Name______________________ **Date**___________ **Period**__

READING: SOUND

In this section we will look at a special type of mechanical wave that is a large part of our lives - the sound wave.

Longitudinal *vs*. Transverse Waves

As is so often the case in the study of physics, terms are defined very precisely and often in a way that seems counter-intuitive. The physical definition of sound is no exception. In physics, **sound is the transfer of energy resulting from the successive compressions and rarefactions of a material medium because of a disturbance in that medium.**

Compression refers to the instances when the disturbance moves the particles of the medium *closer together than they normally are during equilibrium*. You can experience this compression if you will place your hand in front of your mouth and say "what". Immediately behind this compressed air there is a space called a **rarefaction** where the particles of the medium are *farther apart than during equilibrium.*

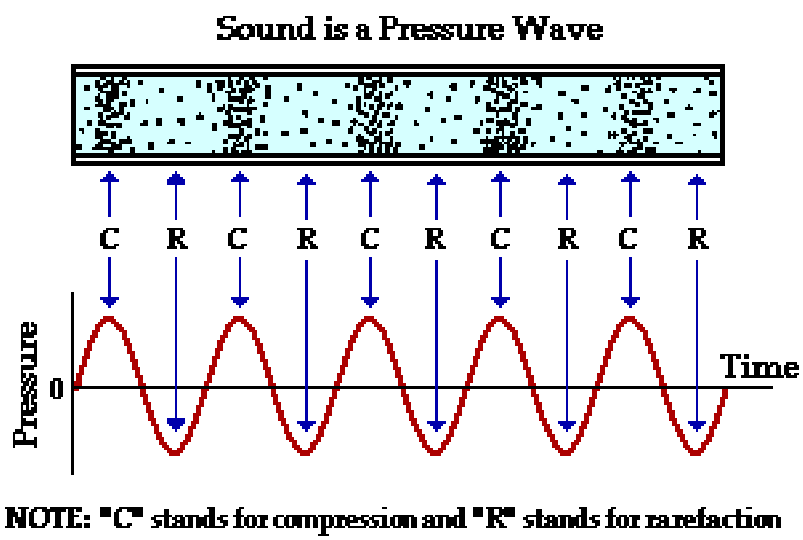


Figure 1. Compression and rarefaction of air particles in a tube at an instant in time. Compression (C) causes the pressure to increase in some regions and the rarefactions (R) cause a depression in pressure. Image courtesy of Bob Henderson, Glenbrook South High School, Glenbrook Illinois. www.glenbrook.k12.il.us/gbssci/phys/Class/sound/u11l1c.html

These successive compressions and rarefactions are known as a longitudinal wave. One can represent this by a graph showing the change in pressure from atmospheric pressure as shown in the graph above. Notice that pressure varies around zero. This just means *equilibrium or atmospheric pressure* (and not zero absolute pressure.)

When an object such as a guitar produces a sound, the initial mechanical disturbance is a transverse wave produced by the plucking of the guitar string. This in turn causes the air to compress and rarefy and produces the longitudinal wave that is the sound.

At times sound waves interfere with each other when they cross paths. The two cases below are two possibilities. The top panel of the figure below shows two waves with compression and rarefaction at the same points in space. Here the waves form a larger amplitude wave. This wave formation is called *constructive interference*. In the bottom panel, the compressed part of one wave overlaps the rarefied part of the second, and the two cancel out, leaving no apparent pattern. This is called *destructive interference*. What do you think you would hear if you heard waves interfere constructively as in the top panel? What would destructive interference sound like? In this unit, you will learn more about this phenomenon in this unit.

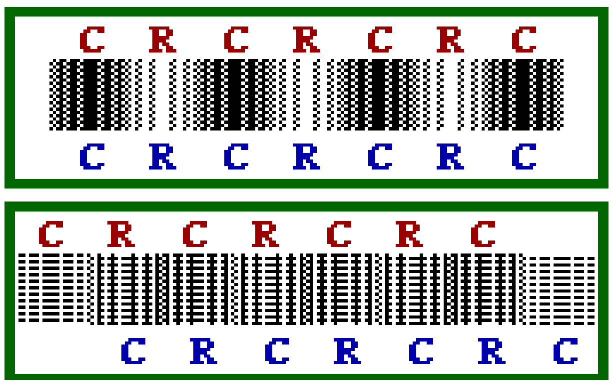


Figure 2. Two overlapping sound waves can cause constructive interference (top) when compression regions line up, or destructive interference when compressions line up with rarefactions.

Speed of sound:

Sound waves can travel through solids, liquids, and gases. Because waves consist of particle vibrations, the speed of a wave depends on how quickly one particle can transfer its motion to another particle. For example, solid particles respond more rapidly to a disturbance than gas particles do because the molecules of a solid are closer together than the molecules of a gas. As a result, sound waves generally travel faster through solids than through gases.

