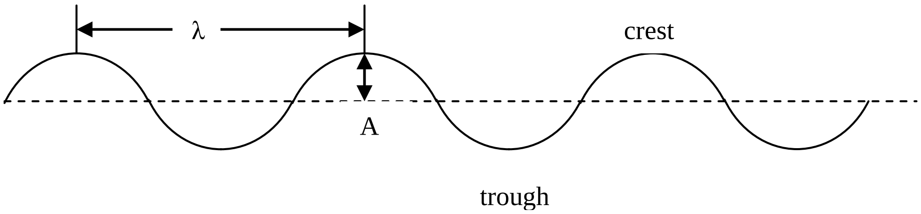
Notes Pre-AP Physics   Ch 12 and 13 – Waves and Sound

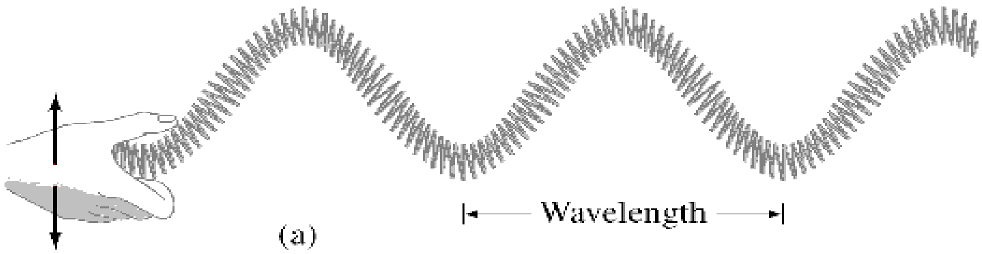
Wave motion

- For the first time we consider the motion of something that is not matter, but energy propagated through matter. A ***wave*** is a traveling disturbance that transfers energy from one place to another, and even though matter may be disturbed as a wave travels through a medium, there is no net movement of matter since the matter will return to its initial position after the wave passes. ***Mechanical waves*** (water, sound, waves on a rope, etc.) require a material medium but ***electromagnetic waves*** (light, radio waves, X-rays, etc.) do not require a known medium and travel at the speed of light ($c=3.00 \times 10^8$ m/s in a vacuum). The diagram below shows the basic structure of a transverse wave.

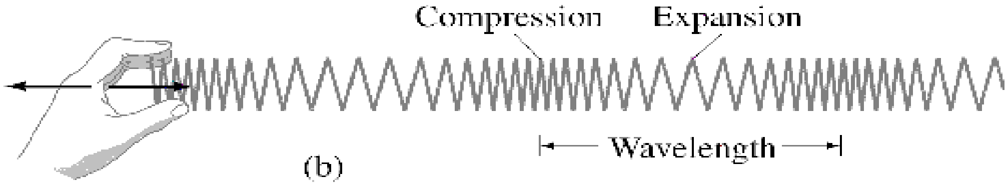


Two types of waves

- There a two basic types of waves classified by the motion of the particles.
  1. ***Transverse waves*** cause particles in the medium to vibrate perpendicularly to the motion of the wave (direction of energy transfer) as shown in diagram (a) below.
  2. ***Longitudinal waves*** (also called compression, pressure, or density waves) cause particles in the medium to move parallel to the direction of the wave as shown in diagram (b) below.



(a)



(b)

- **Note** that some waves are neither truly transverse nor longitudinal. For example, waves in water produce circular motion of water particles because there is both a transverse and longitudinal component.

