low amplitude; b) low frequency and high amplitude; c) long wavelength and low amplitude

Solutions: 1) 1.29 m; 2) 0.92 miles, 1.49 km; 3) 342.7 m/s; 4) 5 sec, 0.2 wave/sec;