Additionally, temperature affects the speed of sound. As temperature rises, the particles of a gas collide more frequently. Thus, in a gas, the disturbance can spread faster at higher temperatures than at lower temperatures. In liquids and solids, the particles are close enough together that the difference due to temperature changes is less noticeable. The formula that relates the speed of sound to temperature is

$$\mathbf{V_{sound} = 331.5\ m/s + 0.6(\Delta T)}$$

Resonance

When a meter stick is dropped on the floor a different sound is heard from when a book is allowed to fall on the floor. Any body made of elastic material will vibrate at its own set of frequencies when disturbed. The object has a **natural frequency** which depends on the elasticity and shape of the object. These vibrations will result in sound waves. When an object is forced to vibrate at its natural frequency, the sound produced will be greater in amplitude than when the object vibrates at other frequencies. This phenomenon is called **resonance.** It is possible to demonstrate resonance by striking various tuning forks and placing them on desks or other wooden objects. In this case, resonance is caused by **forced vibrations.**

If a sound is created by striking a tuning fork and another tuning fork of the same frequency is brought close to the first, the second tuning fork will oscillate at the resonant frequency. The demonstration of breaking a wine glass with sound waves is a typical example. The wine glass starts to vibrate due to being exposed to sound waves of its resonant frequency. When the amplitude is increased, the oscillations in the wine glass exceed the elastic limit of the glass and the glass shatters. This is resonance and is caused by **sympathetic vibrations.**

Resonance can occur whenever an object has successive impulses applied to it. It can happen as troops march across a bridge. Apparently a bridge near Manchester England collapsed as troops marched across it because they marched in rhythm to the natural frequency of the bridge. Another example is the Tacoma Narrows Bridge which collapsed due to wind generated resonance. The video of the Tacoma Narrows Bridge is available on **Cinema Classics.**

Both open and closed tubes can be used to illustrate resonance. In the laboratory, "Sound in Closed Tubes", a vibrating tuning fork is held over the open end to create a sound wave to travel in the tube and reflect at the closed end. For closed tubes, the fundamental frequency of the tube has a wavelength approximately 4 times the length of the tube. The closed end is a node and the open end is an antinode, the length is 1/4 and $v = f\,(4L)$. For an open tube the wavelength of the fundamental is approximately 2 times the length of the tube. Each end is an antinode, the length of the tube is $1/2\,\lambda$ and $v = f\,(2L)$. However, both open and closed tubes can vibrate in a number of frequencies called **harmonics** or **overtones.**

Harmonics and overtones

Harmonics and overtones are very similar in description but vary depending on the instrument. They can best be understood by relating them back to mechanical waves and thinking about the harmonics created in an oscillating spring. It is possible to set up a standing wave with two nodes, three nodes, four nodes, five nodes, etc depending on the strength of the person moving the spring. A stretched string can also have standing waves with varying numbers of nodes all at the same time. When a guitar string or violin string is stroked or plucked, it vibrates in a number of different frequencies at the same time. These frequencies of the other standing waves are called harmonics or overtones. Usually, the lowest vibration is the **fundamental** or the first harmonic and the upper frequencies are the second, third, fourth...2,3,4,etc harmonics or first, second, third...overtones. Likewise, the air in a closed or open tube (organ pipe) as a vibrating system will have the fundamental and one or more higher overtones excited. The harmonics are multiples of the fundamental frequency. Closed tubes produce the odd harmonics, open tubes produce all the harmonics. The closed tubes must have a node at the end so the length of the tube can equal $1/4\lambda$, $3/4\lambda$, $5/4\lambda$, $7/4\lambda$, etc. So only odd harmonics will be produced. The open tube has an antinode at each end so the length can equal $1/2\lambda$, $2/2\lambda$, $3/2\lambda$, $4/2\lambda$, etc. So all the harmonics will be produced.

Musical instruments are sometimes compared by the **quality** of sound produced. The sound quality is a result of the overtones produced by an instrument. Each instrument will develop various amplitudes of each overtone produced and this difference is what creases the sound quality. For instance, a cornet and a trumpet are essentially the same instrument, but produce characteristically different sound. Or, two violins will have different sound quality due to workmanship and materials in the instrument.

Characteristics of sound:

Sound has many characteristics. One of these is pitch, which depends on the frequency of the sound. The frequency of a sound indicates the number of times the disturbance that causes the sound occurs each second. For example, when playing a middle C on the piano a sound with a frequency of 264 Hz is produced. This is the number of times the piano string oscillates each second after being struck. As the frequency is increased the pitch is increased and the resulting sound is higher.