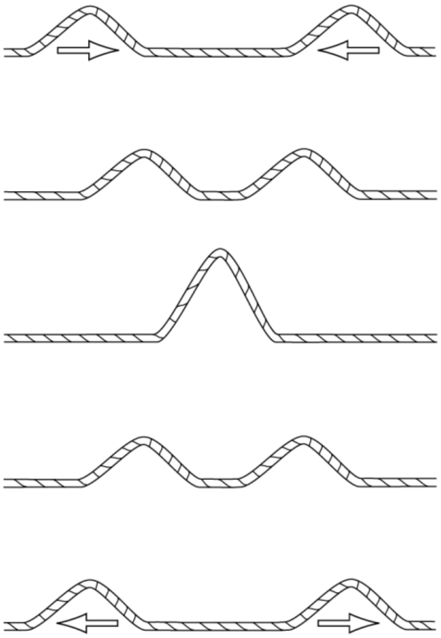
Calculating speed of a wave ($v=\Delta x/t=\lambda/T=\lambda f$)

- Speed of a wave depends only on the properties of the medium. The speed of a wave is constant for any given medium. For example, the speed of sound is typically faster in liquids than in gases, and typically the fastest in solids. But in a given medium, all sound waves travel at the same speed. This is easily verified by listening to the sound produced at a concert. Sound waves from different instruments reach your ears at the same moment, even when the frequencies of the sound waves are different. If speed remains constant and frequency changes, wavelength must change accordingly (λ is inversely proportional to frequency). Speed only changes when a wave travels from one medium to a medium with different properties.

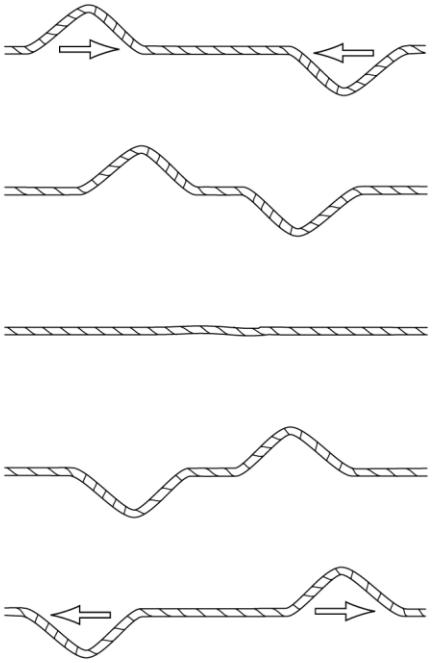
- $v=\lambda f$
- The ***speed*** of a wave is determined by the ***medium.***
- The ***frequency*** of a wave is determined by the ***source.***

Wave interference

- ***Interference*** occurs whenever two waves meet at the same point in space. The ***superposition principle*** states that the displacement of the medium caused by two or more waves is the algebraic sum of the displacements caused by the individual waves.
  1. **Constructive interference** occurs when wave displacements are in the same direction; amplitude of resultant wave is larger.



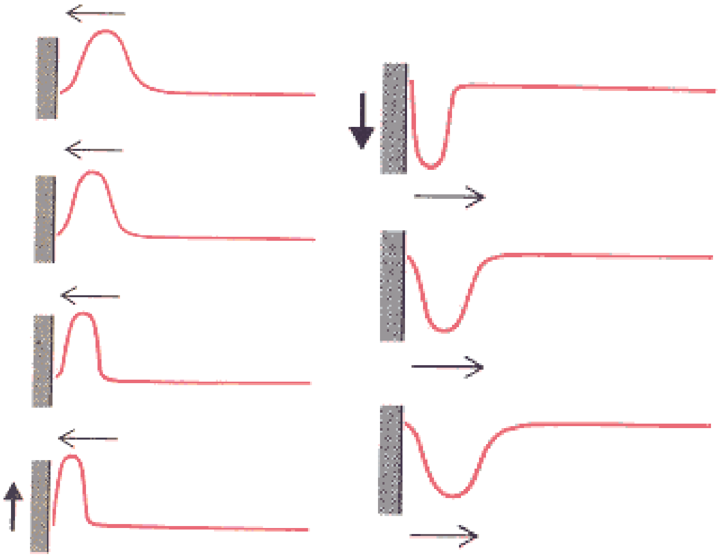
  2. **Destructive interference** occurs when amplitudes are in opposite directions; amplitude of resultant wave is smaller.



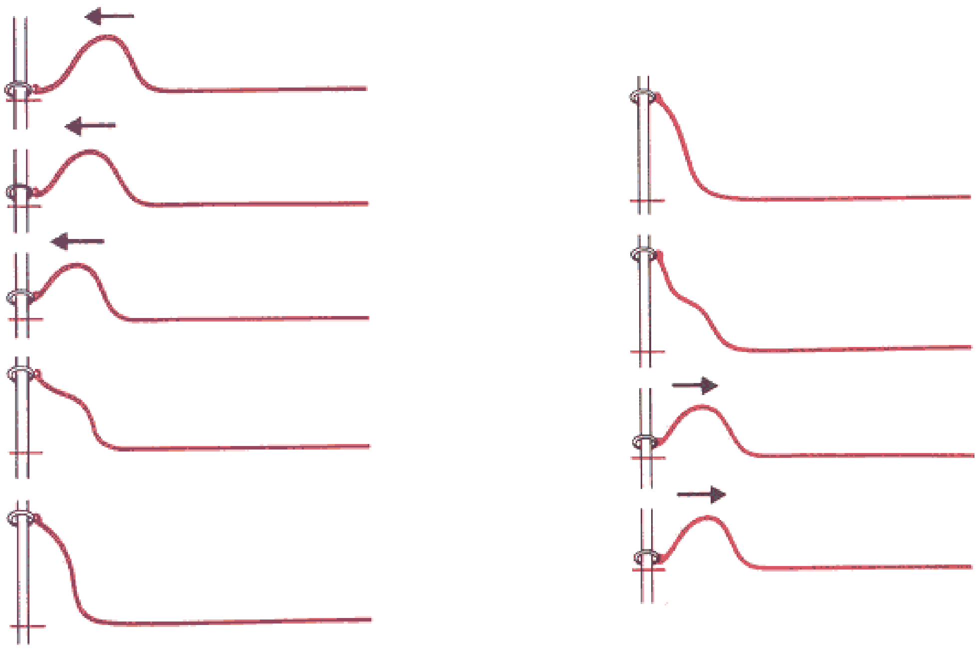
  - **Note** that after the pulses move past the point of interference each pulse returns to its original shape.

Reflection of waves

- Whenever a wave reaches a boundary it can be reflected. If the boundary is fixed the reflected wave will be inverted, but if the boundary is free to move the reflected wave will not be inverted.
  1. ***A wave reflected at fixed boundary will be inverted relative to the original wave.***

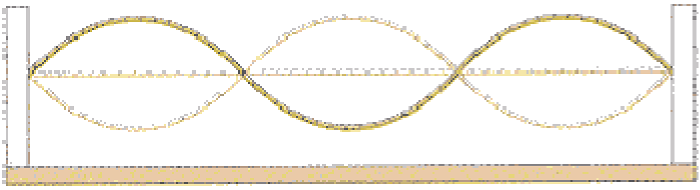


  2. ***A wave reflected at a free boundary will be on the same side as the original wave.***

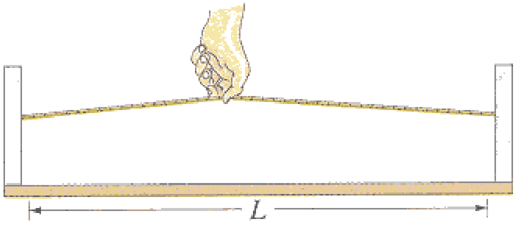


Standing waves

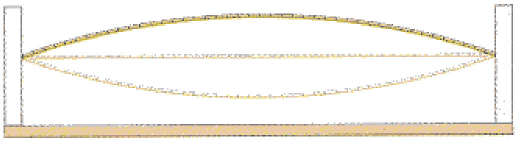
- When you pluck a guitar string, you create waves on the string. Since the string is held between two fixed ends, as the one shown below, the waves will continuously reflect back and forth between the ends undergoing interference at all points in between. Waves that are “trapped” between two boundaries like those on a guitar string are called standing waves. As shown in the diagram below, a **standing wave** is a wave pattern that results when waves of exactly the right frequency interfere producing a resultant wave that appears to “stand in place” as it oscillates. This is because the same type of interference occurs at the same points along the string as it vibrates. *Destructive interference* occurs at the ***nodes*** and complete *constructive interference* occurs at the ***antinodes***. The relative position of the nodes and antinodes on the string do not change.