The range of frequencies to which the average human ear is sensitive is 16 Hz to 20,000 Hz, although the upper range decreases with age and loss of elasticity of the eardrum. Sounds above the range of human hearing are called **ultrasonic** and those below it are called **infrasonic.**

The intensity range of human hearing spans from 1×10^{-12} W/m^{2}to over 1×10^{10} W/m^2. It was desirable to express this quantity as a ratio of a sound's intensity to the minimum sound intensity that can be heard by humans (I/Io). It should be noted that this results in a dimensionless quantity. These values have such a large range, approximately 22 orders of magnitude, that a logarithmic scale was adopted. The basic unit of relative sound intensity was defined as the "*bel*", in honor of Alexander Graham Bell's contributions to science and technology. Using this relative intensity scale the range of human hearing is from 0 bels to approximately 12 bels. This was modified so that the basic unit became the *decibel* (db) which is 1/10 of a bel. Loudness is the name we use the describe the psychological sensation produced by the intensity of the sound.

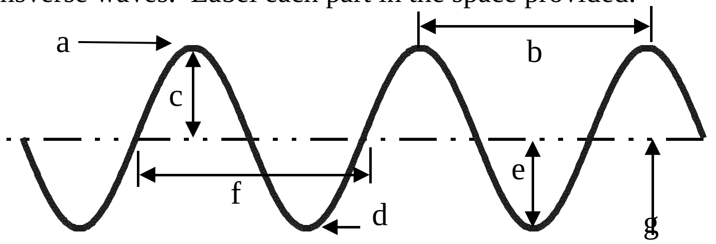
Sounds from a clarinet differ from those produced by a French horn. The cause of this difference is called quality, or timbre. It is a complex occurrence of the fundamental frequency and other overtones.

Name________________________ Date____________ Period___

Waves and Sound, Worksheet 1

1. The illustration below shows a series of transverse waves. Label each part in the space provided.

   a. ____________________
   b. ____________________
   c. ____________________
   d. ____________________
   e. ____________________
   f. ____________________
   g. ____________________



Fill in the blanks:

2. Waves carry __________________________ from one place to another.

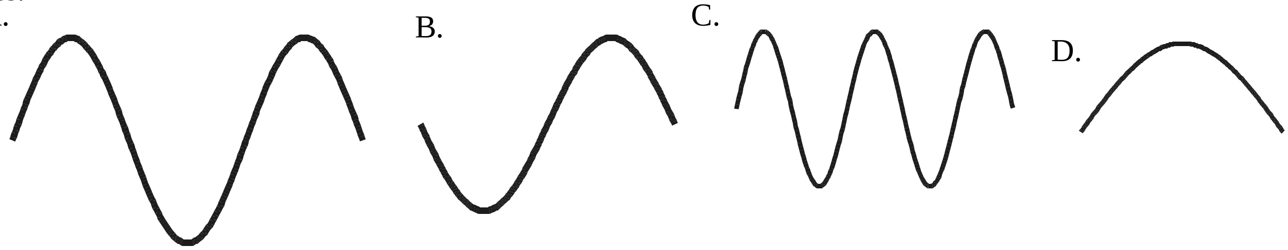
3. The highest point on a transverse wave is the _____________ while the lowest part is the ____.

4. The ____________________ is the height of the wave.

5. The distance from one crest to the next is the ________________.

6. Below are a number of series of waves. Underneath each diagram write the numbers of waves in the series.

A. B. C. D.



A. _________ B. _________ C. _________ D. _________

   a. Which of the above has the biggest amplitude? ________________
   b. Which of the above has the shortest wavelength? ______________
   c. Which of the above has the longest wavelength? _______________

7. Express in words and mathematically the relationship between
   a. period and frequency

b. wavelength and frequency

c. wavelength and period

8. Consider a wave generator that produces 10 pulses per second. The speed of the waves is 300. cm/s.
a. What is the wavelength of the waves?

b. What happens to the wavelength if the frequency of pulses is increased?

9. A wave on Beaver Dam Lake passes by two docks that are 40.0 m apart.

a. If there is a crest at each dock and another three crests between the two docks, determine the wavelength.

b. If 10 waves pass one dock every 16.0 seconds, determine the period and frequency of the wave.

c. What is the speed of the wave?

10. Sally Sue, an enthusiastic physics student enjoyed the opportunity to collect data from standing waves in a spring. She and her partner held the ends of their spring 4.00 meters apart. There were 5 nodes in the standing wave produced. Sally moved her hand from the rest position back and forth along the floor 20 times in 4.00 s. Sketch the situation and determine the following:

a. the wavelength of the wave Sally Sue sent

b. the frequency of the wave produced

c. the speed of the wave

11. What frequency and period would be required for Sally and her cheerful, pleasant, hard-working partner to produce a standing wave with three nodes? Explain your reasoning by identifying your steps.

12. The wavelength of a sound wave in this room is 1.13 m and the frequency is 301 Hz.

a. What is the speed of the wave in the room?

b. If you double the frequency of the sound wave, determine its speed.

c. What happens to the wavelength if you cut the frequency in half? How do you know?