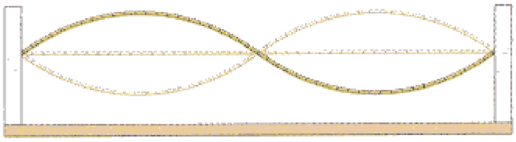
- Only certain frequencies of vibrations produce standing wave patterns as we will see in more detail next chapter.



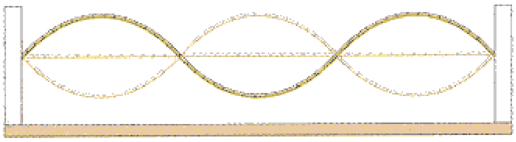
(a)



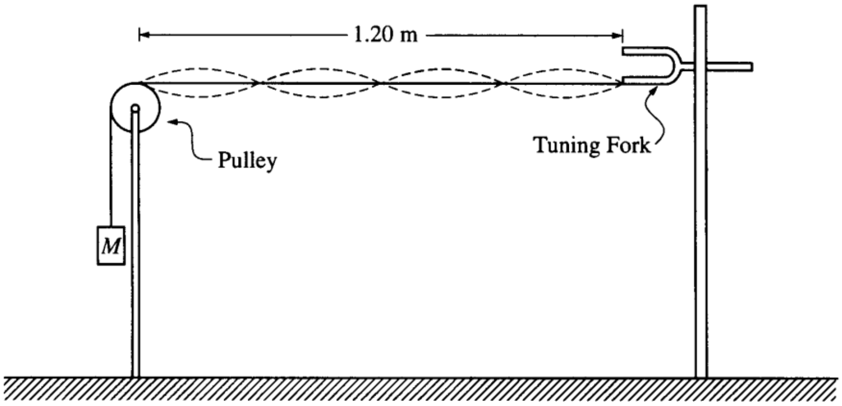
Fundamental or first harmonic, f_1



First overtone or second harmonic, $f_2 = 2f_1$



Second overtone or third harmonic, $f_3 = 3f_1$



Example: To demonstrate standing waves, one end of a string is attached to a tuning fork with frequency 120 Hz. The other end of the string passes over a pulley and is connected to a suspended mass M as shown in the figure above. The value of M is such that the standing wave pattern has four "loops." The length of the string from the tuning fork to the point where the string touches the top of the pulley is 1.20 m. The linear density of the string is 1.0×10^{-4} kg/m, and remains constant throughout the experiment.

a. Determine the wavelength of the standing wave.

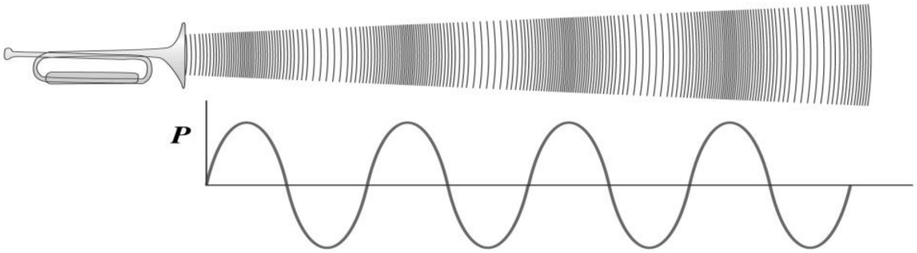
b. Determine the speed of transverse waves along the string.

c. The speed of waves along the string increases with increasing tension in the string. Indicate whether the value of M should be increased or decreased in order to double the number of loops in the standing wave pattern. Justify your answer.

d. If a point on the string at an antinode moves a total vertical distance of 4 cm during one complete cycle, what is the amplitude of the standing wave?

Practice Problems Ch 12: Waves #s 25,31,33,35,37,41,45,48,50,51,57,59

Ch. 13 – Sound



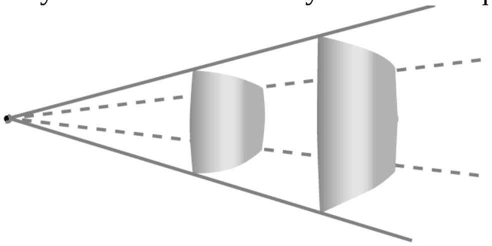
Properties of Sound

- Sound is a ***longitudinal wave*** produced by a vibrating source that causes regular variations in air pressure (graph above).
- **Audible** range of sound for most young people is 20 Hz to 20,000 Hz. **Infrasonic** waves are below 20 Hz and **ultrasonic** waves are above 20,000 Hz. Infra- and ultra- have to do with *frequencies* below and above the normal range of human hearing. This is NOT to be confused with **subsonic** and **supersonic…***these terms have to do with the speeds of moving objects.* For example, a *subsonic* car travels slower than the speed of sound in air, while a *supersonic* jet travels faster than the speed of sound in air.

- Frequency determines the **pitch** – how high or low we perceive the sound to be. ***The higher the frequency the higher the pitch.***
- ***Loudness*** depends upon **amplitude.**

- Speed of sound depends upon the properties of the medium. The speed of sound in air @ 1.0 atm and 20^o C is 343 m/s. The speed of sound in air generally increases by 0.6 m/s for each increase of 1^o C. Speed of sound is generally greater in liquids than gases and typically fastest in solids. Two factors that determine the speed of sound in a medium are ***elasticity*** and ***density***. Elasticity is a measure of how quickly and easily a medium regains its original state or shape. *Elasticity increases speed and density slows it down,* and the interaction of these two factors determines the speed in a given medium. Metal pipes are very dense BUT so elastic that the wave speed in metals is very fast.

- **Intensity** of a sound wave is the rate of energy flow through a given area. Sound waves propagate spherically outward from the source. Since the original amount of energy is spread out over a larger amount of surface area, the intensity of sound decreases by the inverse square law as it moves away from the source.



$$I \propto \frac{1}{r^2}$$

$$Intensity = \frac{Power}{4\pi r^2}$$

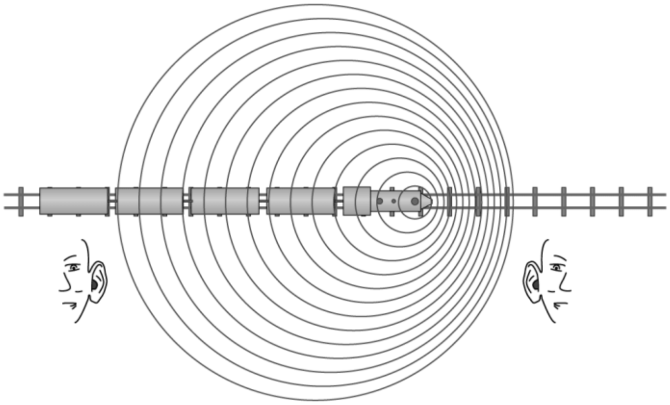
- ***Example #1****:* If the intensity of a person's voice is 4.6×10^{-7} W/m^2 at a distance of 2.0 m, how much power does that person's voice generate?

The Decibel Scale

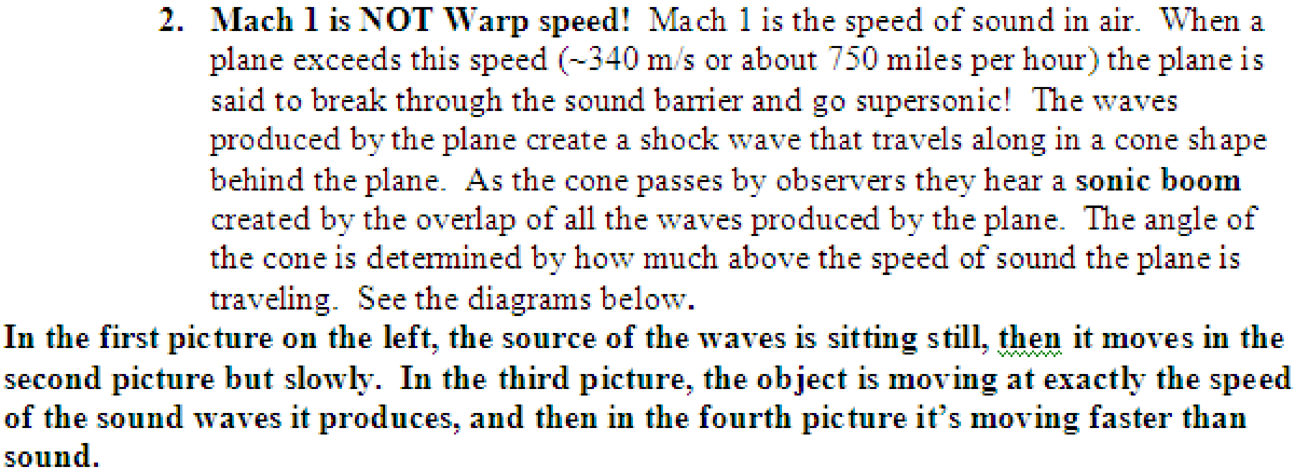
- The intensity of sound determines its loudness or volume, but the relationship is ***NOT*** directly proportional. This is because the sensation of loudness is approximately logarithmic in the human ear. Relative intensity, which is found by relating the intensity of a given sound to the threshold of hearing, corresponds more closely to human perceptions of loudness. Relative intensity is measured in **decibels ($\beta = 10 \log (I/I_o)$); I_o =** threshold of hearing**).** ***A 10 dB increase (10 X the intensity) in sound level is heard as being as about twice as loud.***
  - **Threshold of hearing (I_o)**– approximate lowest intensity of sound that can be heard by the average human ear (occurs at about 1000 Hz with an intensity of 1.0×10^{-12} W/m^2)
  - **Threshold of pain** – approximate loudest sound that the human ear can tolerate (1.0 W/m^2)

Doppler Effect

- **Doppler Effect** or **Doppler Shift** is the change in frequency (and wavelength) due to relative motion of source and/or detector. When the source is moving toward the detector, the observed frequency is higher ***and, since velocity does not change in a given medium***, the wavelength is shortened. Higher frequency sounds have higher pitch, and higher frequency light is called "blue-shifted". Observed frequency is lower (and wavelength longer) when source and observer are moving away from each other. This results in lower pitched sounds and "red-shifted" light.

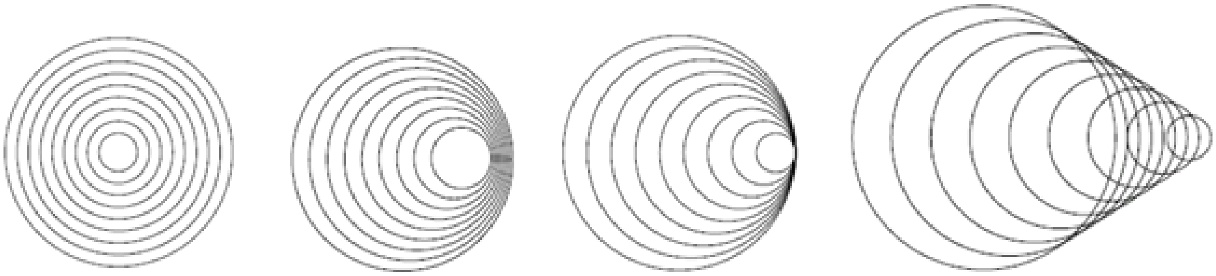


http://www.lon-capa.org/~mmp/applist/doppler/d.htm
http://www.wfu.edu/physics/demolabs/demos/3/3b/3B40xx.html



2. **Mach 1 is NOT Warp speed!** Mach 1 is the speed of sound in air. When a plane exceeds this speed (~340 m/s or about 750 miles per hour) the plane is said to break through the sound barrier and go supersonic! The waves produced by the plane create a shock wave that travels along in a cone shape behind the plane. As the cone passes by observers they hear a **sonic boom** created by the overlap of all the waves produced by the plane. The angle of the cone is determined by how much above the speed of sound the plane is traveling. See the diagrams below.

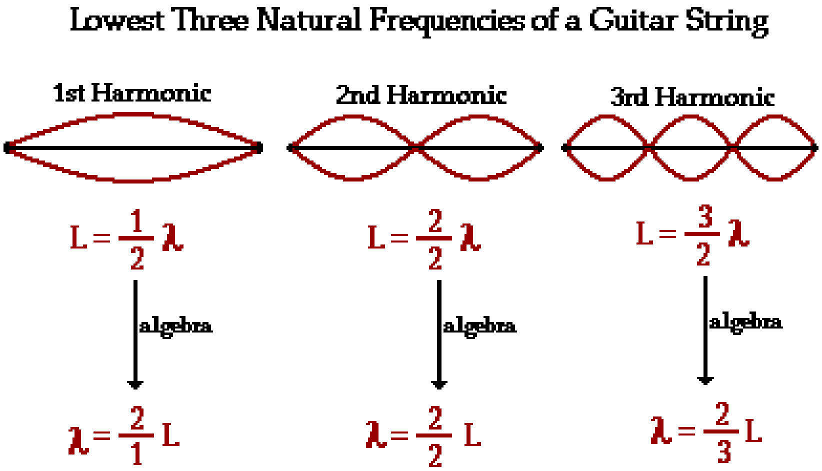
In the first picture on the left, the source of the waves is sitting still, then it moves in the second picture but slowly. In the third picture, the object is moving at exactly the speed of the sound waves it produces, and then in the fourth picture it's moving faster than sound.



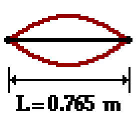
Harmonics

Standing waves on a vibrating string

- **Fundamental frequency (or first harmonic) –** lowest possible frequency of a standing wave **(f_o or f_1);** for a sting fixed at both ends the fundamental frequency occurs when the length of the string is ½ the wavelength.
- **Harmonics –** integral multiples of the fundamental frequency **($f_2 = 2f_1$, $f_3 = 3f_1$, $f_4 = 4f_1$, etc.)**
  $f_n = n\,v/2L$ **n =** harmonic number = 1,2,3…   **L =** length of string

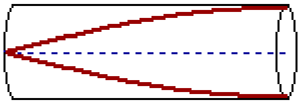


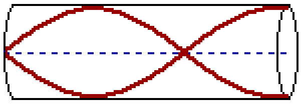
Example #2: The speed of waves in a particular guitar string is found to be 425 m/s. Determine the fundamental frequency (1st harmonic) of the string if its length is 76.5 cm.

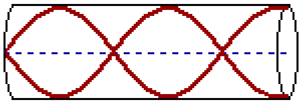


Example #3: A guitar string with a length of 80.0 cm is plucked. The speed of a wave in the string is 400 m/s. Calculate the frequency of the first, second, and third harmonics.

- **Standing waves in an air column**
  - ***Closed-pipe resonator*** **(closed at ONE end)**
    - **Resonance** occurs when the frequency of a force applied to an object matches the natural frequency of vibration of that object. When a sound wave has a wavelength that matches the resonance length of the tube, a standing wave is produced and the sound heard. ***The shortest column of air (therefore the longest wavelength and lowest frequency wave) that can resonate in a closed-pipe resonator is ¼ wavelength***


1st Harmonic

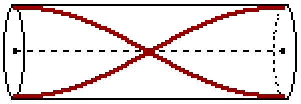

3rd Harmonic

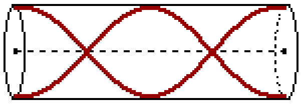

5th Harmonic

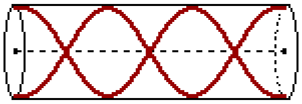
    - Each additional resonance length is spaced by an increase of exactly ½ a wavelength from that point since a displacement antinode must be located at the opening of the tube. Because of this restriction, there is no 2nd harmonic or any even # harmonics in a closed end pipe. ***Only odd harmonics are present in a closed pipe resonator.***
      f_n=n v/4L **n =** harmonic number (only odd integers) = 1,3,5… **L =** length of pipe

Example #4: Titan Tommy and the Test Tubes are playing at Shades in Lincolnshire this weekend. The lead instrumentalist uses a test tube (closed end air column) with a 17.2 cm air column. The speed of sound in the test tube is 340 m/s. Find the frequency of the first harmonic played by this instrument.

  - ***Open-pipe resonator*** **(open at BOTH ends)**
    - The harmonic pattern for an open-pipe resonator is identical to the harmonic pattern for a string fixed at both ends. ***Minimum length of an open-pipe resonator is ½ wavelength and all harmonics are present.***
      f_n=n v/2L **n =** harmonic number = 1,2,3… **L =** length of pipe

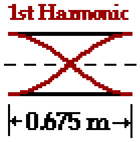

1st Harmonic


2nd Harmonic


3rd Harmonic

Example #5: Determine the length of an open-pipe resonator required to produce a fundamental frequency of 480 Hz when the speed of sound in air is 340 m/s.

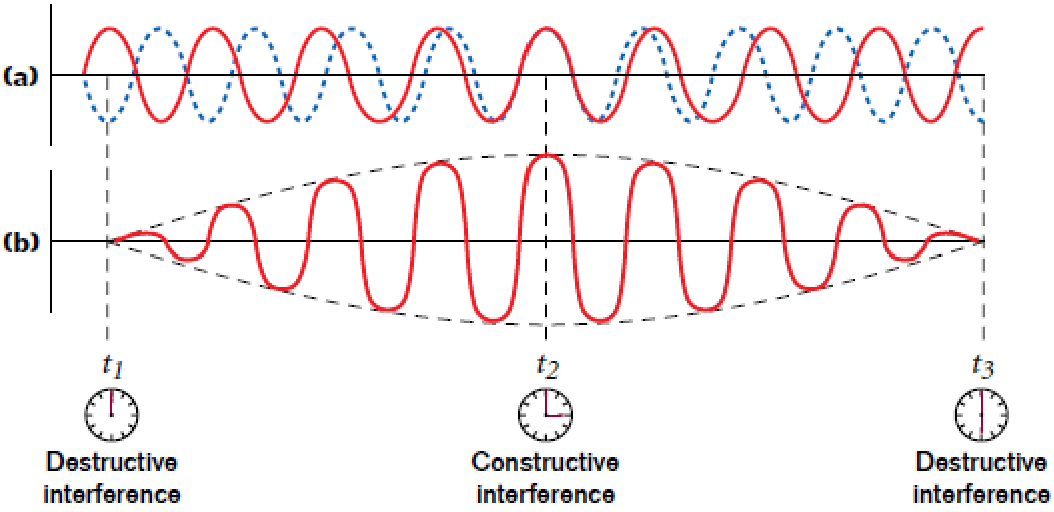
Example #6: Determine the fundamental frequency of an open-pipe resonator which has a length of 67.5 cm when the speed of sound in air is 340 m/s.



Beat Frequency

- ***Beats*** *occur when two waves of slightly different frequencies interfere; the pattern varies in such a way that the listener hears an alternation between loudness and softness. The beat frequency will be the difference between the two frequencies that are interacting. For example, the beat frequency will be 4 Hz when a 356 Hz tone is interacting with a 360 Hz tone.*

$$f_b = f_1 - f_2$$



Practice Problems Ch 13 #s 28,30,39,40,41,44,51, and 53